# CHAPTER 15

# VACUUM AIR SYSTEMS

This chapter describes criteria, production, and the piping distribution network for various vacuum air systems. Because of the diverse uses and different design criteria for each, this chapter is divided into the following separate sections; health care facilities, laboratory systems, industrial applications, and central vacuum cleaning systems.

# FUNDAMENTALS

The performance of any vacuum air system is based on two factors: the flow volume measured in cfm (Lpm) and the maximum vacuum maintained in the system. For most vacuum systems to function, air becomes the transporting medium for any gas or suspended solids, and the pressure provides the energy for transportation. These two essential factors operate in inverse proportion—as the airflow increases, the vacuum pressure decreases. The various systems must be designed to produce specific vacuum pressure and airflow levels that have been determined, often by experience and experimentation, to be most effective in performing their respective tasks. The exception is where vacuum pressure is intended to produce a force used to lift objects or simply to evacuate an enclosed space. For these uses, airflow is only a function of how long it takes the system to achieve its ultimate vacuum pressure.

## *DEFINITIONS AND PRESSURE MEASUREMENT*

### Vacuum Definition

*Vacuum* is defined as an air pressure less than atmospheric. The vacuum level is the difference in pressure between the evacuated system and the atmosphere. Vacuum pressures generally used in the United States fall into three broad categories:

1. Rough (or coarse) vacuum, up to 28 inHg
2. Medium (or fine) vacuum, up to 1 $\mu$m
3. Ultrahigh vacuum, greater than 1 $\mu$m

In other parts of the world, the categories are often classified as follows:

1. Rough vacuum, 760 to 1 torr
2. Medium vacuum, 1 to $10^{-3}$ torr
3. High vacuum, $10^{-3}$ to $10^{-7}$ torr
4. Ultrahigh vacuum, greater than $10^{-7}$ torr

While the definition of *vacuum* is straightforward, measuring a vacuum level (or force) is not. Several methods of measurement are used, and each depends on a different reference point.

### Units of Measurement and Reference Points

***Units of Measurement.*** In order to compute work forces and changes in volume, conversion to negative gauge pressure (psig) or absolute pressure (psia) will be required. The units used are inches of mercury (inHg) and the millibar (mbar). These units originate from the use of a barometer. The basic barometer is an evacuated vertical tube, the top end of which is closed and the bottom end of which is open and placed in a container of mercury open to the atmosphere. The pressure, or “weight,” exerted by the atmosphere on the open container forces the mercury

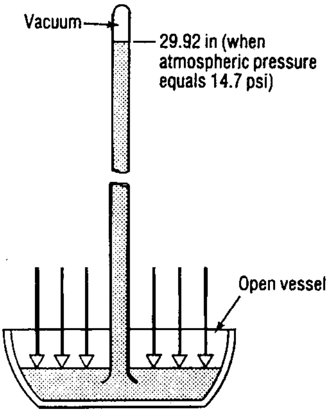


FIGURE 15.1 Basic barometer.

up into the tube. At sea level, this pressure will support a column of mercury 29.92 in high. In pressure units, this becomes 14.69 psi (99.89 kPa). Figure 15.1 illustrates a basic barometer.

The two basic reference points for measuring vacuum are standard atmospheric pressure and a perfect vacuum. When the point of reference is from standard atmospheric pressure to a specified vacuum pressure, this is called *gauge pressure.* If the reference pressure level is measured from a perfect vacuum, the term used is *absolute pressure. Local barometric pressure,* which is the prevailing pressure at any specific location, should not be confused with *standard atmosphere,* which is the mean barometric pressure at sea level.

***Standard Reference Points and Conversions.*** At standard atmospheric pressure, 0 inHg is equal to 14.7 psig, 101.4 kPa, and 29.92 inHg. For ease of calculations, 14.7 psig is adjusted to 15 psig, and 29.92 inHg is adjusted to 30 inHg. These minor deviations yield results well within the accuracy required for engineering calculations used in this handbook. At the opposite end of the scale, 0 psia (a perfect vacuum) has a value of 0 inHg and 29.92 inHg. Table 15.1 compares vacuum pressure from the two most commonly used reference points. Figure 15.2 gives conversion from various pressure units to another. Table 15.2 gives numerical conversion multipliers for converting torr into various other vacuum pressure units. Table 15.3 gives numerical conversion from inHg to psia and inHg absolute.

On the dials of most pressure gauges, atmospheric pressure is assigned the value of zero. Vacuum measurements must have a value of less than zero. Negative gauge pressure is the difference between the system vacuum pressure and atmospheric. Absolute pressure is the pressure (in psi) above a perfect vacuum and is equal to atmospheric pressure less negative gauge pressure.

Other vacuum units are atmospheres, torr, and micrometers (formerly ‘‘micron’’). One standard atmosphere equals 14.7 psi, or 29.92 inHg. Any fraction of an atmosphere is a partial vacuum and would equal negative gauge pressure. To calculate atmospheres knowing absolute pressure in psi, divide that figure by 14.7. A torr is 1⁄760 of an atmosphere, and a micrometer is 0.001 torr. These units of measurements are very high vacuum pressures and so are generally used for research, industrial, or laboratory use. Conversion factors are given in Table 15.2 and Fig. 15.2.

**TABLE 15.1** Basic Vacuum Pressure Measurements

| Units | | | |
|---|---|---|---|
| Negative gauge pressure, $P_g$, psig | Absolute pressure, $P_a$, psia | Inches of mercury, $P_m$ | kPa absolute |
| 0 | 14.7 | 0 | 101.4 |
| Atmospheric pressure at sea level | | | |
| −1.0 | 13.7 | 2.04 | 94.8 |
| −2.0 | 12.7 | 4.07 | 87.5 |
| −4.0 | 10.7 | 8.14 | 74.9 |
| −6.0 | 8.7 | 12.20 | 59.5 |
| −8.0 | 6.7 | 16.30 | 46.2 |
| Typical working vacuum level | | | |
| −10.0 | 4.7 | 20.40 | 32.5 |
| −12.0 | 2.7 | 24.40 | 17.5 |
| −14.0 | 0.7 | 28.50 | 10.0 |
| −14.6 | 0.1 | 29.70 | 1.0 |
| −14.7 | 0 | 29.92 | 0 |
| Perfect vacuum (zero reference pressure) | | | |

Conversion equations:

$$P_a = 0.149\ P_m$$

$$P_m = 2.04\ P_a$$

$$P_a = 14.7 - P_g$$

## General Vacuum Criteria

***Conversion of scfm to acfm.*** Vacuum is used by having air at atmospheric pressure enter a piping system that has a lower pressure. Gas at atmospheric pressure will expand to fill the piping system. The air at standard, atmospheric pressure is called *standard cubic feet per hour* (measured as scfm), and the expanded air in the piping system is called *actual cubic feet per minute* (acfm). Another term used to indicate acfm is *inlet cubic feet per minute* or icfm. Acfm is greater than scfm.

To convert scfm to acfm with a given pressure of inHg and temperature in °F, use the following formula:

$$\text{acfm} = \text{scfm}\,\frac{29.92}{P} \times \frac{T + 460}{520} \tag{15.1}$$

where $P$ = actual pressure, inHg, for the scfm being converted
$T$ = actual temperature, in °F, for the scfm being converted
scfm = standard cubic feet per minute being converted

For practical purposes, a numerical method for solving Eq. (15.1) can be used if the temperature is always 60°F. At that temperature, the second part of the equation becomes unity. Table 15.4 gives numerical values for $29.92/P$. To find acfm, multiply the scfm by the value found in Table 15.4 opposite the vacuum pressure.

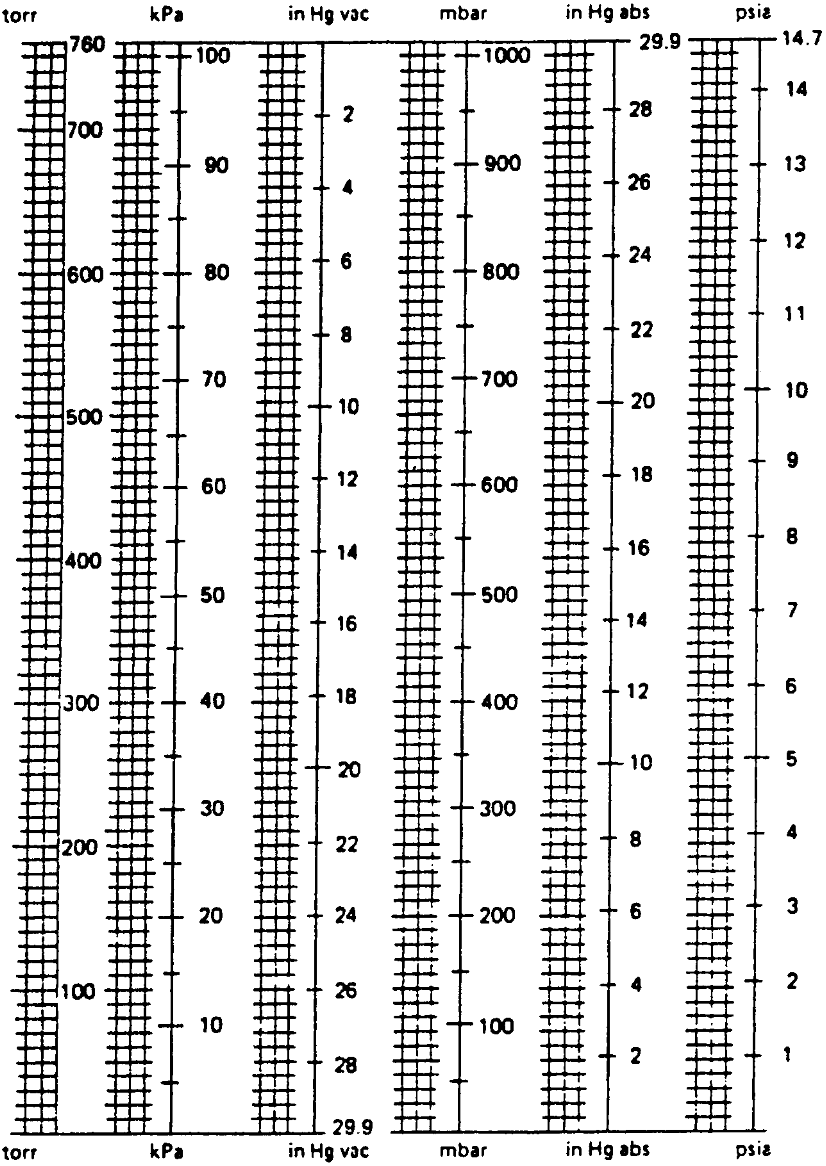


**FIGURE 15.2** Conversion of various vacuum pressure units.

**TABLE 15.2** Numerical Conversion Multipliers for Vacuum Units

0.0010 torr = 1 micrometer mercury (μmHg)
0.0075 torr = 1 pascal (Pa)
0.7501 torr = 1 millibar (mbar)
1.000 torr = 1 millimeter mercury (mmHg)
1.868 torr = 1 in water at 4°C (in $H_2O$)
25.40 torr = 1 in mercury (inHg)
51.71 torr = 1 $\text{lb/in}^2$ (psi)
735.6 torr = 1 tech. atmosphere (at)
750.1 torr = 1 bar
760.0 torr = 1 standard atmosphere (atm)

**TABLE 15.3** Numerical Conversion of inHg to psia and inHg abs

| inHg | inHg abs | psia | kPa absolute | inHg | inHg abs | psia | kPa absolute |
|---|---|---|---|---|---|---|---|
| 0 | 29.92 | 14.70 | 101.4 | 17 | 12.92 | 6.3477 | 43.71 |
| 1 | 28.92 | 14.2086 | 97.9 | 18 | 11.92 | 5.8564 | 40.33 |
| 2 | 27.92 | 13.7173 | 94.5 | 19 | 10.92 | 5.3651 | 36.95 |
| 3 | 26.92 | 13.2260 | 91.5 | 20 | 9.92 | 4.8738 | 35.57 |
| 4 | 25.92 | 12.7347 | 87.77 | 21 | 8.92 | 4.3824 | 30.20 |
| 5 | 24.92 | 12.2434 | 84.39 | 22 | 7.92 | 3.8911 | 26.82 |
| 6 | 23.92 | 11.7521 | 81.01 | 23 | 6.92 | 3.3998 | 23.37 |
| 7 | 22.92 | 11.2608 | 77.63 | 24 | 5.92 | 2.9085 | 19.99 |
| 8 | 21.92 | 10.7695 | 84.19 | 25 | 4.92 | 2.4172 | 16.61 |
| 9 | 20.92 | 10.2782 | 70.81 | 26 | 3.92 | 1.9259 | 13.23 |
| 10 | 19.92 | 9.7869 | 67.43 | 27 | 2.92 | 1.4346 | 9.85 |
| 11 | 18.92 | 9.2955 | 64.05 | 28 | 1.92 | 0.9433 | 6.48 |
| 12 | 17.92 | 8.8042 | 60.67 | 29 | 0.92 | 0.4520 | 3.10 |
| 13 | 16.92 | 8.3129 | 57.29 | 29.12 | 0.80 | 0.3930 | |
| 14 | 15.92 | 7.8216 | 53.91 | 29.22 | 0.70 | 0.3439 | 2.36 |
| 15 | 14.92 | 7.3303 | 50.54 | 29.32 | 0.60 | 0.2947 | 1.52 |
| 16 | 13.92 | 6.8390 | 47.09 | 29.92 | 0 | 0 | 0 |

**TABLE 15.4** Numerical Value to Determine acfm from scfm

*[Expanded air ratio (29.92/P) as a function of pressure, P, inHg]*

| *P* | 29.92/*P* | *P* | 29.92/*P* | *P* | 29.92/*P* | *P* | 29.92/*P* |
|---|---|---|---|---|---|---|---|
| 29.92 | 1.00 | 19.92 | 1.5020 | 9.92 | 3.0161 | 0.80 | 37.40 |
| 28.92 | 1.0345 | 18.92 | 1.5813 | 8.92 | 3.3542 | 0.70 | 42.0742 |
| 27.92 | 1.0716 | 17.92 | 1.6696 | 7.92 | 3.7777 | 0.60 | 49.8667 |
| 26.92 | 1.1114 | 16.92 | 1.7683 | 6.92 | 4.3236 | 0.50 | 59.84 |
| 25.92 | 1.1543 | 15.92 | 1.8793 | 5.92 | 5.0540 | 0.40 | 74.80 |
| 24.92 | 1.2006 | 14.92 | 2.0053 | 4.92 | 6.0813 | 0.30 | 99.7334 |
| 23.92 | 1.2508 | 13.92 | 2.1494 | 3.92 | 7.6326 | 0.20 | 149.60 |
| 22.92 | 1.3054 | 12.92 | 2.3157 | 2.92 | 10.2465 | 0.10 | 299.20 |
| 21.92 | 1.3649 | 11.92 | 2.5100 | 1.92 | 15.5833 | — | — |
| 20.92 | 1.4302 | 10.92 | 2.7399 | 0.92 | 32.5217 | — | — |

**TABLE 15.5** Direct Ratio for Converting scfm to acfm

| inHg | kPa abs | Factor | inHg | kPa abs | Factor |
|---|---|---|---|---|---|
| 1 | | | 16 | 47.07 | 2.15 |
| 2 | 94.5 | 1.1 | 17 | 43.71 | 2.3 |
| 3 | 91.15 | 1.1 | 18 | 40.33 | 2.5 |
| 4 | 87.77 | 1.15 | 19 | 36.95 | 2.73 |
| 5 | 84.39 | 1.2 | 20 | 33.57 | 3 |
| 6 | 81.01 | 1.25 | 21 | 30.20 | 3.33 |
| 7 | 77.63 | 1.3 | 22 | 26.32 | 3.75 |
| 8 | 74.19 | 1.35 | 23 | 23.37 | 4.28 |
| 9 | 70.81 | 1.4 | 24 | 19.99 | 5 |
| 10 | 67.43 | 1.5 | 25 | 16.61 | 6 |
| 11 | 67.05 | 1.55 | 26 | 13.23 | 7.5 |
| 12 | 60.67 | 1.62 | 27 | 9.85 | 10 |
| 13 | 57.29 | 1.75 | 28 | 6.48 | 15 |
| 14 | 53.91 | 1.85 | 29 | 3.10 | 30 |
| 15 | 50.54 | 2.0 | 30 | 0 | 60 |

A direct ratio for converting scfm to acfm for various pressures is given in Table 15.5. Multiply the scfm by the factor found opposite the pressure of the system.

***Adjusting Vacuum Pump Rating for Altitude.*** The rating of a pump at altitude is a lower percentage of its rating at sea level. For each 1000 ft increase in altitude, atmospheric pressure drops by approximately 1 inHg. Refer to Table 15.6 for actual barometric pressure at various altitudes. As an example, for the city of Denver (at 5000 ft), the local atmospheric pressure is 24.90 inHg. Dividing 30 into 24.90 gives a percentage of 83.3 percent. If a pump is rated at 25 inHg at sea level, 83.3 percent of 25 equals 20.8 inHg at 5000 ft. This is the required vacuum pressure that would equal 25 inHg at sea level.

At altitudes above sea level, there is a reduction in the scfm delivered because of the difference in local pressure compared to standard pressure. To compensate for this difference, scfm must be increased. Table 15.7 presents a multiplication factor to accomplish this. To find the adjusted scfm, multiply the actual scfm by the factor found opposite the altitude where the project is located.

***Time for Pump to Reach Rated Vacuum.*** The time a given pump will take to reach its rated vacuum pressure depends on the volume of the system in cubic feet and the capacity of the pump in scfm at the vacuum rated pressure. But simply dividing the system volume by the capacity of the pump will not produce an accurate answer. This is because the vacuum pump does not pump the same quantity of air at different pressures. There is actually a logarithmic relationship that can be approximated by the following formula:

$$T = \frac{V}{Q} N \tag{15.2}$$

where $T$ = time, min
$V$ = volume of system, cf
$Q$ = flow capacity of pump, scfm
$N$ = natural log constant

**TABLE 15.6** Actual Barometric Pressure at Various Altitudes

| Meters | Altitude (sea level equals zero) | | Barometric pressure, inHg | kPa |
|---|---|---|---|---|
| −3040 | −10,000 | | 31.00 | 104.5 |
| − 152 | − 500 | | 30.50 | 102.8 |
| 0 | 0 | Sea level | 29.92 | 100.8 |
| 152 | + 500 | | 29.39 | 99.0 |
| 304 | 1,000 | | 28.87 | 97.3 |
| 456 | 1,500 | | 28.33 | 95.5 |
| 608 | 2,000 | | 27.82 | 93.7 |
| 760 | 2,500 | | 27.31 | 92.0 |
| 912 | 3,000 | | 26.81 | 90.3 |
| 1064 | 3,500 | | 26.32 | 88.7 |
| 1216 | 4,000 | | 25.85 | 87.1 |
| 1368 | 4,500 | | 25.36 | 85.5 |
| 1520 | 5,000 | | 24.90 | 83.9 |
| 1672 | 5,500 | | 24.43 | 81.9 |
| 1824 | 6,000 | | 23.98 | 80.8 |
| 1967 | 6,500 | | 23.53 | 79.3 |
| 2128 | 7,000 | | 23.10 | 77.8 |
| 2280 | 7,500 | | 22.65 | 76.3 |
| 2432 | 8,000 | | 22.22 | 74.9 |
| 2584 | 8,500 | | 21.80 | 73.4 |
| 2736 | 9,000 | | 21.39 | 72.1 |
| 2888 | 9,500 | | 20.98 | 70.7 |
| 3040 | 10,000 | | 20.58 | 69.3 |

**TABLE 15.7** Multiplication Factor for Adjusting scfm at Altitude

| Altitude, ft | Meters | Factor used for required scfm |
|---|---|---|
| 0 | 0 | 1.0 |
| 500 | 152 | 1.02 |
| 1,000 | 304 | 1.04 |
| 1,500 | 456 | 1.06 |
| 2,000 | 608 | 1.08 |
| 2,500 | 760 | 1.10 |
| 3,000 | 912 | 1.12 |
| 3,500 | 1064 | 1.14 |
| 4,000 | 1216 | 1.16 |
| **5,000** | 1520 | **1.20** |
| 6,000 | 1824 | 1.25 |
| 7,000 | 2128 | 1.30 |
| 8,000 | 2432 | 1.35 |
| 9,000 | 2736 | 1.40 |
| 10,000 | 3040 | 1.45 |
| 11,000 | 3344 | 1.51 |

For vacuum up to 15 inHg, $N = 1$.

For vacuum up to 22.5 inHg, $N = 2$.

For vacuum up to 26 inHg, $N = 3$.

For vacuum up to 28 inHg, $N = 4$.

In order to obtain the most accurate answer, obtain pump curves from the manufacturer, and substitute the scfm capacity for the pump at each 5 inHg increment. Add them together to find the total time. The selection of the value for $N$ depends on the highest level of system vacuum pressure and is constant throughout the several calculations.

***Adjusting Pressure Drop for Different Vacuum Pressures.*** The chart for friction loss in a vacuum pipe presented later in this section is based on 15 inHg. For a given scfm and pipe size, the pressure loss at any vacuum pressure other than the 15 inHg the medical-surgical vacuum sizing chart was developed for can be found by dividing the pressure drop in the chart by the ratio found from the following formula:

$$\frac{30 - \text{new vacuum pressure}}{15} \tag{15.3}$$

***Simplified Method of Calculating Velocity.*** Use the following formula to find the velocity of a gas stream under a vacuum:

$$V = C \times Q \tag{15.4}$$

where $V$ = velocity, fpm
$C$ = constant based on pipe size (refer to Table 15.8)
$Q$ = flow rate in acfm, based on an absolute vacuum pressure

As an example, calculate the velocity of 100 scfm through a 2 in pipe with a pressure of 20 inHg.

1. First, find the equivalent absolute pressure of 20 inHg. Using Table 15.3, read 9.92 inHg abs.
2. Convert 100 scfm to acfm at a pressure of 9.92 inHg abs by using Table 15.5. Opposite 10 inHg read 1.5:

$$100 \times 1.5 = 150 \text{ acfm}$$

3. Refer to Table 15.8 to obtain $C$. This table has been developed from flow characteristics of air in Schedule 40 pipe. Opposite 3-in pipe, read 19.53.
4.

$$V = 150 \times 19.53$$

$$V = 2930 \text{ fps}$$

5. When scfm and pressure loss are known, use Fig. 15.22.

***Vacuum Work Forces.*** The total force of the vacuum system acting on a load is based on the vacuum pressure and the surface area on which the vacuum is acting. This is expressed in the following formula:

**TABLE 15.8** Factor for Determining Velocity Based on Pipe Size

| Sched. 40 pipe NPS, in | DN | *C* factor | Sched. 40 pipe NPS, in | DN | *C* factor |
|---|---|---|---|---|---|
| ⅜ | 12 | 740.9 | 2½ | 65 | 30.12 |
| ½ | 15 | 481.9 | 3 | 80 | 19.53 |
| ¾ | 20 | 270.0 | 3½ | 90 | 14.7 |
| 1 | 25 | 168.0 | 4 | 100 | 11.32 |
| 1¼ | 32 | 96.15 | 5 | 125 | 7.27 |
| 1½ | 40 | 71.43 | 6 | 150 | 5.0 |
| 2 | 50 | 42.92 | 8 | 200 | 2.95 |

*Note.* Increase velocity by 5 percent for copper tube.

$$F = P + A \tag{15.5}$$

where $F$ = force, psi
$P$ = vacuum pressure, psig
$A$ = area, in$^2$

Since the above formula is theoretical, it is common practice to use a safety factor in the range of 3 to 5 times the calculated force to compensate for the quality of the air seal and other factors such as configuration of the load and outside forces such as acceleration.

## System Leakage

There is a difference between allowable and acceptable leakage in a vacuum system. Ideally, no leakage is desirable. It is common practice to test laboratory vacuum piping systems, section by section, at rated maximum working pressure for 24 hours with no loss of pressure permitted. For large systems, it is almost impossible to install an entire system that does not have small leaks. If such is the case, what is an acceptable amount?

There is no generally accepted value for allowable leakage in a vacuum system. That figure should be related to the volume of the piping network in order to be meaningful. The Heat Exchange Institute has developed a standard based on system volume. This formula transposed to solve for leakage is:

$$\mathrm{L} = \frac{\left(\dfrac{0.15 \times \mathrm{V}}{\mathrm{T}}\right)}{4.5} \tag{15.6}$$

where L = leakage in SCFM
V = total Piping System Volume in cu.ft.
T = time for vacuum pressure to drop 1″ Hg., in minutes.

After calculating the system volume and the leakage from the system, enter Fig. 15.3 to determine if the intersection of the two values falls within the acceptable portion of the chart.

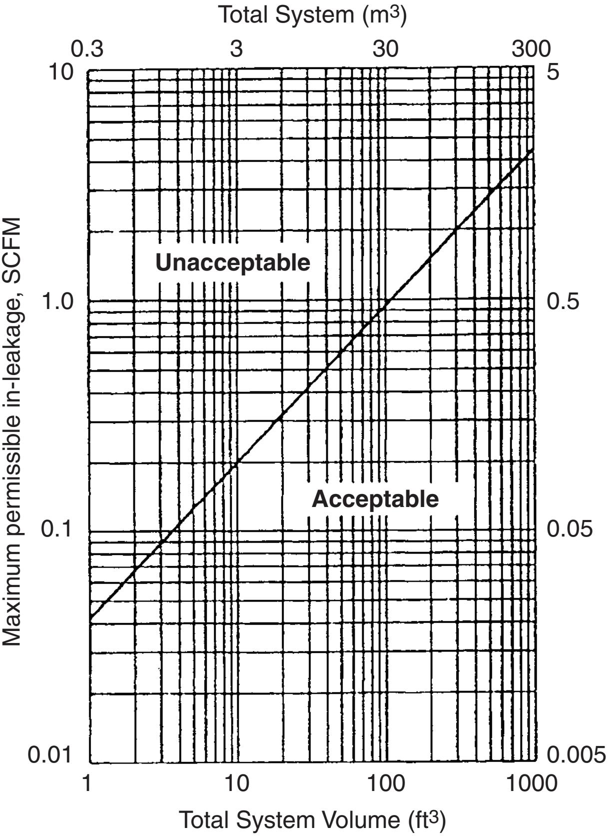


**FIGURE 15.3** (*Courtesy of Heat Exchange Institute*).

## SYSTEM COMPONENTS

### General

Vacuum is produced by a single or multiple vacuum pumps drawing air from remote vacuum inlets or equipment. Except for some industrial applications, vacuum pumps withdraw air from a receiver to produce the vacuum. The piping distribution system is connected to the receiver. The pump(s) are also connected to the receiver and maintain the desired range of vacuum as the demand rises or falls depending on the number of inlets that open or close. When the system vacuum pressure drops to a predetermined level, additional pumps are started. When the desired high level of vacuum is reached, the pumps could be shut off. Larger units may be constantly operated, loading, unloading, or bypassing on demand. Often, there is a timer on the system, allowing the pumps to run for a longer time than required by system pressure to prevent rapid cycling.

Air exhausted from the system must be discharged to the atmosphere by means of an exhaust piping system. The pipe size shall be large enough so as not to restrict

**TABLE 15.9** Vacuum Pump Exhaust Pipe Sizing, in.

| Total vacuum plant capacity (scfm),* all pumps | Equivalent pipe length, ft | | | | | | |
|---|---|---|---|---|---|---|---|
| | 50 | 100 | 150 | 200 | 300 | 400 | 500 |
| 10 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| 50 | 2.00 | 2.50 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| 100 | 3.00 | 3.00 | 3.00 | 4.00 | 4.00 | 5.00 | 5.00 |
| 150 | 3.00 | 4.00 | 4.00 | 4.00 | 5.00 | 5.00 | 5.00 |
| 200 | 4.00 | 4.00 | 4.00 | 5.00 | 5.00 | 5.00 | 5.00 |
| 300 | 4.00 | 5.00 | 5.00 | 5.00 | 6.00 | 6.00 | 6.00 |
| 400 | 5.00 | 5.00 | 6.00 | 6.00 | 6.00 | 8.00 | 8.00 |
| 500 | 5.00 | 6.00 | 6.00 | 6.00 | 8.00 | 8.00 | 8.00 |

*SCFM × 0.03 = $m^3$/min.
1 in × 25.4 = mm.
1 ft × 0.305 = m.

operation of the vacuum pump. For sizing the exhaust piping, refer to Table 15.9, using the equivalent length of exhaust piping as the length of piping.

***Gas Transfer Pumps.*** Vacuum pumps are known as gas transfer pumps. They are essentially air compressors that use the vacuum system as their inlet and discharge ‘‘compressed’’ air to the atmosphere. Gas transfer pumps are the greater majority of pumps used for most applications. They operate by removing gas from the lower pressure in the system and conveying this gas to the higher pressure of the free-air environment through one or more stages of compression provided by a vacuum pump. These pumps are also known as *mechanical rotary pumps* and are most often used for industrial and laboratory purposes. Examples of gas transfer pumps are:

1. Rotary vane [once-through oil (OTO) type or oilless]
2. Reciprocating (rotary) piston pumps
3. Rotary lobe (roots), ordinary lobe or claw
4. Screw
5. Liquid ring
6. Diaphragm
7. Centrifugal (turbo)

The operation of the above pumps are described in Chap. 14, ‘‘Compressed Air.’’

8. Vacuum ejector pump. Technically not a pump, it operates on the venturi principle. Ejector operation is described and illustrated in Fig. 15.4.

Gas transfer pumps are classified as either positive displacement or kinetic. The various types are illustrated in Fig. 15.5.

***Capture Pumps.*** Capture pumps operate on the principal of having the molecules of the gas retained in the pump itself by sorption or condensation on internal surfaces. Examples are the diffusion pump, sorption pump, sublimation pump, sputter-ion pump, and the cryopump. Capture pumps typically are low-volume, ultrahigh

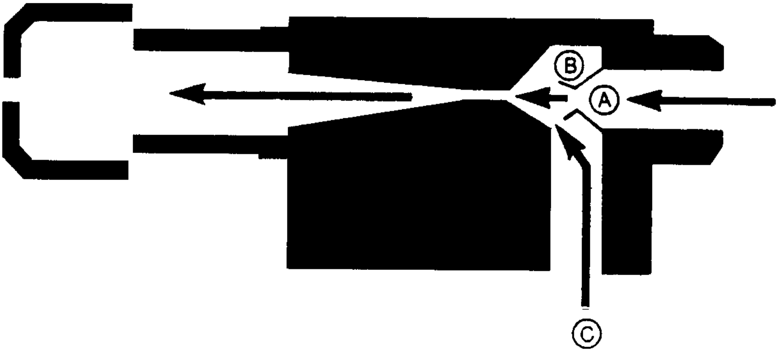


**FIGURE 15.4** Vacuum ejector pump (gas jet). Ejectors operate on the venturi principle. Compressed air enters at *A,* and orifice *B* causes the airstream to increase in velocity, which creates a vacuum at *C.*

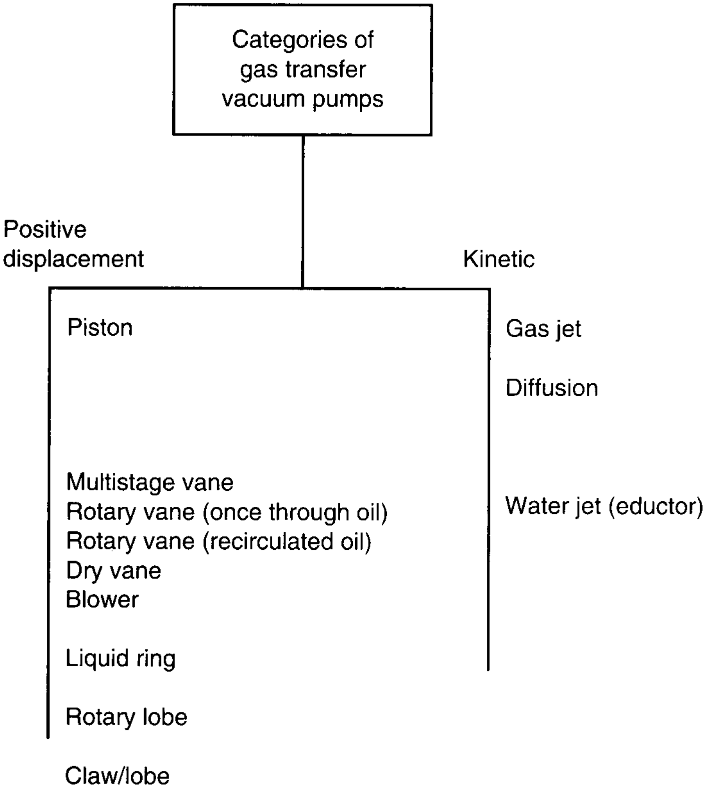
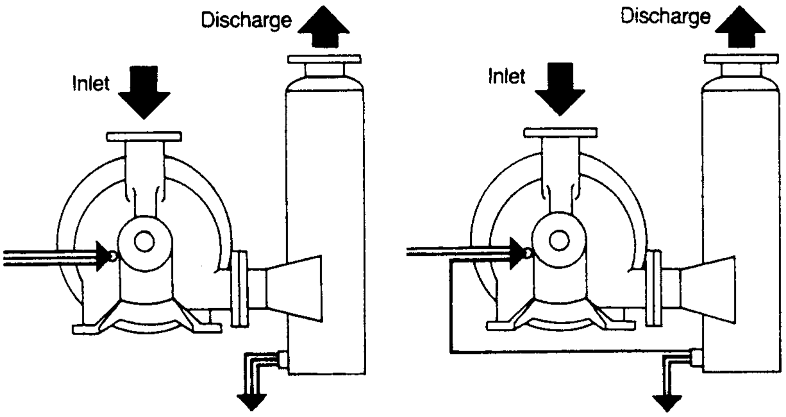


**FIGURE 15.5** Categories of gas transfer vacuum pumps.

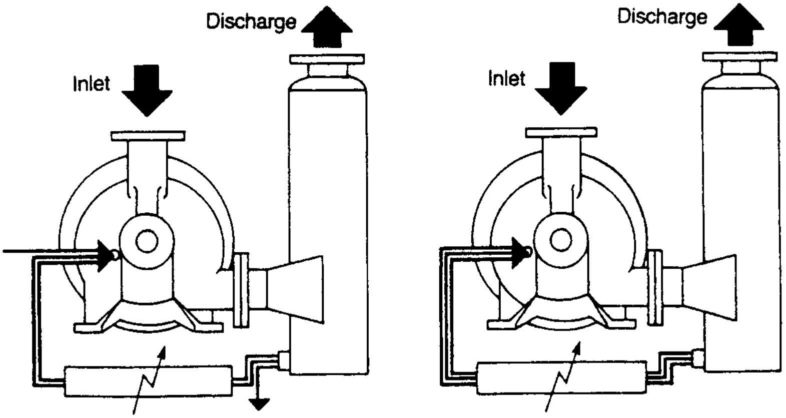
vacuum-producing pressure pumps. They find application mostly in semiconductor and unique research facilities. Because of their extremely limited use, capture pumps are outside the scope of this handbook.

***Seal Liquids.*** For liquid ring pumps, a circulating liquid in the pump casing is an integral part of the pump operation. This liquid is commonly water or oil. This liquid is commonly known as *seal liquid,* a term that is not intended to refer to shaft or any other kinds of sealing.

Water commonly used for sealing purposes must be continuously replaced. With no conservation, approximately 0.5 gpm/hp is used. Manufacturers have developed proprietary water conservation methods that typically reduce the usage to approximately 0.1 gpm/hp. Specific information about any water usage and additional space required must be obtained from each manufacturer. Various seal water piping methods are shown in Fig. 15.6.



*Once-Through Seal* *Partial Recirculation*



*Recirculated Seal With Purge* *Recirculated Seal*

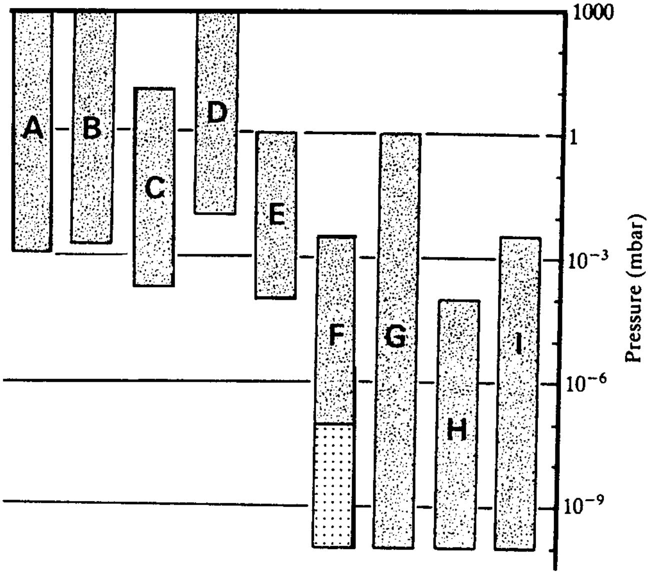
**FIGURE 15.6** Seal water piping arrangements.

Oil used for sealing purposes is recirculated and may have to be cooled. The pump does not require any water to operate. The oil eventually becomes contaminated and must be replaced on a regular basis. Typically, a running time of 1500 to 2000 h is the useful life of the seal oil. Specific information about additional space required must be obtained from each manufacturer. It may be necessary to install a running time meter on these pumps to aid in maintenance. Pumps using oil often require more installation space than other types.

***Operating Ranges of Various Pumps.*** Refer to Fig. 15.7 for typical operating ranges of the various types of pumps.

## Vacuum Pressure Gauges

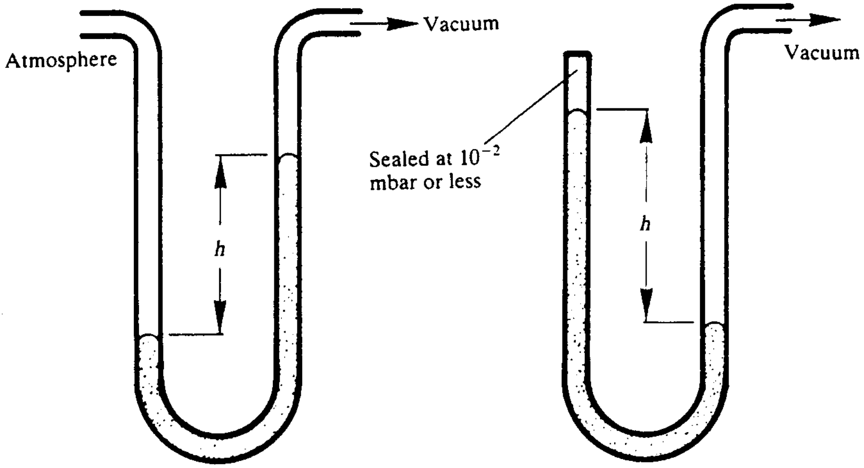
***Manometer.*** A manometer is used to measure relative pressure between the system and local barometric pressure. It consists of a cylindrical U tube partially filled with liquid. One end is connected to the system being measured, and the other end



| KEY | PUMP |
|---|---|
| A | Sorption |
| B | Mechanical rotary |
| C | Mechanical booster (normally used with a rotary pump) |
| D | Dry pump (oil-free rotary) |
| E | Vapor booster |
| F | Diffusion (low pressures obtained with accessories) |
| G | Turbomolecular |
| H | Ion |
| I | Cryo |

**FIGURE 15.7** Operating ranges for various pump types.

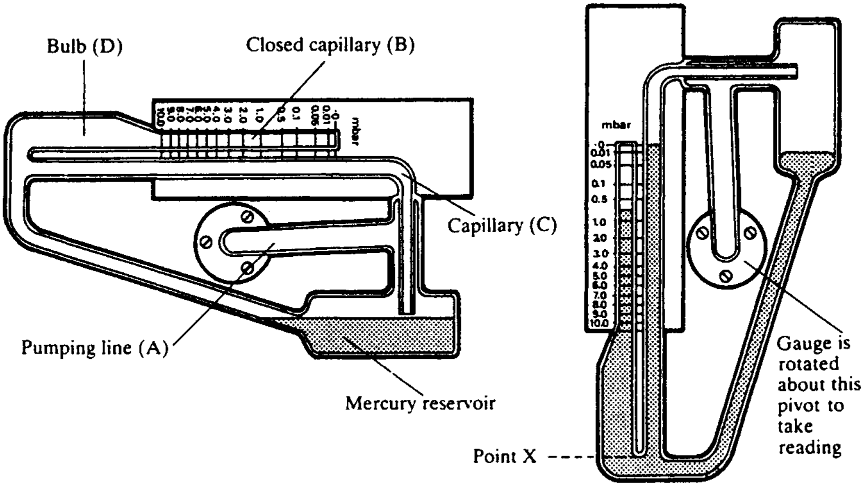
could be open or closed. The difference between liquid levels in each tube is used to calculate the pressure. A manometer is illustrated in Fig. 15.8. A McLeod gauge is a variation of the manometer and is considered more accurate than a simple manometer. The manometer is used in laboratory work and is rarely found in industrial applications. A McLeod gauge is illustrated in Fig 15.9.



(a) Both ends open

(b) Sealed version

**FIGURE 15.8** Manometer vacuum gauge.



(a) In 'ready' position

(b) Pressure reading position

**FIGURE 15.9** McLeod vacuum gauge.

***Bourdon Gauge.*** An often used type of mechanical gauge is the Bourdon gauge. This type of gauge is used to measure the difference between relative pressure between the system and local barometric pressure. Mechanical gauges are simple, inexpensive, and rugged and are the most widely used type of gauge. The heart of the gauge is the Bourdon tube that is closed at one end and open to the vacuum at the other. As the vacuum pressure varies, the tube changes shape. A pointer attached to the tube moves, indicating the pressure on a dial. A Bourdon gauge is illustrated in Fig. 15.10.

***Diaphragm Gauges.*** The diaphragm gauge measures the pressure difference by sensing the deflection of a thin metal diaphragm or capsular element. Similar to the bourden gauge, their operation relies on the deformation of an elastic metal under pressure.

A capacitance meter is, in essence, an electronic diaphragm gauge. Instead of a mechanical linkage, it uses a change in a variable capacitance sensor to detect changes in pressure, which are transmitted electronically. The response time is fast, and the signal can be remotely transmitted.

***Strain Gauges.*** Strain gauges also use the deflection of a diaphragm to produce a change in electrical resistance of the attached strain gauge. The response time is fast, and the signal can be remotely transmitted. A strain gauge is illustrated in Fig. 15.11.

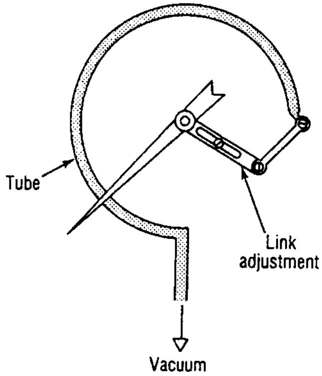


**FIGURE 15.10** Bourdon tube vacuum gauge.

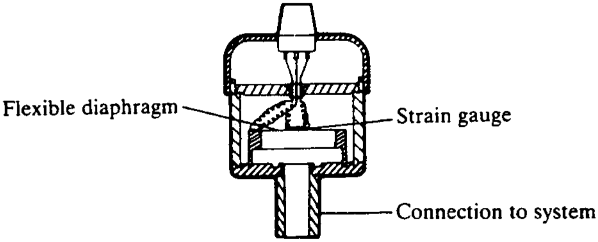


**FIGURE 15.11** Strain gauge.

***Ancillary Equipment.*** A coalescing, or oil mist, filter should be used on the exhaust of any pump that uses oil, to prevent the discharge of that oil into the atmosphere. It can also be used to recover solvents from the discharged airstream.

A knock-out pot is a device that removes entrained liquid or slugs of liquid from entering the inlet of mechanical pumps used in industrial applications. It can also be combined with an inlet filter in one housing.

Inlet filters are used to remove solids or liquids that may be present in the inlet airstream prior to the air entering the pump. Various filter elements are available to remove particulates approximately 0.3 mm in size.

In some cases, it is desired to lower the vacuum pressure to a branch where the system as a whole has a high vacuum pressure. This is done with an air bleed valve on the branch where the lower vacuum pressure is desired. The valve is opened, and air is allowed to enter the system. For precise control, a needle type of valve is used.

# HEALTH CARE FACILITIES (SURGICAL/MEDICAL)

## *GENERAL*

This section will describe vacuum air systems used in health care facilities. These systems include medical-surgical, dental, and waste anesthesia gas disposal. Vacuum air is the nomenclature used to separate this system from the plumbing of sanitary vent system.

## *CODES AND STANDARDS*

The building codes that govern the construction and installation of plumbing, mechanical, and fire protection systems generally do not have specific standards directly regulating vacuum systems. The authorities having jurisdiction do regulate these systems by referring to standards originated by other organizations. These organizations have developed standards that are so widely accepted throughout the industry and by the various authorities that by reference, they have the force of law. These standards are required to be observed for the design, specification, storage, delivery, and testing of the various systems. Principal among them are:

1. National Fire Protection Association (NFPA)
    - ***a.*** NFPA 99, Health Care Facilities
2. Compressed Gas Association (CGA)
    - ***a.*** P 2.1, Recommendations for Medical/Surgical Vacuum Systems in Health Care Facilities
3. Heat Exchange Institute (HEI)
    - ***a.*** Performance Standard for Liquid Ring Pumps
4. JCAHO, Accreditation Manual for Hospitals. 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. This manual also refers to other standards.
5. AIA, Guidelines for Construction and Equipment of Hospital and Medical Facilities.
6. CSA (Canadian Standards Association). Since many medical devices and equipment are sold in Canada, manufacturers commonly conform to the CSA standards when they are more stringent than U.S. standards.

Sometimes local codes refer to specific standards that include a dated issue. In many cases, the date referred to in the code is not the latest issue. It is essential to become acquainted with the differences in the standards between the latest issue and the one referenced and discuss them with the local authorities. It is probable that the reference in the code will be used.

Some anesthesia equipment and devices manufactured in the United States for sale in Canada are not manufactured to U.S. standards but rather to Canadian standards because they are more stringent. The larger equipment manufacturers may also supply other foreign markets where requirements are stricter than those for the U.S. market.

## *MEDICAL-SURGICAL VACUUM AIR SYSTEMS DESCRIPTION*

Medical-surgical vacuum systems, sometimes referred to as *patient vacuum systems,* are used in operating rooms, intensive care areas, medical and surgical suites, and patient rooms to assist in the removal of fluids. They are also used to remove waste anesthesia gases and for laboratory purposes. The operating pressure of this system is in a range of 13 to 20 inHg vacuum. It is commonly reduced when used.

## *SYSTEM COMPONENTS*

Vacuum systems for health care facilities may consist of a vacuum source (pump), a receiver, separator (optional), exhaust to atmosphere system, inlets, gauges, the piping network and alarm systems. Vacuum supply for small dental offices often consists of liquid ring vacuum pumps draining directly to the sanitary sewer. Each component will be discussed as it relates to specific systems.

## *VACUUM SOURCE*

The vacuum source consists of two or more pumps that are designed to operate as system pressure demand requires, a receiver, a separator (optional) used to remove liquids from the vacuum airstream, the interconnecting piping around the pumps and the receiver, and alarms. There is a requirement that the pumps selected must have the capacity selected when the largest pump is out of service. There is no requirement that the surgical-medical vacuum pump be used exclusively for this purpose. Waste anesthesia gas removal and laboratory vacuum use are also permitted to be generated by this source. If there is only one source of vacuum available for both surgical and laboratory services, the laboratory system shall connect separately to the receiver, but it must have its own separator and valving arrangement before such connection.

A schematic detail of a typical surgical-medical source is illustrated in Fig. 15.12. Since there is such a wide diversity of seal or cooling fluid piping, this is not shown. The fluid piping arrangement should be obtained from the pump manufacturer.

### Pumps

There are two types of pumps most often used for vacuum service in health care facilities: liquid ring and sliding vane. A reciprocating pump is also available, but

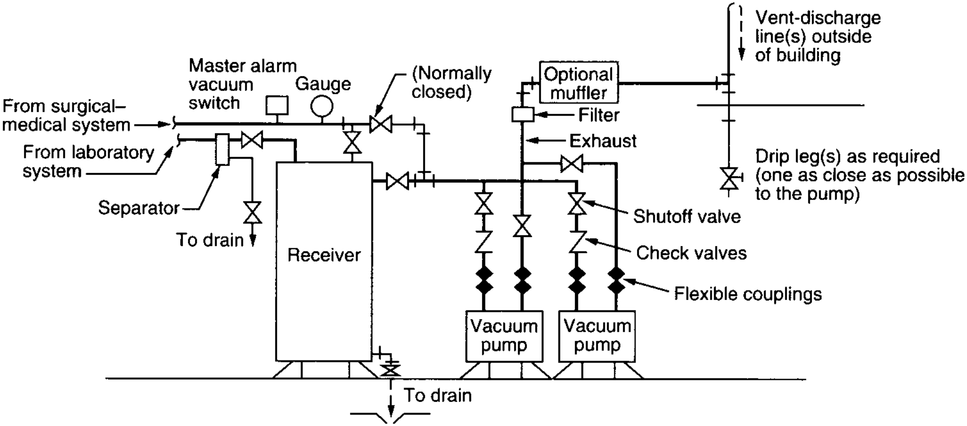


**FIGURE 15.12** Schematic detail of surgical-medical vacuum source.

it is rarely used because of its noise and higher operating and maintenance expense. Liquid ring pumps are relatively vibration free and have the advantage of a lower operating temperature that allows for the safe handling of any rarely used flammable anesthetic gas mixtures. It has a reputation for high reliability and low maintenance requirements. Lastly, it is oil free and will not have to be checked for oil consumption. The disadvantage of this pump is that it requires a continuous supply of water to operate, which is wasted if a recirculated cooling water supply is not available. Options are available to reduce the quantity of water used by recirculating the seal water and replacing only the amount necessary to maintain proper pump temperature. Other methods use a different fluid for the liquid ring, such as oil, that is recirculated and which may require cooling. When used to produce a higher vacuum pressure, the temperature of the seal water has an effect on pressure. The colder the water, the higher the vacuum that can be produced.

Rotary vane pumps are usually the smallest in physical size, have low starting and running torque, and are relatively vibration free. The typical rotary vane pump is capable of achieving a higher vacuum pressure than the typical liquid ring pump.

## Receivers

Receivers are installed primarily to prevent excessive cycling of the pumps by providing a ‘‘reserve’’ of vacuum. Since the majority of vacuum pumps are furnished as a prepiped assembly including the pump, receiver, interconnecting pipe, and valves, the manufacturer selects the size of the receiver based on previous acceptable performance with the size of the pump selected. The receiver shall be rated as an ASME unfired pressure vessel. There is no requirement that a receiver be provided.

Fluid filter traps that pass no liquids when operated properly are used at every vacuum inlet in patient rooms and in operating rooms. However, experience has shown that some liquid does enter the surgical-medical vacuum system piping. Since there is a possibility that fluid may enter, a suitable method shall be provided to drain the receivers. This can be done either manually or automatically.

The manual method requires the installation of a valved drain line from the bottom of the receiver. In order to drain the receiver, it must be isolated and brought to atmospheric pressure. This procedure removes the receiver from service for a limited time. The drain valve is then opened and the liquid discharged into a floor drain. A sight glass shall be provided to observe the level of accumulated liquid in the receiver.

Automatic methods are rarely used because of the higher initial cost, but they will permit uninterrupted use of the receiver. Automatic drainage requires the installation of a separate, smaller drain tank with a level switch inside. The drain tank is installed adjacent to, and lower than, the receiver. A drain line, installed at the bottom of the receiver and controlled by a solenoid valve, shall connect the receiver to the drain tank. The drain tank shall be capable of being isolated from the receiver by means of a solenoid valve. The drain line shall also have a solenoid valve. All valves shall be set to operate in the correct sequence when the level of liquid in the drain tank reaches its set point and sends a signal to each solenoid valve. The effluent is then discharged to a floor drain.

## Separators

When vacuum pumps use a constant flow of seal water, a separator is often necessary to remove water from the exhaust airstream. The effluent is commonly discharged to a floor drain. If the facility will be constantly introducing water into the vacuum piping system, a separator will be necessary before the piping system can be connected to the receiver. The receiver is not intended to be a separator, although a small amount of liquid is expected. In order to provide for draining and service of the receiver without interrupting the vacuum system, a valved bypass shall be provided.

### Interconnecting Piping

The interconnecting piping between the vacuum pumps and devices of the central supply system shall be corrosion-resistant pipe such as copper, brass, stainless steel, or galvanized steel pipe.

### Vacuum Pump Exhaust

Multiple vacuum pump exhausts may be manifolded together if there is a method of isolating individual exhausts so that one pump can be removed from service without affecting the other. Exhaust piping shall be sloped back to the pump. The minimum size of the exhaust pipe should be at least the same size as the vacuum pump exhaust port. The exhaust piping assembly shall be sized to limit the pressure loss to 1 psi or less. The exhaust should have an in-line muffler to lessen the noise and the exhaust line routed outside the facility. The exhaust line end shall have a louver and screen to prevent rain and insects from entering. Systems that serve research laboratories and patient treatment areas shall have a duplex filter on the exhaust. The pressure drop through this filter shall be added to the friction loss through the exhaust pipe in order to calculate total friction loss through the line. For sizing of the exhaust pipe, refer to Table 15.9.

### Alarms at Vacuum Source

For duplex systems, when the second pump (called a *lag pump*) must be started because of low vacuum pressure produced only from the lead pump, a lag-pump-in-use alarm shall be installed in the pump control cabinet. It shall be both visible and audible. This alarm does not have to be repeated in the master alarm panel.

### Inlets

Inlets are any terminals that receive any vacuum device or equipment. Connections to terminals in patient care areas shall be either threaded with a DISS adapter or a quick coupling adapter which is noninterchangeable with any other quick coupling for any other system. A secondary check valve may be required for some equipment but is not required on any patient care terminal. Laboratories generally use plastic hose connected to a serrated end of a laboratory cock.

### Gauges

A main line gauge shall be located upstream (on the inlet side) of the main line shutoff valve. Gauges shall also be located at all anesthesia area locations at the room control valve. The gauges shall read from 0 to 30 inHg. These gauges are usually located in the valve box serving that area.

### Valves

For discussion of valves, see ''Valves'' in compressed air chapter.

## *DISTRIBUTION NETWORK SIZING AND ARRANGEMENT*

### Pipe Material

Piping at the source could be seamless copper tube type L, M, or ACR or other corrosion-resistant material such as stainless steel or galvanized steel pipe (usually Schedule 40 ASTM A-53). Piping for the distribution system should be copper tubing. Copper tube shall be hard temper when installed in exposed locations and soft temper when installed in concealed locations and underground. Whenever piping passes under areas subject to surface loads such as roadways and parking lots, it shall be protected by ducts or casing enclosing the pipe.

Permanent fittings for copper tube shall be copper, brass, or bronze. Nonpermanent fittings, such as unions and flare connections, shall be installed so as to be readily accessible. Other joints, such as threaded and welded, are permitted. If proprietary joints or fabricating processes other than those commonly used are considered for use, they are permitted if they are listed and approved as equal to those joints made by brazing or soldering.

The most often used piping is copper tube type L with brazed joints for piping 4 in and smaller, and galvanized steel pipe with threaded joints for pipe 5 in and larger. Although solder joints are permitted for copper tube, brazed joints are used because all other compressed medical gas systems require this type of joint. The use of brazed joints will eliminate the possibility that other piping systems will be installed using solder. The fittings used shall be of the long turn type to cause as little restriction of the flow as possible.

### Cleanliness of Piping System

The need to have the interior of the pipe clean is not a service requirement for this piping system. If the vacuum system is installed along with other medical gases, as is usually the case, there is a possibility of a cross connection or the inadvertent switching of pipes. This has the potential for contaminating other clean systems or creating a fire hazard. When vacuum lines are installed, it is required that the vacuum piping be either well identified and labeled or cleaned as other compressed medical gas systems. It is far less costly to have the pipe properly labeled or marked than to have it cleaned.

The exterior of the pipe shall be cleaned with soap and water.

## System Sizing Procedures

***Number of Inlets.*** The first consideration is to locate and count all of the inlets for each respective vacuum system that uses the same source. 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 showing inlet locations shall be used.

There are guidelines published by the AIA, and ASPE that recommend the minimum number of station outlets for various services in specific areas. The most often used recommendations to determine the number of inlets for hospitals are those specified by the JCAHO since their 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 regulators, such as state or local authorities, may require that their approval of plans be obtained. 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. Vacuum inlets are included in Table 14.32 of the AIA recommendations. Table 14.34 provides recommended guidelines for the minimum number of facility station inlets and outlets that are a compilation from the AIA. Table 15.10 is the recommended number of inlets based on AIA recommendations.

***Flow Rate.*** Each individual station inlet must provide a minimum flow rate for proper functioning of connected equipment under design conditions. The estimated flow rates for various system inlets and equipment are given in Table 15.10.

Many of the design parameters used to size the medical-surgical vacuum system have been adapted from information arrived at after extensive field surveys of hospital systems.

***Diversity Factor.*** The flow rate from the total number of inlets connected to the system, 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. To allow for this fact, a diversity, or simultaneous use, factor has been developed. It is used to reduce system flow rate in conjunction with the total connected load for sizing the piping distribution system. This factor varies for different areas throughout any facility.

All areas (except WAGD and laboratory) of the facility are divided into separate usage groups: high usage called group A and lower usage called group B. Refer to Table 15.10 for the usage group assigned to each location. The actual diversity factor, or percent of usage, is a function of the total connected load and is found using Fig. 15.13. Enter the figure knowing the use group and the number of inlets. Read the percent use factor on the left. Table 15.11 is a direct numerical reading of Fig. 15.13 for convenience when sizing a large system. For discussions of the WAGD and laboratory diversity factors, refer to the following subsections.

**TABLE 15.10** Recommended Number of Vacuum Inlets for Health Care Facilities

| | Minimum number of station inlets | Usage group | Demand in scfm |
|---|---|---|---|
| Anesthetizing Locations | | | |
| Operating room | 3/rm | A | 1.5 per room |
| Cystoscopy/Endoscopy | 3/rm | A | |
| Delivery | 3/rm | A | |
| Special procedures | 3/rm | A | |
| Other anesthetizing locations | 3/rm | A | |
| Acute Care Locations (Nonanesthetizing Locations) | | | |
| Neonatal | 4/bed | A | 0.25 per outlet |
| Recovery room (postanesthesia) | 3/bed | A | |
| Critical care | 3/bed | A | |
| Special procedures | 2/rm | A | |
| Emergency rooms | 1/bed | A | |
| Emergency rooms—cardiac | 2/bed | A | |
| Cardiac ICU (CCU) | 2/bed | A | |
| Catheterization lab | 2/rm | B | |
| Surgical excision rooms | 1/rm | B | |
| Dialysis unit | (½)/bed | B | |
| Birthing rooms (LDRP or LDR) | 2/rm | A | |
| Postpartum bedroom | 1/rm | B | |
| Subacute Care Areas (Nonanesthetizing Locations) | | | |
| Nurseries | 1/bed | B | |
| Infant resuscitation station | 1/bassinet | A | |
| Exam and treatment rooms | 1/bed | B | |
| Respiratory care | Convenience | | |
| Other | | | |
| Autopsy | 1/table | B | |
| Central supply | Convenience | B | |
| Equipment repair, calibration, and teaching | Convenience | B | |
| Laboratory* | | — | 1.0 |

* Author's recommendation—not in original table.

## SYSTEM SIZING

### Vacuum Pump (Source) Sizing Procedure

The vacuum pump size and equipment arrangement is found as follows:

1. Determine the total number of inlets throughout the facility, and categorize them based on groups A or B. If the number of inlets is unknown, an estimate can be made by using Table 15.10. Use the scfm listed for each inlet. For each WAGD and laboratory inlet, allow 1 scfm.
2. Calculate the flow rate from all of the connected outlets in each use group, using values obtained from Table 15.10.
3. For each separate group A, B, and anesthetizing locations, enter Fig. 15.13 or Table 15.11 with the total inlets in each group, and read the use factor. WAGD

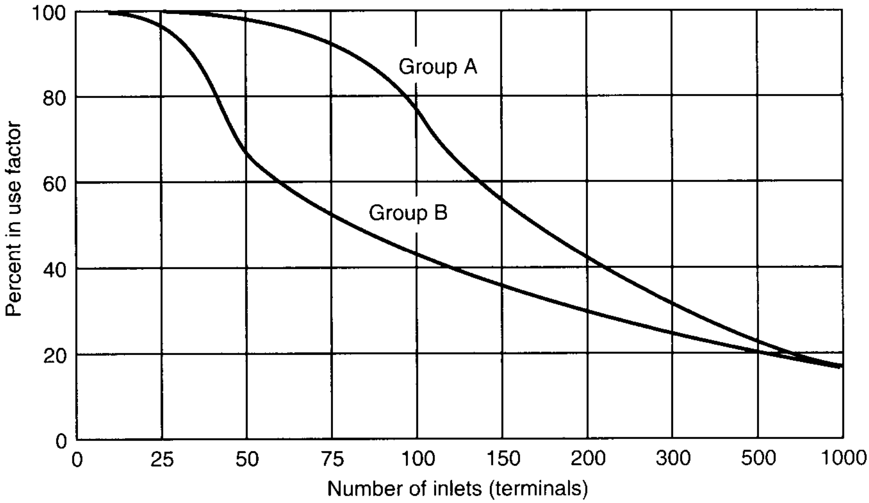


**FIGURE 15.13** Simultaneous use curves for health care facilities.

outlets use the total connected load and have no diversity factor. For laboratory outlets, use the diversity figure found in Table 15.12.

4. To calculate the actual total system scfm, multiply the scfm from each of the individual groups of inlets by the appropriate use factors. Add the A use group, the B use group, the anesthetizing locations, and scfm together to find the required medical requirement. To this, add the laboratory and WAGD figures to find the total system scfm. Adjust the scfm figure for altitude if necessary.
5. The pump scfm ratings are selected based on a multiple-pump arrangement. If duplex pumps are selected, each pump shall be sized for 100 percent of the load. For a three-pump arrangement, 100 percent of the load shall be available with one pump out of service. In some cases, greater operating and horsepower efficiencies can be obtained with a three- or possibly four-pump arrangement. This must be analyzed for each project. The pumps should be sized for an operation based on the lead pump start setting pressure and system scfm. Since most manufacturers actually rate their pumps on acfm, scfm must be converted to acfm using Eq. (15.4).
6. The vacuum pressure at the pump should be based on 20 inHg. A minimum vacuum pressure at the farthest outlet should be 14 inHg. An often used figure of 5 inHg friction loss in the piping system would allow for a margin of safety to allow for greater-than-expected use. For a duplex pump installation, the following start and stop conditions for the pump are recommended for 14 inHg terminal pressure:

| | Start, inHg | Stop, inHg |
|---|---|---|
| Lead pump | 18 | 21 |
| Lag pump | 17 | 20 |

For a triplex installation, the following start and stop conditions for the pump are recommended for 14 inHg terminal pressure:

**TABLE 15.11** Direct Reading of Simultaneous Use Factors for Health Care Facilities

| | Diversity | |
|---|---|---|
| No. of inlets | *A* | *B* |
| 15 | 100 | 100 |
| 20 | 100 | 99 |
| 25 | 100 | 96 |
| 30 | 100 | 92 |
| 35 | 99 | 86 |
| 40 | 99 | 78 |
| 45 | 99 | 70 |
| 50 | 98 | 66 |
| 57 | 97 | 62 |
| 60 | 96 | 59 |
| 65 | 95 | 56 |
| 70 | 94 | 54 |
| 75 | 92 | 52 |
| 80 | 90 | 50 |
| 85 | 87 | 48 |
| 90 | 84 | 46 |
| 95 | 80 | 44 |
| 100 | 75 | 42 |
| 110 | 70 | 40 |
| 120 | 66 | 39 |
| 130 | 62 | 38 |
| 140 | 58 | 36 |
| 150 | 55 | 35 |
| 160 | 53 | 34 |
| 170 | 50 | 33 |
| 180 | 47 | 32 |
| 190 | 44 | 30 |
| 200 | 42 | 29 |
| 220 | 38 | 28 |
| 240 | 36 | 27 |
| 260 | 34 | 27 |
| 280 | 32 | 26 |
| 300 | 31 | 25 |
| 340 | 30 | 24 |
| 380 | 28 | 23 |
| 420 | 26 | 22 |
| 460 | 24 | 21 |
| 500 | 22 | 21 |
| 600 | 21 | 20 |
| 700 | 20 | 20 |
| 800 | 19 | 19 |
| 900 | 19 | 19 |
| 1000 | 18 | 18 |

*Note:* Diversities are based on an average hospital. Specialty hospitals may require higher diversity.

**TABLE 15.12** Vacuum Pipe Sizing Chart

*(Maximum velocity: 5000 fpm; pipe material: L tubing; pressure drop: inHg per 100 ft)*

| | | Pipe diameter, in | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| sLpm | scfm | ¾ | 1 | 1¼ | 1½ | 2 | 2½ | 3 | 4 |
| 28.3 | 1 | 0.08 | | | | | | | |
| 56.6 | 2 | 0.27 | 0.08 | | | | | | |
| 85.0 | 3 | 0.53 | 0.15 | | | | | | |
| 113.3 | 4 | 0.88 | 0.25 | 0.09 | | | | | |
| 141.6 | 5 | 1.3 | 0.36 | 0.14 | | | | | |
| 169.9 | 6 | 1.8 | 0.50 | 0.19 | | | | | |
| 198.2 | 7 | | 0.65 | 0.24 | 0.11 | | | | |
| 226.6 | 8 | | 0.82 | 0.30 | 0.13 | | | | |
| 254.9 | 9 | | 1.01 | 0.37 | 0.16 | | | | |
| 283.2 | 10 | | 1.22 | 0.45 | 0.20 | | | | |
| 424.8 | 15 | | | 0.91 | 0.40 | 0.11 | | | |
| 566.4 | 20 | | | | 0.66 | 0.18 | | | |
| 708.0 | 25 | | | | | 0.26 | 0.09 | | |
| 850.0 | 30 | | | | | 0.36 | 0.13 | | |
| 990.0 | 35 | | | | | 0.47 | 0.17 | | |
| 1130.0 | 40 | | | | | | 0.21 | 0.09 | |
| 1275.0 | 45 | | | | | | 0.26 | 0.11 | |
| 1415.0 | 50 | | | | | | 0.32 | 0.14 | |
| 1700 | 60 | | | | | | 0.44 | 0.19 | |
| 2000 | 70 | | | | | | | 0.25 | 0.06 |
| 2250 | 80 | | | | | | | 0.31 | 0.08 |
| 2550 | 90 | | | | | | | | 0.10 |
| 2830 | 100 | | | | | | | | 0.12 |
| 3540 | 125 | | | | | | | | 0.18 |
| 4250 | 150 | | | | | | | | 0.25 |
| 4950 | 175 | | | | | | | | 0.35 |
| 5665 | 200 | | | | | | | | 0.44 |

| | Start, inHg | Stop, inHg |
|---|---|---|
| Lead pump | 19 | 21 |
| Second pump | 18 | 20 |
| Third pump | 17 | 19 |

**7.** The pump selected will have a capacity based on the total acfm calculated in step 4 and capable of producing the highest vacuum pressure established.

## Distribution Piping Sizing Procedure

***Establishing System Design Criteria.*** There are two figures needed to size the piping network. The first is the allowable pressure drop (which includes friction loss in the piping system, exhaust pipe losses, and losses through in-line devices such as filters or traps) for the entire network, in inHg per 100 ft of pipe (33 m). This is found by dividing the allowable pressure loss into the total equivalent length of pipe, in 100s of feet. The second is the adjusted scfm (connected scfm multiplied by a diversity factor) at the design point of the piping network.

To find the allowable friction loss for the network, first find the equivalent length of pipe. This is the actual, measured run of pipe, in feet, added to a distance, also in feet, that allows for the additional friction loss through fittings, filters, valves, and so on. The usual method of finding the equivalent run is to add 50 percent to the actual run. If the measured run is 300 ft (90 m), add 150 ft (45 m) to obtain the equivalent run, which is 450 ft.

The allowable friction loss is found by subtracting the design vacuum pressure desired at the most remote inlet from the highest pressure at the source, which is the lead pump stopping pressure. Generally accepted low pressure is 14 inHg at the most remote outlet, with 15 inHg being a more conservative figure. The previous discussion on pumps will determine the lead pump stop pressure.

There is no single accepted system to determine friction loss (pressure drop) criteria. For most systems, and for ease of calculations, it is generally accepted practice to allow a total friction loss of 3 to 5 inHg for the piping system, using any remaining pressure loss available as an allowance to compensate for in-line devices and vacuum pump source interconnecting piping.

Using the previous equivalent run of 450 ft (135 m) and a total friction loss of 3 inHg, the friction loss for the piping system is calculated by dividing 4.5 (450 ft divided by 100 because the chart uses loss per 100 ft) by 3 (inHg). This gives a figure of 0.66 inHg per 100 ft of pipe as the allowable friction loss for the piping network.

***Pipe Sizing Procedure.*** The piping distribution network is sized starting from the most remote point and working forward to the source. The scfm criteria, the use groups for each individual inlet, and the determination of the use factor is the same as that used to size the pump.

Starting at the most remote inlet on each branch, add together all the individual outlets by use group, starting with the first inlet and continuing toward the source. At each design point, find the scfm of each inlet. Add inlets with different use groups and specific uses separately. Multiply the inlet scfm by the appropriate diversity factor. Add this to other separate specific inlet scfm. This will result in calculating the design scfm in that particular pipe at the point being sized. This is continued separately at each design point to connection with the submain and finally the main. Determine the size pipe by using the vacuum sizing chart, Fig. 15.12. Entering the chart with the design scfm and the allowable system friction loss, find the intersection of the two values and select the larger pipe size. Entering Table 15.12 with the adjusted scfm, find a friction loss figure that is equal to or less than the allowable figure calculated; then read up to find the pipe size at the top of the column where the value is found. This chart is based on a vacuum pressure of 15 inHg, which is a commonly used and generally accepted value. To find pressure losses for values other than 15 inHg, use Eq. (15.5).

***General Design Considerations.*** There are several basic recommendations regarding the sizing of a system that shall be followed when sizing a complete network:

1. Because of the use of the diversity factor, it may be possible for a branch line to have a greater size than the main it is fed from. Always use the largest-size pipe calculated at any junction.
2. Do not use any diversity factor for OR's.

3. The smallest-size pipe shall be ½ in to any individual inlet. Use ¾ in as a minimum size for any branch and 1-in size minimum for any main or riser.

***Valves and Valve Locations.*** The required valves and their locations are similar to those provided for the compressed gas systems in health care facilities. In short, valves must be provided at the base of all risers serving more than one floor and to isolate sections of the piping network for repair, maintenance, and expansion without interference to the remainder of the system. The valves shall be metallic and of a type that will not create more friction loss than the pipe itself. Refer to the compressed air, health care facilities section, of Chap. 14 for additional discussion.

***System Alarms.*** In addition to the lag-pump-in-use alarm, the only other code-mandated alarm is low vacuum pressure for both the entire system and the anesthetizing systems. The low-pressure alarm is activated when the system vacuum pressure decreases to 12 inHg or to a point considered below the ''normal'' operating pressure range established by the facility. The pressure sensor for the system shall be located on the facility (inlet) side of the main line shutoff valve.

The pressure sensor for specific facility areas outside the pump room shall be set to activate below a pressure of 12 inHg. Anesthetizing areas shall have the sensor and a gauge located on the inlet side of any room control valve.

A high vacuum pressure alarm is not required. Refer to compressed air, Chap. 14, health care section, for further discussion of the location of annunciation and location of pressure sensor alarms.

## PURGE AND TESTS

After installation, the entire system shall be blown clear of all debris with oil-free nitrogen. After this purge, conduct the following tests:

1. Visually inspect all joints at atmospheric pressure to assure penetration of solder or brazing alloy into the joint.
2. Pressure test the piping system at 15 psig (105 kPa) with oil-free nitrogen, and again observe joints for leakage.
3. Test only the piping system prior to the pumb being installed with nitrogen at 60 psig (35 kPa) and allow it to stand for 24 h. A maximum loss of 5 psig is permitted.
4. Test for cross connection as discussed in Chap. 14.
5. Test the entire system, including the pumps, gauges, and alarms, with vacuum at 12 inHg for 1 h. A maximum loss of 1.5 inHg is allowed.
6. Test the alarm system to assure activation when pressure falls below 12 inHg at the farthest outlet.
7. Test the piping to assure that the outlets, when evacuating 3 scfm (0.9 $m^3/m$), shall not reduce an adjacent outlet to a pressure below 12 inHg.

After all of the tests have been successfully completed, the system is then ready for operation.

# WASTE ANESTHETIC GAS DISPOSAL

This section will describe vacuum systems used to remove waste anesthetic gas expelled from patients within operating rooms and other anesthetizing locations.

## GENERAL

A brief description of anesthetic gas delivery will aid in the understanding of the waste anesthetic gas disposal (WAGD) system. Anesthetic gas is a mixture composed of air, oxygen, nitrous oxide, and anesthetic in various proportions. It is mixed in an anesthesia machine to which all of the compressed gases are connected and mixed. Often a liquid anesthetic is used, and the compressed gas is bubbled through the liquid and then delivered to the patient. The tube transporting the anesthetic gas is connected to a "circle breathing system" that is worn by the patient and allows inhalation. The mixture exhaled by the patient is directed into an adsorber, purified, and rebreathed by the patient. This line contains an expired-gas valve that acts as a check valve. A gas scavenger interface is installed on the exhaust of the adsorber that contains a popoff valve (a safety valve), which has the connection to the WAGD system and is provided with both a pressure and vacuum relief valve. It is this valve that protects the patient against full vacuum, and it has proven to be extremely reliable. Approximately one-half of the volume of anesthesia mixture will be expelled to the WAGD system, which is approximately 1 to 2 Lpm. A schematic illustration of a typical anesthesia machine is shown in Fig. 15.14.

Anesthetic gases, if allowed to accumulate within any room, can produce conditions that are capable of causing numerous problems. If constantly inhaled, any of the gases may cause health problems or reduce the effectiveness of the surgeon and other members of the operating team. Regardless of the problem, it is required that the gas be removed from the area as quickly as they are released and disposed of. There are both active and passive methods used for removal.

There are differences of opinion regarding acceptable concentrations. The most often used guideline is the AIA's *Guidelines for Construction and Equipment of*

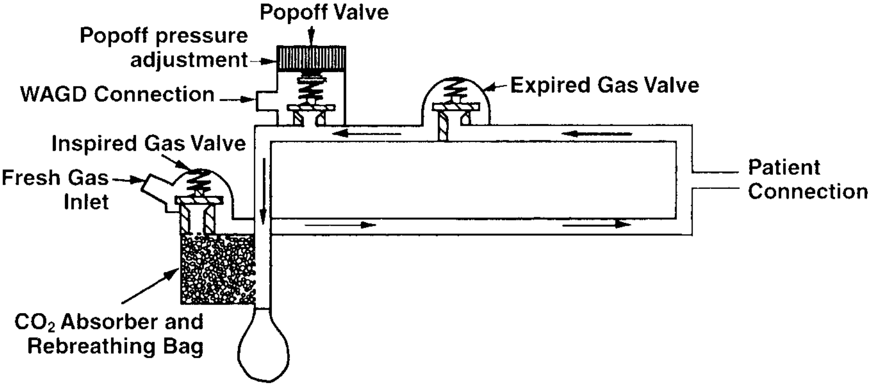


**FIGURE 15.14** Schematic illustration of a typical anesthesia machine.

*Hospitals and Medical Facilities.* It states: "Acceptable concentrations of anesthetizing agents are unknown at this time. The absence of specific data makes it difficult to set up specific standards. However, any scavenging system must remove as much of the gas as possible from the room environment."

The most severe problem mentioned in some standards is flammable anesthesia gases, although this problem has mostly disappeared. Modern practice has phased out the use of these gases. The WAGD method most commonly used is to have a dedicated vacuum inlet to collect the vapors and transport them away for disposal.

## METHODS OF ANESTHESIA GAS REMOVAL

There are four basic systems used for WAGD:

1. Room air changes
2. High vacuum active
3. Low vacuum active
4. Passive

### Room Air Changes

One method is to increase the number of air changes inside the room to prevent gases from accumulating. This is not considered a very reliable or effective solution because of the problems controlling turbulence and avoiding dead spots in the individual rooms. Other problems are that since the air is contaminated, it cannot be recirculated. The wasted cost of once-through heating and cooling of the air makes operating costs very high.

### Passive

A second method is to use only the pressure generated by the anesthetic machine itself to force the waste gas into a small-sized hose or tube for disposal outside the building or into an HVAC exhaust duct. This type of system is mostly used when no provision has been made for a dedicated WAGD system and has the advantage of being relatively free of danger to the patient. Past history of installed systems have been plagued by collapsed hoses, inadequate airflow, and improperly sized tubing. Maintenance is also very high. These systems work best when there is a good airflow to carry away the gases. The cost of this system is low, and the gas removal capabilities are considered poor.

### Low Vacuum Active

This active method uses a low-pressure fan and small-diameter ductwork as a dedicated system to draw off the gases and exhaust them to outside the building or into the HVAC exhaust system. Because of the low vacuum pressure involved, usually inthe range of 6 to 12 in WC, the ducts must be relatively large. If the facility is large, the system becomes very complex. This system also requires accurate balancing in order to operate properly. The cost of this system is moderately high, and the gas removal capabilities are good. Because of the low pressure of the vacuum, this system is increasingly being used. In some codes it is mandated. The reason for this is that if an accident occurs and the full force of the vacuum system is exposed to the patient, it is not a life-threatening condition as may happen when using the medical-surgical vacuum system with a pressure of 15 to 20 inHg. It must be pointed out that the modern equipment in use has been manufactured to superior standards and has not caused this problem.

### High Vacuum Active

The most often used system in the United States is either a dedicated WAGD system with its own dedicated pump or connection of the WAGD from the anesthesia machine directly into a dedicated outlet connected to the medical-surgical vacuum system. This type is called a *shared system.* Current good practice recommends that a dedicated WAGD system be used, although it is not mandated by code at this time. One problem associated with a shared system is that some of the anesthesia gases are not compatible with many gasket and seal materials and some types of piping used in standard medical-surgical vacuum systems. The most potentially serious problem is the possibility that the patient could be exposed to the full vacuum of the system upon failure of interface device safeguards on the anesthesia machine. Although a very remote possibility, this is a life-threatening condition. A schematic diagram of the interface from the WAGD inlet with the anesthesia machine is illustrated in Fig. 15.15.

## SYSTEM SIZING

For a dedicated, piped system, a minimum vacuum pressure of 14 inHg is recommended. For a shared system, the inlets are connected to the surgical-medical sys-

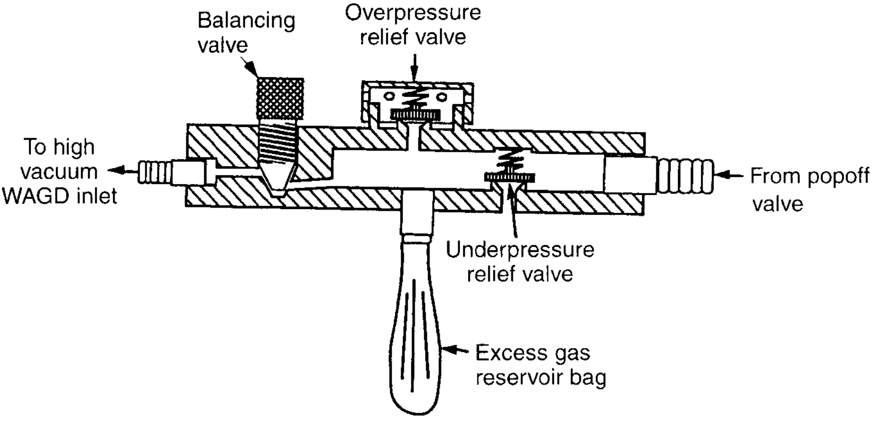


**FIGURE 15.15** Interface of high-pressure WAGD inlet with the anesthesia machine.

**TABLE 15.13** Advantages and Disadvantages of WAGD Systems

| System type | Patient safety | Cost of installation | Ease of use | Ability to prevent gas accumulation |
|---|---|---|---|---|
| Air changes | Good | Low | Good | Poor |
| High vacuum | Poor | Mod. to high | Moderate | Good |
| Low vacuum | Good | Moderate | Good | Good |
| Passive | Good | Low | Moderate | Poor |

tem, which has a minimum pressure of approximately 15 inHg. Vacuum pressure developed at the pump should be 19 or 20 inHg. Calculate the flow rate, determine the allowable friction loss per 100 ft of pipe, and use Table 15.12 to find the size pipe.

The flow rate shall be 1 scfm per WAGD inlet. No diversity factor is used. The total connected scfm shall be added separately to the surgical-medical system calculations if it is used as a source.

For the dedicated piped system, a larger pressure drop in the system can be allowed because there is only gas to be evacuated. A recommended loss of 6 inHg/100 ft will allow for smaller-sized pipes while keeping the velocity below 4000 scfm.

The ducted system uses 1 scfm per inlet with a pressure of about 12 in WC. Connection from the duct outlet is made with either a flexible hose or with copper pipe using appropriate adapters. Use standard HVAC criteria for sizing the main ducts allowing 1 scfm per inlet.

## SYSTEM OPERATING CHARACTERISTICS

Advantages and disadvantages of the various systems are listed in Table 15.13.

# DENTAL VACUUM SYSTEMS

## GENERAL

The dental vacuum system provides suction for the removal of fluids and suspended residue from oral cavities during operative and other dental procedures.

## CODES AND STANDARDS

NFPA-99 is the standard for design and installation for this system. There is very little specific material on dental vacuum systems, and the reference is made to the surgical-medical vacuum system for a majority of the requirements.

## SYSTEM COMPONENTS

The components of this system are the vacuum pumps, separators (if required), and the exhaust system. As an ancillary part of the liquid ring vacuum pump assembly, water conservation methods are used by many manufacturers to reduce the amount of water used for this type of pump.

### Vacuum Pumps

The two most often used types of pumps is the liquid ring and the centrifugal blower. Of these types, the liquid ring is commonly used for installations up to 5 hp motors. It also has the smallest installation space requirement since there is no need for a separator. The single disadvantage is that the pump must use water to seal the pump and is an integral part of its operation. The amount of water used is approximately 0.5 gpm/hp. Water conservation methods developed by manufacturers can often reduce the water flow rate to 0.1 gpm/hp, but the filtering arrangement requires more space. It is strongly recommended.

The blower is a centrifugal type of fan that will provide a larger flow rate and is generally used for motors 5 hp and larger. Since it cannot tolerate any moisture, a separator is mandatory. This source does not use any water, but it requires a larger amount of space for its installation because of the separator. The disadvantage is that it is not generally capable of producing as high a vacuum as the liquid ring pump.

Receivers are generally not used except for large installations because the vacuum system runs continuously.

### Separators

A separator removes liquids and suspended solids from the vacuum airstream. It could be placed upstream of the vacuum pump to remove system liquids before they could enter the pump, or placed downstream on the exhaust line to remove liquids and oil before being discharged to the environment.

Because typical systems are shut down at night, the separators can be drained at this time. Air is prevented from entering the separator by a check valve held closed by the negative air pressure. When the system is returned to atmospheric pressure, the check valve opens and allows the effluent to drain to the sanitary system.

Separators could be provided with an overflow. Often, an automatic switch is provided to shut down the system if the liquid level rises too high. In this case, it should be drained manually.

For vacuum systems used in dental laboratories only, the debris in the system may be dry. It is common practice to use a cyclonic dry separator using a dry filter bag for this type of system.

## *DESIGN CRITERIA*

### General

Dental work is divided into three general categories: dental surgery, general dentistry, and laboratory uses.

It is recommended that the vacuum source for surgical uses should be separate from the other systems because the surgical vacuum could be considered a life support system. The reason is that very often the patient may be under anesthesia and the vacuum prevents accumulation of fluids that may choke the patient. For general dentistry, the patient is conscious and is capable of communicating to the dentist that fluids are accumulating.

### Vacuum Pressure

The recommended vacuum pressure for the various systems are as follows:

1. *Dental surgery:* 12 to 17 inHg
2. *General dentistry:* 8 to 12 inHg
3. *Laboratory:* 5 to 9 inHg
4. For small practices, experience has shown that a vacuum pressure of 10 to 12 inHg will serve both surgery and general dentistry requirements.

The connection to the dental surgical vacuum system is often made using a typical filter bottle on the inlet similar to that used for the medical-surgical vacuum system.

### Flow Rate

The commonly used dental equipment has the following average flow rates. There is no difference in the instruments between dental surgery and general dentistry.

1. *Saliva ejector:* 2 to 3 scfm (depending on tip opening)
2. *High-volume ejector:* 5 to 10 scfm (used to remove drill water)
3. *Hygienist:* 5 scfm
4. *One dentist and one hygienist:* 15 scfm
5. *Dental laboratory inlet:* 20 to 30 scfm. This is necessary to capture a wide variety of dust from grinding operations by the use of a ‘‘fishmouth’’ installed at each station.

Other often used flow rates are set according to the following selection criteria:

1. Two chairs: 15 scfm
2. Four chairs: 22 scfm
3. Five chairs: 30 scfm
4. Eight chairs: 44 scfm

When establishing the flow rate for dental offices, experience has shown that a figure of 5 scfm/chair is the lowest marginally acceptable flow rate, 10 scfm/chair is a good, average flow rate, and 15 scfm/chair is the flow rate used for offices that will have additional special-purpose equipment.

### Diversity Factor

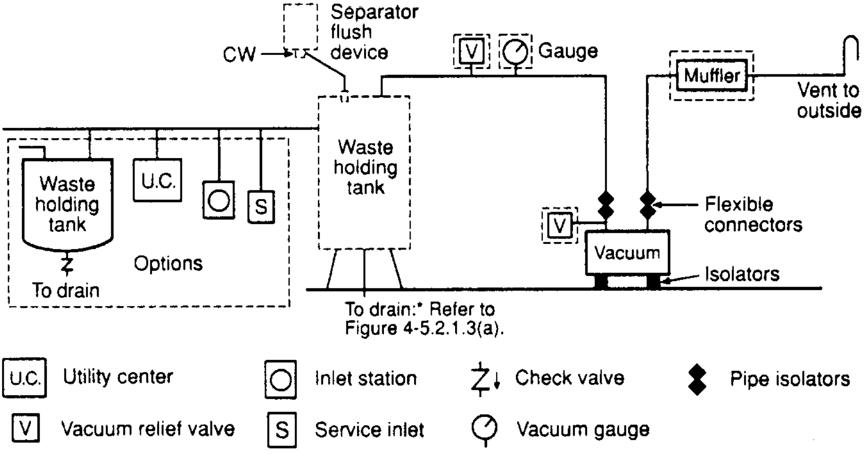
There is no generally accepted method or criteria for determining the diversity factor for dental vacuum. Since each facility is different, the largest anticipated simultaneous use shall be obtained from the end user. Information obtained from successful working systems in facilities and from designers-installers of dental equipment have established the following general criteria for both dentists and laboratory inlets:

1. 1 to 2 chairs: 100 percent
2. 3 to 4 chairs: 75 percent
3. 5 to 10 chairs: 60 percent

## *VACUUM GENERATION*

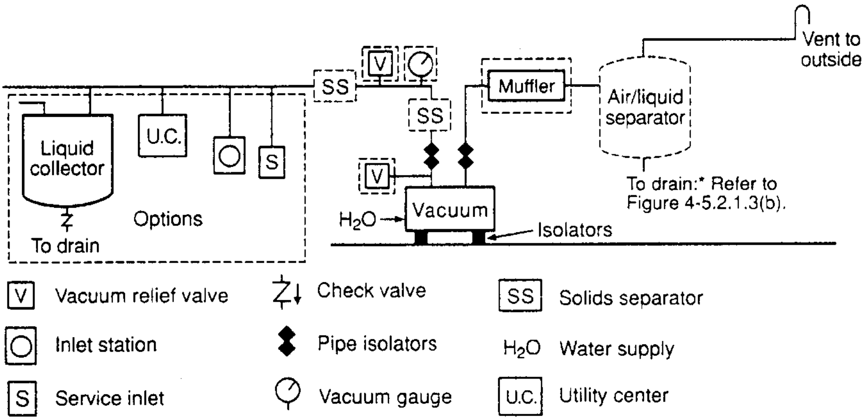
Although any type of pump could be used to produce dental vacuum, the liquid ring and blower types are the most often used. A major consideration is the small amount of space available in which to put all the mechanical systems, such as air compressors and vacuum pumps, in a small facility. The space available will often dictate the type of vacuum pump selected.

Information obtained from various manufacturers indicates that the liquid ring pumps are preferred for pumps up to 3 to 5 hp units. For one dental unit a simple and less costly liquid ring type of pump, referred to as a *water flood machine,* could be used. The liquid ring pump uses a constant water supply that mixes with the system fluids that are discharged directly to the sanitary system drain. Since all liquids are run through the pump, no separator is required.



* Note 1: Does not have to be below floor.
Note 2: Dotted lines indicate optional items.

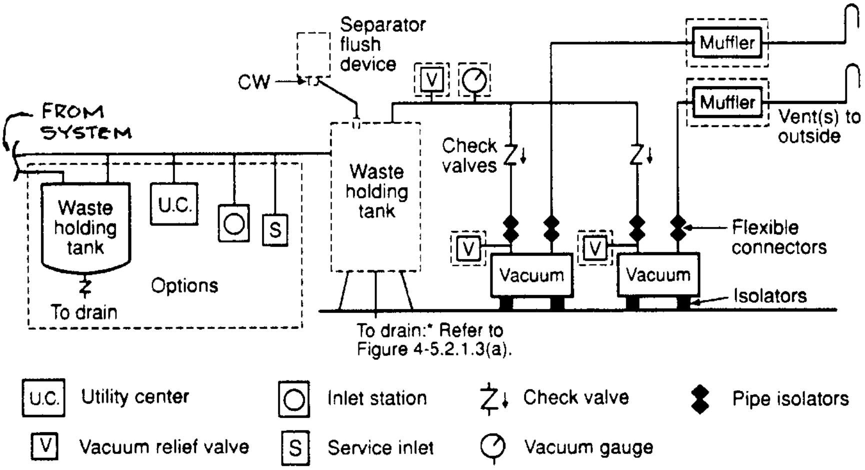
**FIGURE 15.16** Typical Level 3 wet or dry piping system with single vacuum source. (*Courtesy of NFPA.*)



* Note 1: Does not have to be below floor. Note 2: Dotted lines indicate optional items.

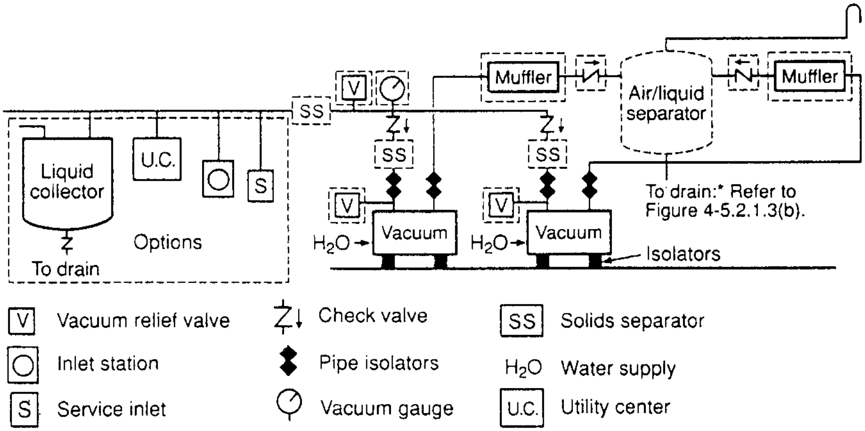
**FIGURE 15.17** Typical Level 3 wet or dry piping system with single vacuum pump source.

A centrifugal pump is often used for motors larger than 3 to 5 hp (depending on the manufacturer) and is capable of supplying 10 to 12 inHg vacuum pressure for general dentistry requirements. A typical schematic based on the various pump arrangements is illustrated in Figs. 15.16, 15.17, 15.18 and 15.19. Typical receiver drainage is illustrated in Figs. 15.20 and 15.21.



* Note 1: Does not have to be below floor. Note 2: Dotted lines indicate optional items.

**FIGURE 15.18** Typical Level 3 wet or dry piping system with duplex vacuum source.



* Note 1: Does not have to be below floor. Note 2: Dotted lines indicate optional items.

**FIGURE 15.19** Typical Level 3 wet or dry piping system with duplex vacuum source.

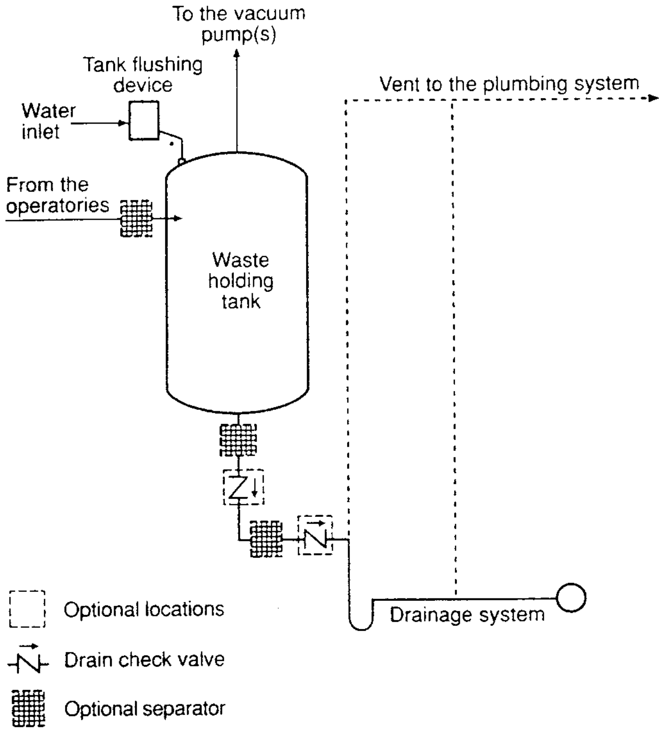


**FIGURE 15.20** Drainage from a gravity-drained, liquid collector tank.

Another feature of many systems is an automatic wash. This consists of a potable water supply provided at one point of the piping system or only at the separator. Controlled by a timer and a solenoid valve, the solenoid is opened at a set time during the night for a 5- to 10-min period. Often, the wash is started at night when the system is shut down.

A large majority of installations are set to run continuously during the day and are shut down at night. For this type of system, a common method used to control vacuum pressure is to have an automatic line pressure relief valve controlled by a pressure switch set to the desired pressure. This valve allows air to enter the piping system if the vacuum pressure gets too high and closes when the design pressure is reached.

## Exhaust

The pump exhaust shall be independently piped outside the facility, as similarly required for medical-surgical vacuum pumps. The exhaust pipe size is found using Table 15.9.

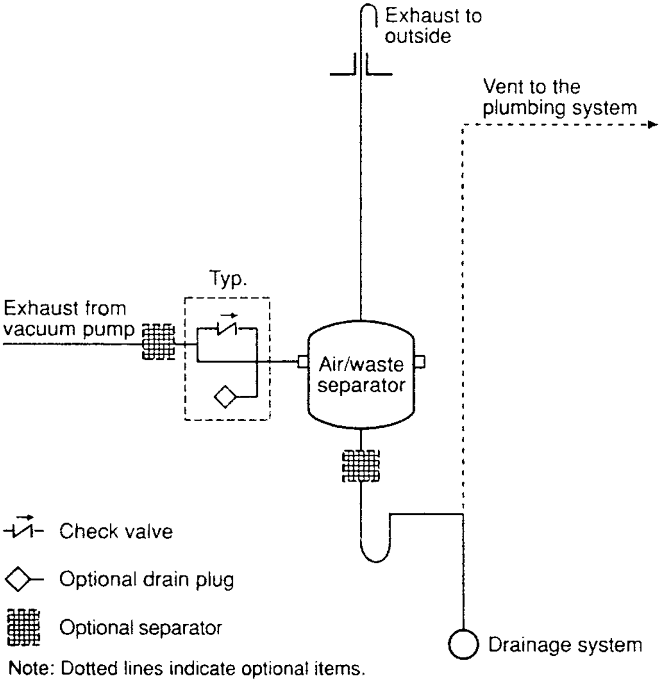


**FIGURE 15.21** Drainage from a positive discharge vacuum pump through an air/liquid separator.

## VACUUM SOURCE DESIGN CONSIDERATIONS

All pumps should be duplexed, each capable of 100 percent capacity. If a separator is required, the size is a function of the pump capacity, with manufacturers recommending the size based on the horsepower of the pumps. Sizes of the separator range from approximately 10 to 60 gal, with larger sizes used with the larger pumps. Space conditions also play an important part in sizing the separator, since mechanical space is often very limited in small dental offices. This may require that the size separator be reduced to fit the space or eliminated by using a liquid ring pump.

## DISTRIBUTION NETWORK

### Pipe Material, Joints, and Installation

The pipe, materials, joints, and installation are the same as for medical-surgical systems. The most often used material is copper tube type L. Plastic is not recommended as a piping material. Joints are usually soldered when using copper pipe.

### System Sizing

1. Obtain the layout of the facility, count all the inlets and chairs, and determine the length of run.
2. Determine the maximum number of simultaneous users.
3. Calculate the total connected scfm, and select the maximum vacuum pressure required.
4. Establish the range of vacuum pressure required. Using the allowable vacuum pressure drop for the system and the equivalent length of run, calculate the allowable pressure drop per 100-ft run of pipe using the lowest acceptable pressure.
5. Select the vacuum source and arrangement. This is based on adjusted scfm (using the connected load multiplied by the diversity factor), highest vacuum pressure desired, and available space.
6. Starting at the most remote point in the system, at each design point, calculate the adjusted scfm by multiplying the total connected load by the diversity factor. Entering Fig. 15.28 with the adjusted scfm and the allowable pressure drop, determine the size pipe by finding the highest allowable friction loss figure without exceeding the value, and finding the pipe size at the top of the table. Proceed to the source, using the same methods.

## *GENERAL DESIGN CONSIDERATIONS*

It is very important to have the piping pitch back to the source in order to allow any liquid drain back to the floor drain provided at the source equipment. Pitch should not be less than ⅛ in per foot, with a ¼ in pitch preferred. Another important consideration is to have the piping properly supported to avoid liquids accumulating at low points of the pipe system. In general, piping shall be oversized. Branches shall not be less than ¾ in with mains and rises not less than 1 in in size. Provide cleanouts to allow for easy cleaning and removal of stoppages.

# LABORATORY VACUUM SYSTEMS

The laboratory vacuum system serves general chemical, biological, and physics laboratory purposes, principally drying, filtering, transferring fluid, and evacuating air from apparatus. The usual working pressure of standard vacuum systems is in the range of 15 to 20 inHg. In some cases, there is a need for ''high'' vacuum in the range of 24 to 29 inHg, which is usually produced with a separate vacuum pump. The major difference between laboratory and surgical-medical systems is that the laboratory vacuum system does not normally carry liquids, but some invariably are introduced into the system. It is used primarily for pumping down and maintaining a vacuum rather than the transport of liquids or solids back to the source.

## CODES AND STANDARDS

There are no codes and standards that are required to be used directly in the design of vacuum systems for laboratories. The most important requirements are those of the end user and good engineering practice. Often, NFPA-99 is used as a guide.

Laboratories conducting biological work where airborne pathogens could be released are required to follow the appropriate biological level criteria established by the NIH. For most biological installations it is recommended that check valves be installed in each branch line to every room or area to prevent any cross discharge. In addition, the vacuum pump exhaust shall be provided with duplex 0.2-$\mu$m filters on the exhaust to eliminate all pathogenic particulates.

## VACUUM SOURCE

The vacuum source usually consists of two or more pumps that are designed to operate as system demand requires, a receiver used to provide a vacuum reservoir and to separate liquids from the vacuum airstream, the interconnecting piping around the pumps and receiver, and alarms. A duplex pump arrangement is usually selected if the system is critical to the operation of the laboratory. In some smaller installations where the vacuum system is not critical, it may be acceptable to have a single vacuum pump. The pumps selected should be oil free.

The principal types of vacuum pumps are divided into two general groups: gas transfer and capture. Capture pumps are outside the scope of this chapter. The types of pumps fall into the category of gas transfer and are as follows:

1. Rotary vane
2. Liquid ring
3. Rotary screw
4. Reciprocal

Rotary vane pumps include oil lubricated dry vane and oil flooded types. The oil lubricated is the oldest type requiring the oil to be dripped on the vanes for easy sliding. The oil flooded is a later improvement over the drip type. The dry vane type is the most often used.

If the pump manufacturer expresses the flow rate in ACFM, SCFM is calculated from the total connected inlets, the diversity factor and eq. 5. The stopping point of the pump is the required vacuum level, with levels similar to that discussed in the pump selection. Refer to the discussion in the medical-surgical section for advantages and disadvantages of each type of pump. The receiver, interconnecting piping, and exhaust arrangement are also similar. The basic difference is the absence of mandated alarms. None are required except for those necessary for maintenance by the end user. A detail of a typical laboratory vacuum pump assembly is illustrated in Fig. 15.22.

## REDUNDANCY

The redundancy of laboratory systems is based on the system capacity required with one pump being worked on or otherwise out of service. Only one fault is postulated. If there is a fire along with a power outage, additional provisions must be made. Mixed sizes are also not included in this chapter.

There are two scenarios to be considered. The first is that there is no excess capacity in the system. The second is that the system will provide full capacity if one pump is down or out of service. The only way to find out is to question the client (or end user) as to their needs and comply with them. The question to ask is how important is it to have 100% redundancy.

It is normal to have multiple pumps unless the client is determined to have the least first cost. If the client chooses no excess, write a letter giving your reasons for disagreeing with the lack of capacity. This will allow your firm to have something in the file if things go wrong. If the number of pumps is to be more than one, the answer is not simple. The decision has to be made as to how many, with the understanding that the various pump combinations would be almost infinite. With the decision not to have excess capacity, the number of pumps must be considered. Is it to be 50% and 50%, three at 33% or four at 25%. For no excess capacity, it is normal to have two 50% pumps. This will have at least the capability of some usefulness during an outage.

It is most normal to have excess capacity. This will allow the pumps to keep up with the full load with one of the pumps out of action. This means that the pump assembly will consist of two pumps or more, with the combination of pumps having the full load capacity. The range of pump combinations is almost infinite. It would be up to the manufacturer to explain how the pump assembly would be set up in order to make a decision. The most common would be two 60% or two 75% pumps. This will allow almost full operation except during ‘‘design’’ operating conditions. If design parameters are exceeded, the second pump will start giving additional vacuum production. It is common to have three 50% pumps mounted on a receiver. This way it will be able to handle full design load with one pump out of service.

A similar consideration should be given to the compressed air source pumps.

## DISTRIBUTION NETWORK

### Pipe Material and Joints

Piping for the distribution system shall be a corrosion-resistant material such as copper tube type K, L, or M, stainless steel, or galvanized steel pipe (usually

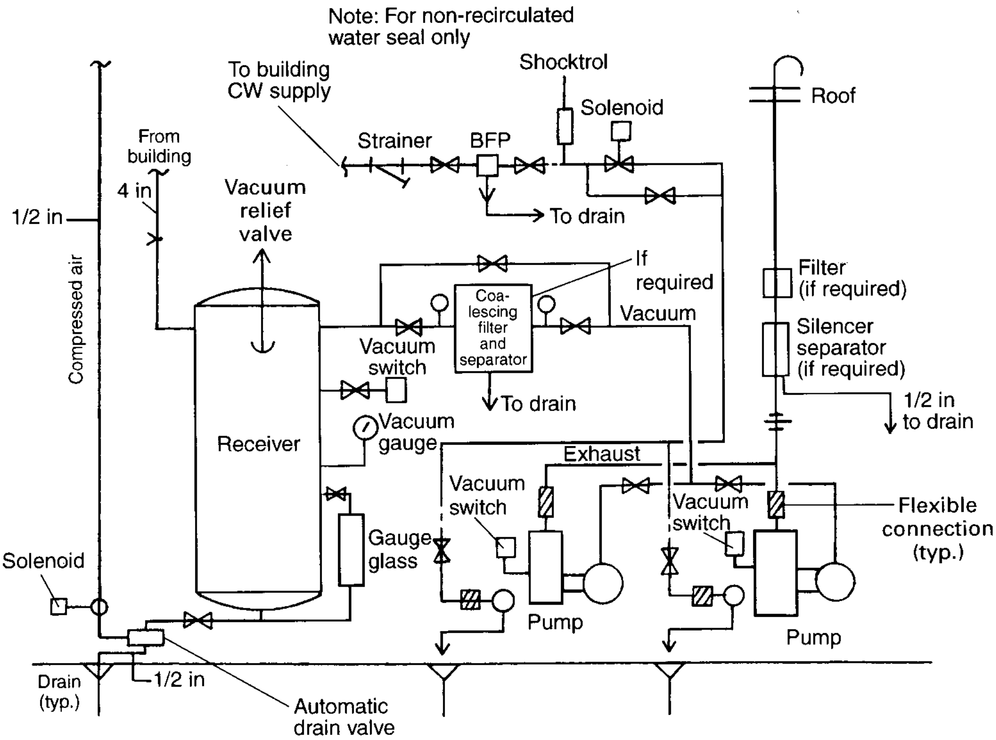


**FIGURE 15.22** Schematic detail of a typical laboratory vacuum pump assembly.

Schedule 40 ASTM A-53). Copper tube shall be hard temper except when installed underground, when soft temper should be used. Whenever piping passes under areas subject to surface loads such as roadways and parking lots, it shall be protected by ducts or secondary containment. Although cost has a major influence on the selection of the piping material, the most commonly used is copper tube type L, ASTM B-88 up to 4 in in size, with soldered joints. Pipe 5 in and larger is usually Schedule 40 galvanized steel pipe with threaded joints. Fittings shall be long turn drainage pattern so as not to impede the flow of fluids in the pipe.

## SIZING CRITERIA

### Number of Inlets

There is no code or other mandated requirements for specific locations of laboratory vacuum inlets. The number of inlets is determined by the user, based on a program of requirements for all rooms and areas and equipment used in the facility. Inlets for laboratory stations, fume hoods, and so on shall be appropriate for the intended use, based on requirements of the end user.

***Flow Rate.*** The basic flow rate from each laboratory inlet shall be 1.0 scfm. This is an arbitrary number and is based on experience. This flow rate is used in conjunction with the diversity factor.

***Diversity Factor.*** The diversity factor established for general laboratories is based on experience. It has been found to be slightly more than that used for compressed air because the vacuum is often left on for longer periods of time. Refer to Fig. 15.23 for a direct reading chart to determine the adjusted general laboratory vacuum

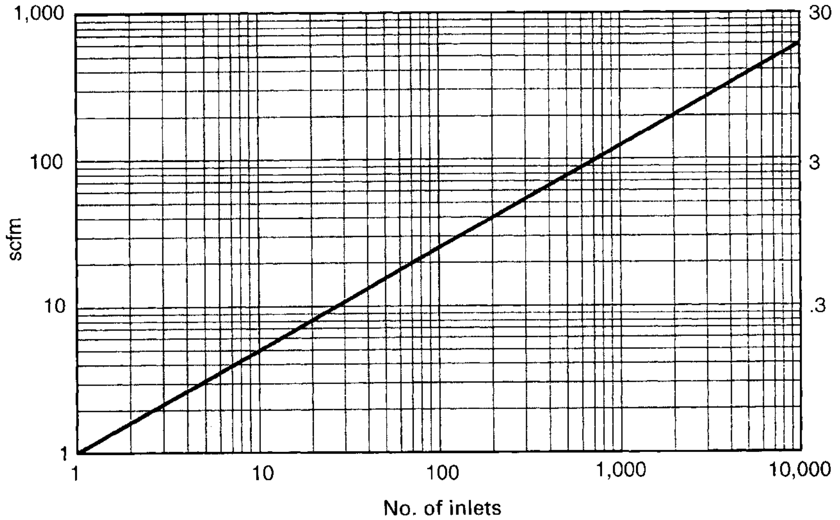


**FIGURE 15.23** Laboratory vacuum demand, direct reading.

**TABLE 15.14** Diversity Factor for Laboratory Vacuum Air Systems

| Number of inlets | Percent use factor |
|---|---|
| 1–2 | 100 |
| 3–5 | 80 |
| 6–10 | 66 |
| 11–20 | 35 |
| 21–100 | 25 |

flow rate using the number of connected inlets. Refer to Table 15.14 for the diversity factor for up to 100 inlets.

For the design of classrooms, the diversity factor for one and two classrooms on one branch is 100 percent. For more than two classrooms, use a diversity factor double for that of compressed air in Table 14.13 but never less than the largest scfm calculated for the first two rooms. Since the above flow rates and diversity factors are arbitrary, they must be used with judgment and modified if necessary to adjust for special conditions and owner requirements. Always consult the user for definitive information regarding the maximum probable simultaneous usage.

***Allowable Friction Loss.*** A generally accepted figure used to size a piping system is to allow a friction loss of 3 inHg for the entire system (after the source assembly) and a maximum velocity of 5000 fpm. If noise may be a problem, use 4000 fpm. For smaller systems, use a figure of 1 inHg for each 100 ft of pipe.

***Vacuum Pump Sizing.*** The source pump for laboratories is selected using the flow rate of gas calculated using all inlets, the diversity factor for the whole facility, and the required vacuum pressure. In general, it has been found that in most facilities, the vacuum pumps are oversized.

If the pump manufacturer expresses the flow rate in acfm, scfm is calculated from the total connected inlets, the diversity factor, and Eq. (15.1) or Table 15.4 or 15.5. The stopping point of the pump is similar to that previously discussed in the pump selection for the surgical-medical vacuum system. The exhaust and interconnecting piping is similar to that of the surgical-medical vacuum system.

***Piping Network Sizing.*** The following method is used to size the pipe at each design point:

1. Calculate the adjusted scfm (sLpm) at each point using the connected scfm (sLpm) reduced by the diversity factor at each design point.
2. Calculate the allowable friction loss per 100 ft of pipe.
3. Enter Table 15.12 with the scfm (sLpm), and find the value equal to or less than the previously determined allowable pressure loss. Read the size at the top of the column where the selected value is found.

# VACUUM CLEANING SYSTEMS

This section will discuss vacuum systems used for removing unwanted solid dirt, dust, and liquids from floors, walls, and ceilings. This can be accomplished by the use of either a permanent, centrally located system or a portable, self-contained, electric powered unit. The central system will transport the dirt to a central location where it can be easily disposed of or recovered. Portable units can be easily moved throughout all areas of a facility. They are outside the scope of this handbook.

## *TYPES OF SYSTEMS AND EQUIPMENT*

There are three types of permanent systems: dry, wet, and a combination system. The dry system is intended exclusively for free-flowing, dry material. It is the most commonly used, with cleaning capabilities ranging from cleaning carpets to removing potentially toxic and explosive product spills from floors in an industrial facility. Equipment consists of a vacuum producer, one or more separators that remove collected material from the airstream, tubing to convey the air and material to the separator, and inlets located throughout the facility. A wide variety of separators are available to allow disposal and recovery of the collected material.

The wet system is intended exclusively for liquid handling and pickup. It is commonly found in health care, industrial, and laboratory facilities where sanitation is important and frequent washings are required. Equipment consists of a vacuum producer, a wet separator constructed to resist the chemical action of the liquids involved, piping or tubing of a material resistant to the chemical action of the liquid, and inlets located throughout the facility. A typical wet vacuum cleaning pump assembly is illustrated in Fig. 15.24.

A combination system is capable of both wet and dry pickup. Equipment consists of a vacuum producer, a wet separator constructed to resist the chemical action of the liquid mixtures involved, pipe or tubing of a material resistant to the chemical action of the combined solid-liquid, and inlets located throughout the facility. Another method uses a portable wet separator attached to the dry piping system at the inlet location.

## *CODES AND STANDARDS*

There are no codes or standards governing the design and installation of vacuum cleaning systems.

## *SYSTEM COMPONENTS*

### Vacuum Producer (Exhauster)

Vacuum producers for typical vacuum cleaning systems consist of a single or multistage centrifugal unit powered by an electric motor. The housing can be con-

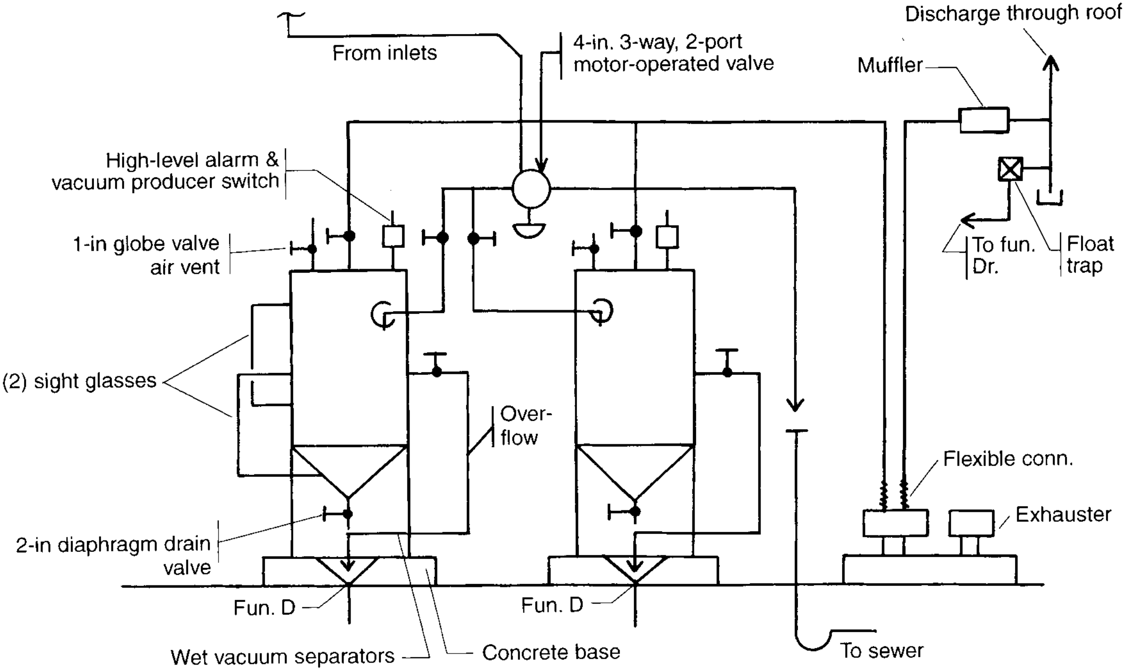


**FIGURE 15.24** Schematic of a typical wet vacuum cleaning pump assembly.

structed of various materials to handle special chemicals such as nonsparking aluminum for potentially explosive dust. The discharge of the unit can be positioned at various points to accommodate requirements of the exhaust piping system.

### Separators

Separators are used to remove the solid particulates in the airstream generated by the vacuum producers. For dry systems, tubular bag and centrifugal separators can be used. If only dust and other fine materials are expected, a tubular bag type is adequate. The bag(s) are permanently installed and removed only when replacement is necessary. They function as an air filter for fine particles and collect a majority of the dirt. This dirt eventually falls into a hopper or dirt can at the bottom of the unit. To empty the entire unit, the system must be shut down. The bag(s) must be shaken to remove as much of the collected material as practical and emptied into the dirt can. The dirt can is removed (or the hopper is emptied into a separate container) in order to clean out the unit. The dirt can should be sized to contain at least one full day's storage. Units are available with multiple bags to increase filter bag area. Shaking can be done either manually or automatically, with a motor-operated shaker. The motor-operated shaker has adjustable time periods to start operation after a variable length of time from shutdown of the system and for a variable length of time for the bags to be shaken. If continuous operation is required, compressed air can be used to blow through the bags and remove the dirt without requiring a shutdown.

The centrifugal separator is designed to remove coarser dry particles from the airstream. It is also used when additional dirt storage is needed and also when more than six simultaneous operators are anticipated. The air enters the separator tangentially to the unit, forcing the air containing particulates into a circular motion within the unit. Centrifugal force accomplishes separation.

The wet separator system collects the liquid, separates the water from the airstream, and discharges the waste to a drain. This type of separator can be equipped with an automatic overflow shutoff that stops the system if the water level reaches a predetermined high water level and can be equipped with automatic emptying features.

Immersion separators are used to collect explosive or flammable material in a water compartment. If there is a potential for explosion, such as in a grain- or flour-handling facility, the separator shall be provided with an integral explosion relief-rupture device that is vented to the outside of the building.

### Filters

Vacuum producers are normally exhausted to the outside air, and usually do not require any filtration. However, when substances removed from the facility are considered harmful to the environment, an HEPA filter must be installed in the discharge line to eliminate the possibility of contamination of the outside air. The recommended location is between the separator and vacuum producer.

### Silencers

When the exhaust from the vacuum producer is considered too noisy, a silencer shall be installed in the exhaust to reduce the noise to an acceptable level. Pulsating airflow will require special design considerations. Connection to silencers shall be made with flexible connections. Separate supports for silencers are recommended.

## Inlets

Inlets are female inlet valves and are equipped with a self-closing top-hinged cover. They provide a quick connection for any male hose or equipment. The cover can be locked closed as an option. Many different inlet types are available in various materials and in sizes ranging from 1½ to 4 in.

## Control and Check Valves

Valves for the vacuum cleaning system are different than standard valves. They are used to control the flow or stop the reverse flow of air in the vacuum cleaning system. When a valve is used as a regulating valve, it is called a *wafer butterfly valve* or an air gate valve. An air gate is illustrated in Fig. 15.25. A less costly substitute for an air gate is called a blast gate, and it operates using a sliding plate in a channel. An air gate is illustrated in Fig. 15.26. The plate has a hole that matches the size of the opening in the channel, with room to close off the opening completely. Air gates can be used only in low-pressure systems and are generally available in sizes from 2 to 6 in.

Check valves are typically spring-loaded, swing-type and are hinged in the center. A typical check valve is illustrated in Fig. 15.27.

## Air Bleed Control

If the exhauster is constantly operated with low or no inlet air, there is a possibility that the exhauster motor will become hot enough to require shutdown due to overheating. To avoid this, an air bleed device can be installed on the inlet to the

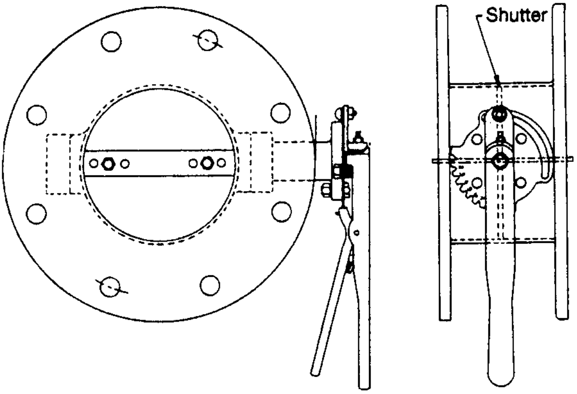


**FIGURE 15.25** Air gate valve.

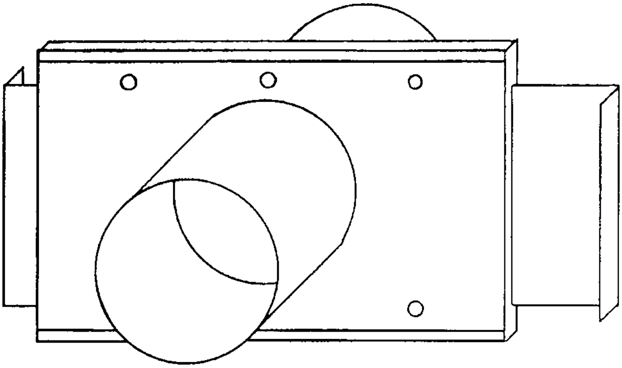


**FIGURE 15.26** Typical blast gate. (*Courtesy Spencer Turbine.*)

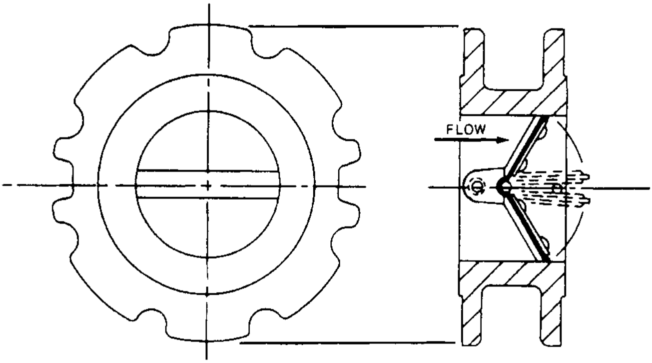


**FIGURE 15.27** Check valve. (*Courtesy Spencer Turbine.*)

exhauster that will automatically allow air to enter the piping system. If the facility indicates that overheating may be a possibility, the manufacturer of the unit should be consulted to determine the need for this device for the system selected.

## Pipe and Fittings

The most often used material is thin-wall tubing, generally in a range of 12 to 16 gauge. This tubing is available in plain carbon steel, zinc coated steel, aluminum, and stainless steel. Fittings are special, designed for the vacuum cleaning system. Tubing is normally joined using shrink sleeves over the joints. Compression fittings and flexible rubber sleeves and clamps are also used. Tubing shall be supported every 8 to 10 ft, depending on size, under normal conditions. Standard steel pipe is often used in areas where the additional strength is required. In special areas where leakage and strength are mandatory, the tubing joints can be welded if required.

## DETAILED SYSTEM DESIGN

### Inlet Location and Spacing

The first step in system design is to locate the inlets throughout the facility. The spacing of inlets depends on the length of hose selected for use. After this is decided, the inlet locations shall be planned in such a manner that all areas are capable of being reached by the selected hose length. This must take into account furniture, doorways, columns, and all obstructions. Some small overlap must be provided to allow for hoses not being able to be stretched to the absolute end of their length. Consideration should be given to providing a 25 ft, 0 in, spacing for areas where spills are frequent, heavy floor deposits may occur, and where frequent spot cleaning is necessary.

Generally, there are several alternate locations possible for any given valve. Inlets should be placed near room entrances. Wherever possible, try to locate inlets in a constant pattern on every floor. This allows for the location of common vertical risers since the distance between floors is less than the distance between inlets. In any system, minimizing piping system losses by a careful layout will be reflected in reduced power requirements of the exhauster.

The inlets should be located between 24 and 36 in above the floor.

### Determining Number of Simultaneous Operators

This is a major consideration for design purposes because an underdesigned system will not produce the desired level of vacuum and an oversized system will be costly. The maximum number of simultaneous operators is decided by the housekeeping or maintenance departments of the facility and depends on a number of factors:

1. Is the preferred method to have gang cleaning? Is it possible to alter this practice in order to use a less costly system?
2. What is the maximum number of operators expected to use the system at the same time?
3. Is the work done daily?

For commercial facilities where there may be no available information, the following guidelines are based on experience and can be used to estimate simultaneous use based on productivity. These figures consider the greater efficiency of using a central system compared to portable units, often in the order of 25 percent. They must be verified and based on actual methods anticipated:

1. For carpets, one operator will be expected to cover 20,000 $ft^2$ of area for regular carpeting in an 8-h shift. For long or shag carpets, the figure is about 15,000 $ft^2$. Another generally accepted figure is 3000 $ft^2/h$ for standard floors and 2500 $ft^2/h$ for shag and long carpets.
2. For hotels, an average figure of 100 rooms, including adjacent corridors, per 8-h shift would be expected. For long or shag carpets, the figure is about 75 rooms.
3. For theaters, use the number of seats divided by 1000 to establish the number of simultaneous operators.
4. For schools, an average figure is 12 classrooms per day for a custodian to clean in addition to other duties normally accomplished.

### Inlet Valve and Hose Sizing

Experience has shown that the use of 1½-in size hose and tools for cleaning floors, walls, and ceilings is the most practical size. Smaller, 1-in size tools are used for cleaning production tools, equipment, and benches. Larger hoses and tools are used for picking up expected large spills and used to clean large tanks, boxcars, and the holds of ships. Refer to Table 15.15 for general recommendations for tool and hose sizes.

Standard hoses are available in 25-, 37.5-, and 50-ft lengths. For general cleaning, the location of inlet valves should allow for convenient cleaning with 50 ft as the maximum hose length. This represents a labor saving by halving the times an operator has to change outlets. This length should not be exceeded except for occasional cleaning because of excessive pressure drop.

### Locating the Vacuum Producer Assembly

The vacuum producer assembly consists of the vacuum producer, commonly called an *exhauster,* and separators. The following shall be considered in locating the vacuum equipment:

1. Provide enough headroom for the piping above the equipment and to allow the various pieces to be easily brought into the room or area where it is to be installed.
2. Ideally, the vacuum producer assembly should be installed on the floor below the lowest inlet of the building or facility and in a central location to minimize the differences at remote inlet locations.
3. A convenient means to dispose of the dirt should be close by. If a separator is used, an adequately sized floor drain will be required.
4. Enough room around the separators shall be provided to allow for easy inspection, and where the dirt bins must be emptied, room must be provided for the carts needed to move them. Dry separators could also be located outside the building for direct truck disposal of the dirt if sufficiently protected.

**TABLE 15.15** Recommended Sizes of Hand Tools and Hose

| Nominal size, in | Average floor cleaning and moderate spills | Close hand work | For removing heavy spills or large quantities of materials | Overhead vacuum cleaning | Standard hose length, ft |
|---|---|---|---|---|---|
| 1 | Not used | Yes | Inadequate | Not used | 8 |
| 1½ | Excellent | Yes | Fair | Preferred | 25 and 50 |
| 2 | Good | No | Good | Poor | 25 and 50 |
| 2½ | Not used | No | Excellent | Not used | 25 and 50 |

***Source:*** Courtesy Hoffman.

## Sizing the Piping Network

***General.*** After the inlets and vacuum equipment have been located, the layout of the piping system accomplished, and the number of simultaneous operators decided upon, the process of system sizing can begin. Cleaning systems using hose and tools shall have sufficient capacity so that only one pass over the area being cleaned is all that is necessary. With adequate vacuum, light to medium dirt deposits shall be removed as fast as the operator moves the floor tool across the surface. The actual cleaning agent is the velocity of the air sweeping across the floor.

***Inlet Tool Size.*** The recommended inlet size for hand tools and hose is given in Table 15.15.

***Vacuum Pressure Requirements and Hose scfm.*** In order to achieve the necessary air velocity, the minimum recommended vacuum pressure for ordinary use is 2 inHg. For hard-to-clean and industrial materials, 3 inHg vacuum pressure is required. The flow rate must be enough to bring the dirt into the tool nozzle. Refer to Table 15.16 to determine the minimum and maximum recommended flow rate of air and the friction losses of each hose size for the flow rate selected. For ordinary carpeting and floor cleaning purposes, a generally accepted flow rate of 70 scfm is recommended.

***Recommended Velocity.*** The recommended velocity in the vacuum cleaning piping system depends on the orientation of the pipe (horizontal or vertical) and the size. Since the velocity of the air in the pipe conveys the suspended particles, it should be kept in a recommended range. Refer to Table 15.17, which indicates recommended velocity based on pipe size and the horizontal or vertical orientation of the pipe. The higher velocity is recommended for dense material or for material considered difficult to move. It is the air velocity that moves the dirt in the system. Oversizing the pipe will lead to low velocity and poor system performance.

### *Pipe Sizing*

*Selecting the Number of Outlets in Simultaneous Use.* Facilities may have many inlet valves, but only a few will be used at once. Under normal operating conditions, these inlets will be chosen at random by the operators. In order to aid in the determination of simultaneous usage, the following conditions should be expected:

1. Adjacent inlet valves will not be used simultaneously.
2. For calculation of simultaneous use, the most remote inlet on the main and the inlet closest to the separator will be assumed to be in use along with other inlet valves between these two.
3. Where mains and outlets are located on several floors, the use of inlets will be evenly distributed along a main on one floor or on different floors.
4. For long horizontal runs on one floor, allow for two operators on that branch.

*Sizing the Piping Network.* Refer to Table 15.18 for selecting the initial pipe size based on the number of simultaneous operators. This table has been calculated to achieve the minimum velocity of air required for adequate cleaning. In this table, "line" refers to permanently installed pipe from inlet to separator, and "hose" is the hose connecting the tool to the inlet. A 1½-in-diameter hose is recommended except where the size of the material to be cleaned will not pass through the hose or a large volume of material is expected.

**TABLE 15.16** Flow Rate and Friction Loss for Vacuum Cleaning Tools and Hoses

| | | Minimum volume and pressure drop | | Maximum volume and pressure drop | |
|---|---|---|---|---|---|
| Use | Nominal size of tools and hose, in | Volume, scfm | Pressure drop, in Hg | Volume, scfm | Pressure, in Hg |
| Bench use | 1-in diam., 8-ft<br>1-in flexible hose | 40 | 1.20 | 50 | 1.90 |
| White rooms or areas with very low dust content | 1½-in diam., 50-ft<br>1½-in flexible hose | 60 | 2.25 | 90 | 4.10 |
| Usual industrial | 1½-in diam., 50-ft<br>1½-in flexible hose | 70 | 2.80 | 100* | 4.80 |
| Fissionable materials or other heavy metallic dusts and minute particles of copper, iron, etc. | 1½-in diam., 50-ft<br>1½-in flexible hose | 100 | 2.50 | 120 | 4.20 |
| Heavy spills cleaning railroad cars and ship holds | 2-in diam., 50-ft<br>2-in flexible hose | 120 | 2.60 | 150 | 3.80 |

*Note:* The pressure drop in flexible hose is 2½ times the pressure drop for the same length and size of Schedule 40 pipe.

*Can be exceeded by 10 percent if necessary.

***Source:*** Courtesy Hoffman.

**TABLE 15.17** Recommended Velocities for Vacuum Cleaning System

| | Horizontal runs of branches and mains and vertical down-flow risers | | Vertical up-flow risers | |
|---|---|---|---|---|
| Nominal tubing size, in | Minimum velocity, ft/min | Recommended max. velocity, ft/min | Minimum velocity, ft/min | Recommended max. velocity, ft/min |
| 1½ | 1800 | 3000 | 2600 | 3800 |
| 2 | 2000 | 3500 | 3000 | 4200 |
| 2½ | 2200 | 3900 | 3200 | 4700 |
| 3 | 2400 | 4200 | 3800 | 5100 |
| 4 | 2800 | 4900 | 4200 | 6000 |
| 5 | 3000 | 5400 | 4800 | 6500 |
| 6 | 3400 | 6000 | 5000 | 7200 |

1 ft/min = .3 m/min.

***Source:*** Courtesy Hoffman.

**TABLE 15.18** Pipe Diameter Based on Simultaneous Usage

| Line dia., in | No. of operators 70 scfm, 1.5-in hose | No. of operators 140 scfm, 2-in hose |
|---|---|---|
| 2 | 1 | — |
| 2½ | 2 | 1 |
| 3 | 3 | 2 |
| 3½ | 4 | 2 |
| 4 | 5 | 3 |
| 5 | 8 | 4 |
| 6 | 12 | 6 |
| 8 | 20 | 10 |

***Source:*** Courtesy Spencer Turbine.

After the initial selection of the pipe sizes, the actual velocity and friction loss based on anticipated flow rates in each section of the piping system should be checked by using Fig. 15.28. This chart is a more accurate method of determining the pipe size, friction loss, and velocity of the system. Enter the chart with the adjusted scfm and allowable pressure loss. Read the pipe size at the point where these two values intersect. If this point is between lines, use the larger pipe size. If any parameter is found to be outside any of the calculated ranges, the pipe size should be revised.

Pipe sizing is an iterative procedure, and the sizes may have to be adjusted to reduce or increase friction loss and velocity as design progresses.

***Piping System Friction Losses.*** With the piping network sized, the next step is to precisely calculate the worst-case total system friction losses, in inches of mercury, in order to size the exhauster. This is calculated by adding together all of the following values, starting from the most remote inlet from the exhauster and continuing to the source.

1. *Initial level of vacuum required.* For average conditions the generally accepted figure is 2 inHg. For hard-to-clean material, industrial applications, and long shag carpet, the initial vacuum should be increased to 3 inHg.
2. *Pressure drop through the hose and tool.* Refer to Table 15.16 for the friction loss through individual tools and hose based on the intended size and length of hose and the flow rate selected for the project.
3. *Loss of vacuum pressure due to friction of the air in the pipe.* Losses in the straight runs of the piping system are based on the flow rate of air in the pipe at the point of design. Refer to Fig. 15.18. Fittings are figured separately, using an equivalent length of pipe to be added to the straight run. Refer to Table 15.19 to determine the equivalent length of run for each type and size of fitting. Starting from the farthest inlet, use the scfm, the pipe size, fitting allowance, and the pipe length along the entire run of pipe to find the total friction loss.
4. *Loss through the separator.* A generally accepted figure is 1 inHg loss through all types of separators. The exact figure must be obtained from the manufacturer.
5. *Exhaust line loss.* This can usually be ignored except for long runs. Allow 0.1 inHg as an average figure for a run of 100 ft.

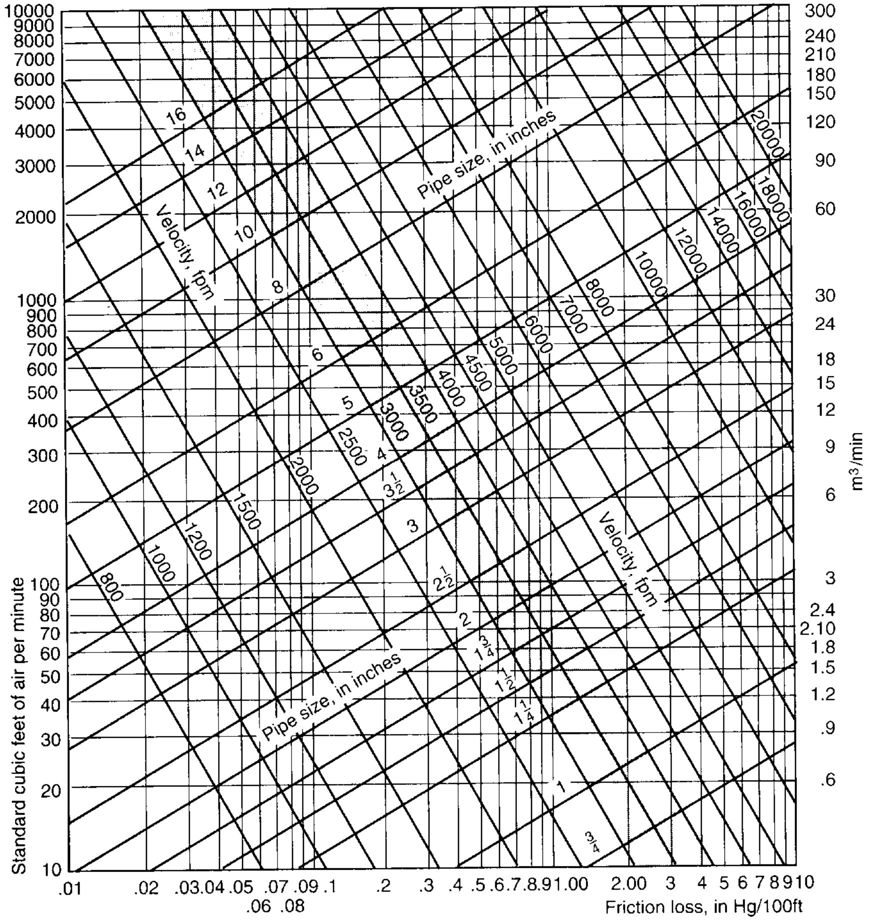


**FIGURE 15.28** Vacuum cleaning piping friction loss chart. Friction loss, in inches of mercury per 100 ft of line with inlet air at 70°F and 14.7 psia. (*Courtesy Spencer Turbine.*) 1 fpm = .3 M/min.

## Vacuum Producer (Exhauster) Sizing

***Exhauster Inlet Rating Determination.*** It is now possible to size the exhauster. There are two exhauster ratings that must be known in order to select the size and horsepower. They are: (1) worst-case piping system vacuum pressure losses and (2) the flow rate, in scfm, of air required by the system.

The vacuum pressure required from the exhauster is the total necessary to overcome all piping system losses. This consists of the total pressure drop from all components in the piping network from the inlet farthest from the exhauster. These are the initial inlet vacuum level required, the pressure lost through the tool and hose selected, the friction loss of air flowing through the piping system, the pressure lost through separators, filters, and silencers, and finally the exhaust pressure to be overcome, if required, These values are added together to establish the vacuum rating of the exhauster.

**TABLE 15.19** Equivalent Length of Vacuum Cleaning Pipe Fittings

| Nominal size of pipe, in | Using cast iron drainage fittings<br>90° change in direction | 45° change in direction |
|---|---|---|
| 1¼ | 3 | 1½ |
| 1½ | 4 | 2 |
| 2 | 5 | 2½ |
| 2½ | 6 | 3 |
| 3 | 7 | 4 |
| 4 | 10 | 5 |
| 5 | 12 | 6 |
| 6 | 15 | 7½ |
| 8 | 20 | 10 |

*Note:* For smooth-flow fittings, use 90 percent of these values.

The flow rate of air, in scfm, entering the system is calculated by multiplying the number of simultaneous operators by the scfm selected as appropriate for the intended clean-up requirements. For smaller, less complex systems, using only the actual selected inlet scfm is sufficient.

***Separator Selection and Sizing.*** The separator is sized based on the scfm of the vacuum producer and the type of material expected to be collected. Refer to Table 15.20 to select a separator based on the classification of material expected to be collected.

For dry separators, a starting point for sizing would provide a ratio of filter bag area to the bag volume of 6:1 for smaller volumes of coarse material and 3:1 for fine dust and larger quantities of all material. Wet and centrifugal separator sizing is proprietary to each manufacturer and is dependent on the quantity and type of material expected to be removed.

Some automatic separator cleaning systems use compressed air to aid in dislodging the dust. The air pressure recommended is generally in the range of 100 to 125 psig (700 to 875 kPa).

***Exhauster Discharge.*** The discharge from the exhauster is usually routed through steel pipe to be vented outside the building. It is also possible to route the exhauster discharge into an HVAC exhaust duct that is routed directly to outside the building.

For a piped exhaust, if the end is elbowed down, it shall be a minimum of 8 ft, 0 in, above grade. If the end is vertical, an end cap shall be installed to prevent rain from entering the pipe. A screen will prevent insects from entering. The size shall be equal to or one size larger than the size pipe into the exhauster. Use HVAC ductwork sizing methods to find the size of the exhaust piping while keeping the air pressure loss to a minimum.

The pressure loss through the exhaust pipe shall be added to the exhauster inlet pressure drop, the total of which will be calculated into the pressure that the exhauster must overcome. For short runs of about 20 ft, 0 in, this can be ignored.

**TABLE 15.20** Classification of Material for Separator Selection

| | Very fine | | Fines | | Granular | | Lumpy | | Irregular |
|---|---|---|---|---|---|---|---|---|---|
| Volume of material | Recommended sep. (*S*) | Ratio volume to bag area | Recommended sep. (*S*) | Ratio volume to bag area | Recommended sep. (*S*) | Ratio volume to bag area | Recommended sep. (*S*) | Ratio volume to bag area | Separator selection & bag area |
| Small | CENT. | Not appl. | CENT. | Not appl. | CENT. | Not appl. | CENT. | Not appl. | dependent on material |
| Medium | TB | 6:1 | CENT. | 6:1 | CENT. | Not appl. | CENT. | Not appl. | |
| | | | CENT. and TB | | | | | | |
| Large | CENT. and TB | 3:1 | CENT. and TB | 6:1 | CENT. and TB | 6:1 | CENT. | Not appl. | |

**Definition of terms:**

**Small:** Light accumulations such as found in clean rooms, white rooms, laboratories, and so on

**Medium:** Average accumulations such as found in classrooms, motels, assembly areas, and so on

**Large:** Heavy accumulations such as found in foundries, spillage from conveyor belts, waste from processing machines, and so on

**Fines:** 100 mesh to $\frac{1}{8}$ in

**Very fine:** Less than 100 mesh

**Granular:** $\frac{1}{8}$ to $\frac{1}{2}$ in

**Lumpy:** Lumps $\frac{1}{2}$ in and over

**Irregular:** Fibrous, stringy, and so on

*Note:* Centrifugal separators do not utilize bags.

*Abbreviations:* CENT = centrifugal; TB = tubular bag.

***Source:*** Courtesy Spencer Turbine Co.

## Exhauster Rating Adjustments

***scfm Adjustment for Long Runs.*** For systems with long runs or complex systems with both long and short runs of piping, some adjustment in the selected inlet scfm shall be made. This is necessary because the actual scfm at the inlets closest to the exhauster will be greater than the scfm at the end of the longest run due to the lesser friction loss. The adjustment will establish an average inlet scfm flow rate for all inlets that will be used for ease of system sizing instead of the actual inlet scfm.

In order to establish the adjusted scfm, it will be necessary to separately calculate the total system friction loss for each branch line containing inlets nearest and farthest from the exhauster. Following the procedures previously explained will result in minimum and maximum system friction loss figure. The following formula will calculate the adjusted inlet scfm used for design purposes:

$$\text{Adjusted scfm} = \frac{\text{farthest inlet friction loss, inHg}}{\text{closest inlet friction loss, inHg}} \times \text{selected scfm} \qquad (15.6)$$

To size the exhauster, the adjusted scfm figure will be used instead of the selected scfm, and it will be multiplied by the number of simultaneous operators.

***Adjustment Due to Elevation.*** All of the above calculations are based on scfm. If the location of the project is at a higher elevation than sea level, the scfm should be adjusted to allow for the difference in barometric pressure. Refer to Table 15.7 for the factor. This factor shall be multiplied by the scfm figure to calculate the adjusted scfm to be used in sizing the exhauster.

***Adjustment for Different scfm Standards.*** Another adjustment to the scfm figure used to size the exhauster that may be required is if the equipment manufacturer uses the inlet cfm (icfm) instead of scfm. *Inlet cfm* is the actual volume of air at the inlet of the exhauster using local temperature and barometric conditions. Previously discussed temperature and barometric conversions shall be used.

To convert scfm to acfm, refer to Eq. (15.1).

## Preliminary Sizing Method

At the start of a project, it may be necessary to establish the preliminary horsepower rating of the exhauster for the electrical discipline and physical size of the vacuum producer assembly to establish preliminary space conditions. The following method will allow this selection.

First, find the longest equivalent piping run, in feet. Then estimate the number of simultaneous operators. Using Fig. 15.29, draw a vertical line up from the bottom where the length is indicated until it intersects the length of hose that will probably be selected. From that point of intersection, draw a horizontal line to the left side of the figure. At the intersection of the line with the left side, read the vacuum

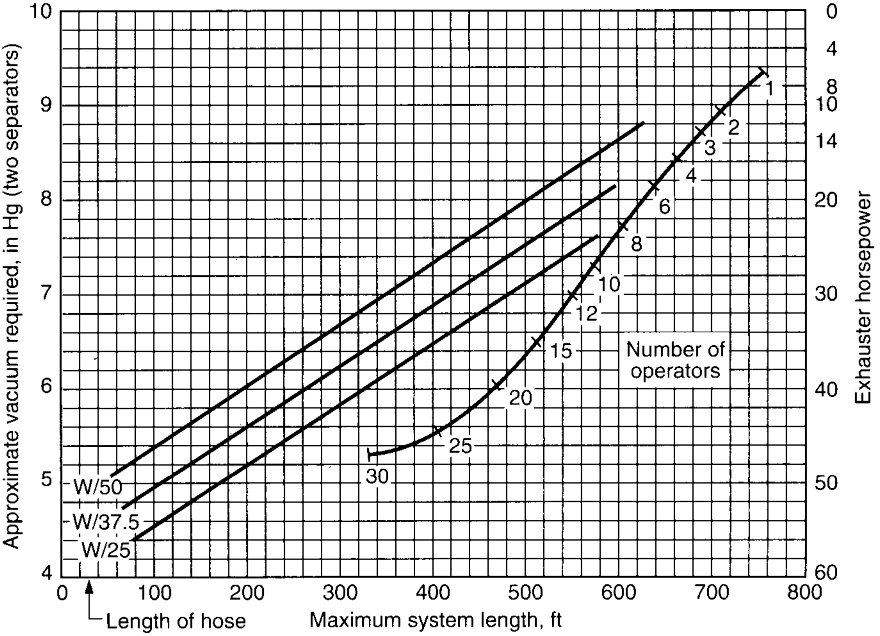


**FIGURE 15.29** Preliminary exhauster horsepower determination. (*Courtesy Spencer Turbine.*)

requirement. From the intersection of the horizontal line with the left edge, draw another line from the left side intersection point to where it intersects the line indicating the number of simultaneous operators. Continuing this line to the right edge of the nomograph will establish the horsepower.

With the horsepower and vacuum parameters now established, calculate the preliminary flow rate from the number of simultaneous operators and the scfm used for each inlet. With this information, select the equipment from a manufacturer's catalog.

### General Design Considerations

Abrasion is the wearing away of the interior of the pipe wall by large, hard particles at the point where these particles strike the pipe. The effects are greatest at changes of direction of the pipe, such as elbows and tees, and under bag plates of separators. When abrasive particles are expected, it is recommended that either cast iron drainage fittings or Schedule 40 steel pipe fittings using sanitary pattern sweeps and tees be substituted for the normally used tubing materials.

It is good practice to provide a safety factor scfm to assure that additional capacity is available from the exhauster without affecting the available vacuum. This should not exceed 5 percent of the total scfm, and it is used only when selecting the exhauster, not for sizing the piping system. Select the exhauster size, and then add the safety factor. The unit selected should have that extra flow available.

The piping shall be pitched toward the separator. Install plugged cleanouts at the base of all risers and at 90° changes in direction to allow any blockages to be easily cleared.

Piping geometry in the design of wet system piping could become critical. Every effort shall be made to keep the piping below the inlet valves to prevent any liquid from running out of the inlet after completion of the cleaning routines and to ease the flow of the liquid into the pipe. The wet system pipe should pitch back to the separator at about ⅛ in/ft. All drops should be no larger than 2 in in size, and only one inlet shall be placed on a single drop. Each drop should terminate in a plugged tee facing down. This will allow any liquid still clinging to the sides of the pipe to collect at the bottom of the riser and be carried away the next time the system is used.

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