Vacuum-Air Systems

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INTRODUCTION

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 type of vacuum-air system, this chapter is divided into the following separate sections: laboratory systems applications, and central vacuum-cleaning systems.

FUNDAMENTALS

"Vacuum" is defined as an air pressure that is less than atmospheric pressure. 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 basic categories:

1. Rough (or coarse) vacuum, up to 28 in. Hg.
2. Medium (or fine) vacuum, up to 1 μ.
3. Ultra-high vacuum, greater than 1 μ.

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. Ultra-high vacuum, greater than 10 -7 .

The performance of any vacuum-air system is based on two factors: the flow volume, measured in cfm (L/min), 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 transpor-tation. 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.

PRESSURE MEASUREMENT

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

To compute work forces and changes in volume, conversion to negative gage pressure (psig) or absolute pressure (psia) is required. The units used are inches of mercury (in. Hg) and the millibar (mb). These units originate from the use of a barometer. The basic barometer is an evacuated vertical tube with its top end closed and the open bottom 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 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).

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

At standard atmospheric pressure, 0 in. Hg is equal to 14.7 psig (101.4 kPa) and 29.92 in. Hg. For the ease of calculations, 14.7 psig is adjusted to 15 psig and 29.92 in. Hg is adjusted to 30 in. Hg. These minor deviations yield results well within the range of accuracy required for engineering calculations in this handbook. At the opposite end of the scale, 0 psia (a perfect vacuum) has an absolute value of 0 in. Hg and 29.92 in. Hg at sea level. Table 5-1 compares vacuum pressure from the two most commonly used reference points. Figure 5-1 gives conversions from one pressure unit to another. Table 5-2 gives nu-merical conversion multipliers for converting torr into various other vacuum-pressure units. Table 5-3 gives numerical conversions from in. Hg. to psia and in. Hg. absolute. Table 5-4 gives conversions from kPa to in. Hg.

On the dials of most pressure gauges, atmospheric pressure is assigned the value of 0. Vacuum mea-surements must have a value of less than 0. Negative gauge pressure is the difference between the system vacuum pressure and atmospheric pressure. Absolute pressure is the pressure (in psi) above a perfect vacuum and is equal to atmospheric pressure less negative gauge pressure.

Table 5-1 Basic Vacuum-Pressure Measurements

Units			
Negative Gauge (psig)	Absolute Pressure (psia)	Inches of Mercury (in. Hg)	KiloPascals Absolute (kPa)
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
-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)

Table 5-2 Conversion Multipliers for Vacuum Units

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

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Other vacuum units are atmospheres, torrs, and microns (μ). One standard atmosphere equals 14.7 psi, or 29.92 in Hg. 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 1/760of an atmosphere, and a micron is 0.001 torr. These units of measurements are very high vacuum pressures and so are generally used for research, industrial, or laboratory use.

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 minute" (scfm), otherwise known as "free" air, 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" (icfm). The acfm is greater than the scfm.

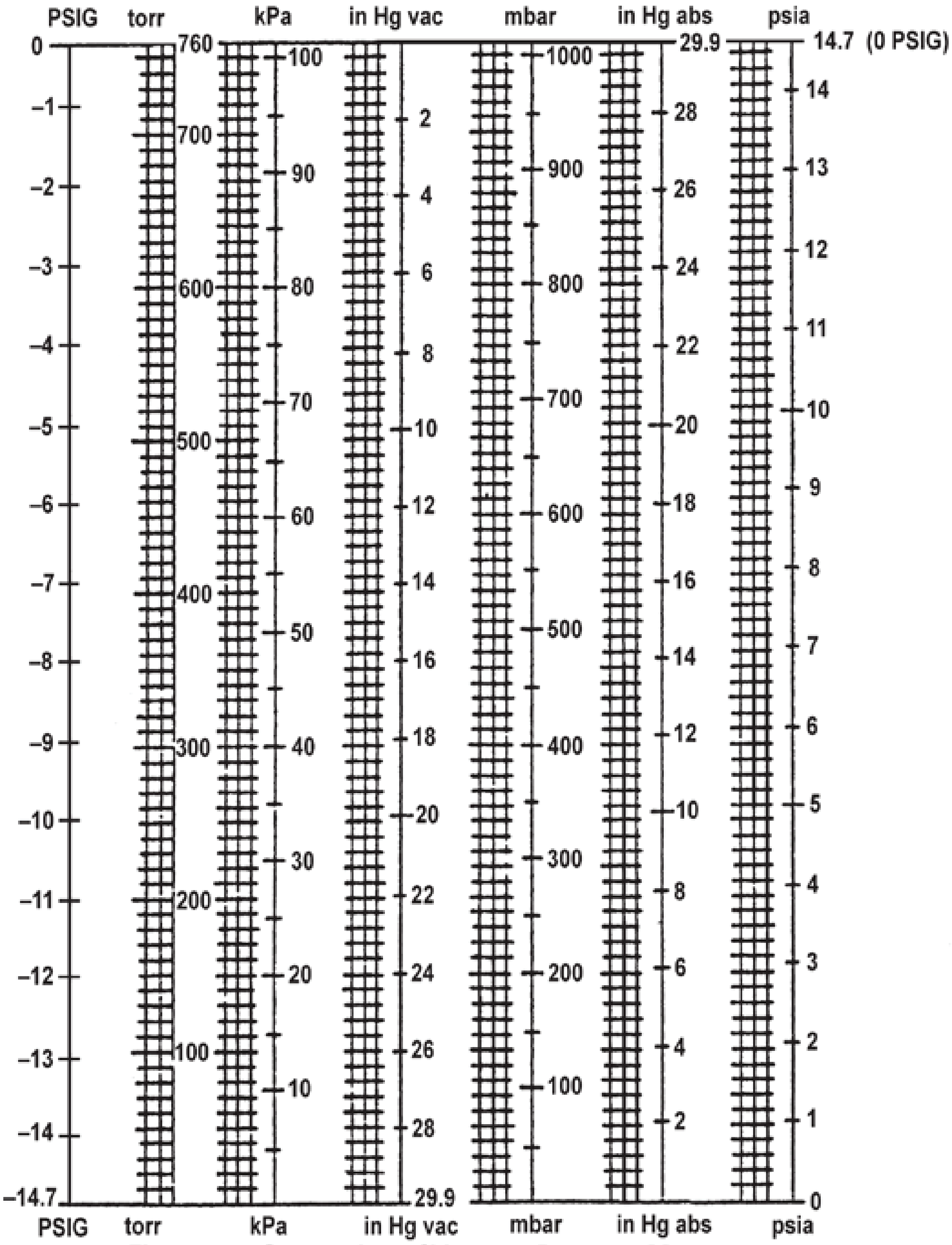

Figure 5-1 Conversion of Vacuum-Pressure Measurements

To convert scfm to acfm with a given pressure (in. Hg) and temperature (°F), use the following formula:

Equation 5-1

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

Where

P = Actual pressure for the scfm being converted, in. Hg

T = Actual temperature for the scfm being converted, °F

For practical purposes, a numerical method for solving Equation 5-1 can be used if the temperature is always 60°F. At that temperature, the second part of the equation becomes unity. Table 5-5 gives numerical values for 29.92/P. To find acfm, multiply the scfm by the value found in Table 5-5 opposite the vacuum pressure.

A direct ratio for converting scfm to acfm for various pressures is given in Table 5-6.

ADJUSTING VACUUM-PUMPRATING FOR ALTITUDE

The rating of a pump at altitude is diminished from its full capacity rating at sea level. For each 1000-ft increase in altitude, atmospheric pressure drops by approximately 1 in. Hg. Refer to Table 5-7 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 in. Hg. Dividing 30 into 24.90 gives 83.3%. If a pump is rated at 25 in. Hg at sea level, 83.3% of 25 equals 20.8 in. Hg at 5000 ft. This is the vacuum pressure that would equal 25 in. Hg at sea level.

At altitudes above sea level, there is a reduction in the scfm delivered because of the difference between local pressure and standard pressure. The scfm must be increased to compensate for this difference. Table 5-8 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 cfm, 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:

Equation 5-2

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

Where

T = Time, min

V = Volume of system, ft^3

Q = Flow capacity of pump, cfm

N = Natural log, constant

Note: For vacuum up to 15 in. Hg, N = 1

For vacuum up to 22.5 in. Hg, N = 2

Table 5-3 Conversion of in. Hg to psia and in. Hg abs

in. Hg	in. Hg abs.	psia	in. Hg	in. Hg abs.	psia
0	29.92	14.70	24	5.92	2.9085
1	28.92	14.2086	25	4.92	2.4172
2	27.92	13.7173	26	3.92	1.9259
3	26.92	13.2260	27	2.92	1.4346
4	25.92	12.7347	28	1.92`	0.9433
5	24.92	12.2434	29	0.92	0.4520
6	23.92	11.7521	29.12	0.80	0.3930
7	22.92	11.2608	29.22	0.70	0.3439
8	21.92	10.7695	29.32	0.60	0.2947
9	20.92	10.2782	29.42	0.50	0.2456
10	19.92	9.7869	29.52	0.40	0.1965
11	18.92	9.2955	29.62	0.30	0.1473
12	17.92	8.8042	29.72	0.20	0.0982
13	16.92	8.3129	29.82	0.10	0.0491
14	15.92	7.8216	29.83	0.09	0.0442
15	14.92	7.3303	29.84	0.08	0.0393
16	13.92	6.8390	29.85	0.07	0.0344
17	12.92	6.3477	29.86	0.06	0.0295
18	11.92	5.8564	29.87	0.05	0.0246
19	10.92	5.3651	29.88	0.04	0.0197
20	9.92	4.8738	29.89	0.03	0.0147
21	8.92	4.3824	29.90	0.02	0.0098
22	7.92	3.8911	29.91	0.01	0.0049
23	6.92	3.3998	29.92	0.00	0.00

Table 5-4 Basic Vacuum Pressure Conversion

kPa abs	in. Hg	in. Hg abs	psia
101.4	0	29.92	14.70
97.9	1	28.92	14.2086
94.5	2	27.92	13.7173
91.5	3	26.92	13.2260
87.77	4	25.92	12.7347
84.39	5	24.92	12.2434
81.01	6	23.92	11.7521
77.63	7	22.92	11.2608
74.19	8	21.92	10.7695
70.81	9	20.92	10.2782
67.43	10	19.92	9.7869
64.05	11	18.92	9.2955
60.67	12	17.92	8.8042
57.29	13	16.92	8.3129
53.91	14	15.92	7.8216
50.54	15	14.92	7.3303
47.09	16	13.92	6.8390
43.71	17	12.92	6.3477
40.33	18	11.92	5.8564
36.95	19	10.92	5.3651
33.57	20	9.92	4.8738
30.20	21	8.92	4.3824
26.82	22	7.92	3.8911
23.27	23	6.92	3.3998
19.99	24	5.92	2.9085
16.61	25	4.92	2.4172
13.23	26	3.92	1.9259
9.85	27	2.92	1.4346
6.48	28	1.92`	0.9433
3.10	29	0.92	0.4520
2.36	29.22	0.80	0.3930
1.35	29.52	0.70	0.3439
0.61	29.72	0.60	0.2947
0	29.92	0	0

Table 5-5 Numerical Value to Determine acfm from scfm

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

Notes: 1) Expanded air ratio, 29.92/P, as a function of pressure, P, (in. Hg).
2) 1 in. Hg = 3.38 kPa

Table 5-6 Ratio for Converting scfm to acfm (sL/s to aL/s)

in. Hg	kPa abs	Factor	in. Hg	kPa abs	Factor
1	97.9	1.05	16	47.09	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	26.82	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	64.05	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	29.92	0	60

For vacuum up to 26 in. Hg, N = 3
For vacuum up to 28 in. Hg, N = 4

For the most accurate answer, obtain pump curves from the manufacturer and substitute the cfm capacity for the pump at each 5 in. Hg 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 (Table 5-11 and Table 5-12) is based on 15 in. Hg. For a given scfm and pipe size, the pressure loss at any vacuum pressure other than the 15 in. Hg the chart was developed for, can be found by dividing the pressure drop in the chart by the factor found from the following formula:

Equation 5-3

$$F = 30 - \frac{\text{new vacuum pressure(psi)}}{15}$$

Where

F = Factor to be multiplied by values in Table 5-11 and Table 5-12

SIMPLIFIED METHOD OFCALCULATING VELOCITY

Use the following formula to find the velocity of a gas stream under a vacuum:

Equation 5-4

$$V = C \times Q$$

Where

V = Velocity, fpm

C = Constant based on pipe size (Refer to Table 5-9.)

Q = Flow rate based on an absolute vacuum pressure, acfm

Example 5-1

Calculate the velocity of 100 scfm through a 2-in. pipe with a pressure of 20 in. Hg.

1. First, find the equivalent absolute pressure of 20 in. Hg. Using Table 5-9, read 9.92 in. Hg abs.
2. Convert 100 scfm to acfm at a pressure of 9.92 in. Hg abs. by using Table 5-6. Opposite 10 in. Hg read 1.5. 100 × 1.5 = 150 acfm
3. Refer to Table 5-9 to obtain C. This table has been developed from the flow characteristics of air in Schedule 40 pipe. Opposite 3-in. pipe read 19.53.
4. V = 150 × 19.53 V = 2930 fps

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:

Equation 5-5

$$F = P \times A$$

Where

F = Force, psi

P = Vacuum pressure, psig

A = Area, in.^{2}

Table 5-7 Barometric Pressure Corresponding to Altitude

Altitude[a]		Barometric Pressure	
ft	m	in. Hg	kPa
-10,000	-3040	31.00	104.5
-500	-152	30.50	102.8
0	0	29.92	100.8
500	152	29.39	99.0
1,000	304	28.87	97.3
1,500	456	28.33	95.5
2,000	608	27.82	93.7
760	760	27.31	92.0
3,000	912	26.81	90.3
3,500	1,064	26.32	88.7
4,000	1,216	25.85	87.1
4,500	1,368	25.36	85.5
5,000	1,520	24.90	83.9
5,500	1,672	24.43	81.9
6,000	1,824	23.98	80.8
6,500	1,976	23.53	79.3
7,000	2,128	23.10	77.8
7,500	2,280	22.65	76.3
8,000	2,432	22.22	74.9
8,500	2,584	21.80	73.4
9,000	2,736	21.39	72.1
9,500	2,888	20.98	70.7
10,000	3,040	20.58	69.3

[a] Sea level = 0.

Table 5-8 Factor for Flow Rate Reduction Due to Altitude

Altitude		Factor Used for
ft	m	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	1,064	1.14
4,000	1,216	1.16
5,000	1,520	1.20
6,000	1,824	1.25
7,000	2,128	1.30
8,000	2,432	1.35
9,000	2,736	1.40
10,000	3,040	1.45
11,000	3,344	1.51

Note: 1 scfm = 0.472 sL/s

Table 5-9 Constant for Finding Mean Air Velocity

Sched. 40 Pipe Size, in. (NPS)[a]	DN	Constant	Sched. 40 Pipe Size, in. (NPS)[a]	DN	Constant
⅜	12	740.9	2½	65	30.12
½	15	481.9	3	75	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

a 1 in. = 25.4 mm

Since the above formula is theoretical, it is common practice to use a safety factor that is 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 the configuration of the load, and outside forces, such as acceleration.

SYSTEM COMPONENTS

GENERAL

Vacuum is produced by a single or multiple vacuum pump source 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 that allows the pumps to run for a longer time than is 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 the operation of the vacuum pump. To size the exhaust piping, refer to Table 5-10, using the equivalent length of exhaust piping as the length of piping.

Alarms are required for maintenance purposes or to annunciate trouble in the system (generally inadequate vacuum pressure). Specific alarms are mandated by code for health-care facilities.

VACUUM PUMPS

The principal types of vacuum pump are divided into two general groups: gas transfer and capture. Capture pumps are not used in pharmaceutical facilities and are, therefore, outside the scope of this handbook.

Gas-Transfer Pumps

Gas-transfer pumps are essentially air compressors that use the vacuum system as their inlet and discharge "compressed" air to the atmosphere. The great majority of pumps used for most applications are gas-transfer pumps. They operate by remov-ing gas from the lower-pressure system and conveying it to the higher pressure of the free air environment through one or more stages of compression provided by a vacuum pump. These pumps, also known as "mechanical rotary type pumps," are those used most often for industrial and laboratory purposes. Examples of gas-transfer pumps include:

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

Gas-transfer pumps are divided into positive displacement and kinetic types.

Seal Liquids

For liquid-ring pumps, a circulating liquid in the pump casing is an integral part of the pump operation. Commonly known as "seal liquid," it is not intended to refer to shaft or any other kinds of sealing.

Water used for sealing purposes must be continuously replaced. With no conserva-tion, 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.

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 hrs 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 that use oil often require more installation space than those that don't.

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 could be open or closed. The difference between the liquid levels in each vertical leg of the "U" tube is used to calculate the pressure.

Table 5-10 Vacuum-Pump Exhaust Pipe Sizing

Total Vacuum Plant Capacity, All Pumps		Equivalent Pipe Length, ft (m)						
		50 (15.2)	100 (30.4)	150 (45.6)	200 (60.8)	300 (91.2)	400 (121.6)	500 (152)
scfm	sL/s	Pipe Size, in. (DN)[a]						
10	4.72	2 (50)	2 (50)	2 (50)	2 (50)	2 (50)	2 (50)	2 (50)
50	23.6	2 (50)	2½ (65)	3 (75)	3 (75)	3 (75)	3 (75)	3 (75)
100	47.2	3 (75)	3 (75)	3 (75)	4 (100)	4 (100)	5 (125)	5 (125)
150	71	3 (75)	4 (100)	4 (100)	4 (100)	5 (125)	5 (125)	5 (125)
200	55	4 (100)	4 (100)	4 (100)	5 (125)	5 (125)	5 (125)	5 (125)
300	142	4 (100)	5 (125)	5 (125)	5 (125)	6 (150)	6 (150)	6 (150)
400	189	5 (125)	5 (125)	6 (150)	6 (150)	6 (150)	8 (200)	8 (200)
500	236	5 (125)	6 (150)	6 (150)	6 (150)	8 (200)	8 (200)	8 (200)

[a]1 in. = 25.4 mm

Bourdon Gauge
An often-used type of mechanical gauge is the Bourdon gauge. This type of gauge is used to measure the difference between the system vacuum pressure and local barometric pressure and is the most widely used type of gauge.

Diaphragm Gauge
The diaphragm gauge measures the pressure difference by sensing the deflection of a thin metal diaphragm or capsular element. Similarly to the Bourdon gauge, its operation relies on the deformation of an elastic metal under pressure.

Strain Gauge
Strain gauges also use the deflection of a diaphragm to produce a change in electri-cal resistance of the attached 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 discharge airstream.

A “knockout pot” is a device that removes entrained liquid or slugs of liquid, preventing them from entering the inlets of mechanical pumps used in industrial applications. It can 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 just prior to the air entering the pump. Various filter elements are avail-able to remove particulates approximately 0.3 μ in size.

In some cases where the system as a whole has a high vacuum pressure, it is desir-able to lower the vacuum pressure to a branch. 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 valve is used.

LABORATORY VACUUM SYSTEMS
The laboratory vacuum system serves general chemical, biological, and physics laboratory purposes, principally drying, filtering, fluid transfer, and evacuating air from apparatus. The usual working pressure of standard vacuum systems is in the range of 15 to 20 in. Hg. In some cases, there is a need for “high” vacuum in the range of 24 to 29 in. Hg, 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, though some invariably are introduced into the system. Rather, it is used primarily for pumping down and maintaining a vacuum rather than transporting air or solids back to the source.

CODES AND STANDARDS
There are no codes and standards 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.

Laboratories conducting biological work where airborne pathogens could be re-leased 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 0.02-μ filters on the exhaust to eliminate all pathogenic particulates.

VACUUM SOURCE
The vacuum source usually consists of two or more pumps 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 betweem the pumps and receiver, and alarms. A duplex pump arrangement is usually se-lected 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 two most comonly used pump types are the liquid ring and the sliding vane. A detail of a typical laboratory vacuum-pump assembly is illustrated in Figure 5-2.

DISTRIBUTION NETWORK
Piping for the distribution system shall be a corrosion-resistant material such as cop-per tube types K, L, or M; stainless steel; or galvanized steel pipe (usually schedule 40 ASTM A-53). Copper tube shall be hard temper except when installed underground, in which case, soft temper should be used. Whenever piping passes under areas sub-ject to high 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 selec-tion of the piping material, the most commonly used material 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 have an extra long-turn radius pattern so as not to impede the flow of fluids in the pipe.

SIZING CRITERIA

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

Flow Rate
The basic flow rate from each laboratory inlet shall be 1.0 scfm. This is a number based on experience. This flow rate is used in conjunction with the diversity fac-tor.

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 Figure 5-3 for a direct reading chart to determine the adjusted general laboratory vacuum flow rate using the number of connected inlets.

For the design of classrooms, the diversity factor for one and two classrooms on one branch is 100%. For more than two classrooms, use a diversity factor that is double that for compressed air in Table 13-13 but never less than the largest scfm calculated for the first two rooms. Since the above flow rates and diversity factors are based on experience, 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 in. Hg 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 in. Hg 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. It has been found that in most facilities 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 Equation 5-1. The stopping point of the pump is the required vacuum level to support all processes. The exhaust and interconnecting piping is similar to a 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 at each point, using the connected scfm reduced by the diversity factor at each point.
2. Calculate the allowable friction loss/100 ft of pipe.
3. Enter Table 5-11 for copper tube or Table 5-12 for steel pipe with the adjusted scfm and the allowable friction loss. 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 discusses 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 portable, self-contained, electric-powered units. The central system transports 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. Their most common use is for clean rooms; a portable unit is kept within a clean room to handle spills. Another use is where controlled substances are used and must be accounted for. If there is a spill, the easiest method of cleanup is to have a por-table unit brought to the accident area. The containment bag is weighed before the cleanup begins and again after the cleanup is completed. The difference is the weight of the controlled substance.

TYPES OF SYSTEM AND EQUIPMENT

There are three types of permanent system: dry, wet, and a combination system. The dry system is intended exclusively for free-flowing, dry material. It is the most commonly used type, 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. There is a wide variety of separators to allow disposal and recovery of the collected material.

The wet system is intended exclusively for liquid handling and pickup. It is com-monly found in health-care, industrial, and laboratory facilities where sanitation is important and frequent washings are

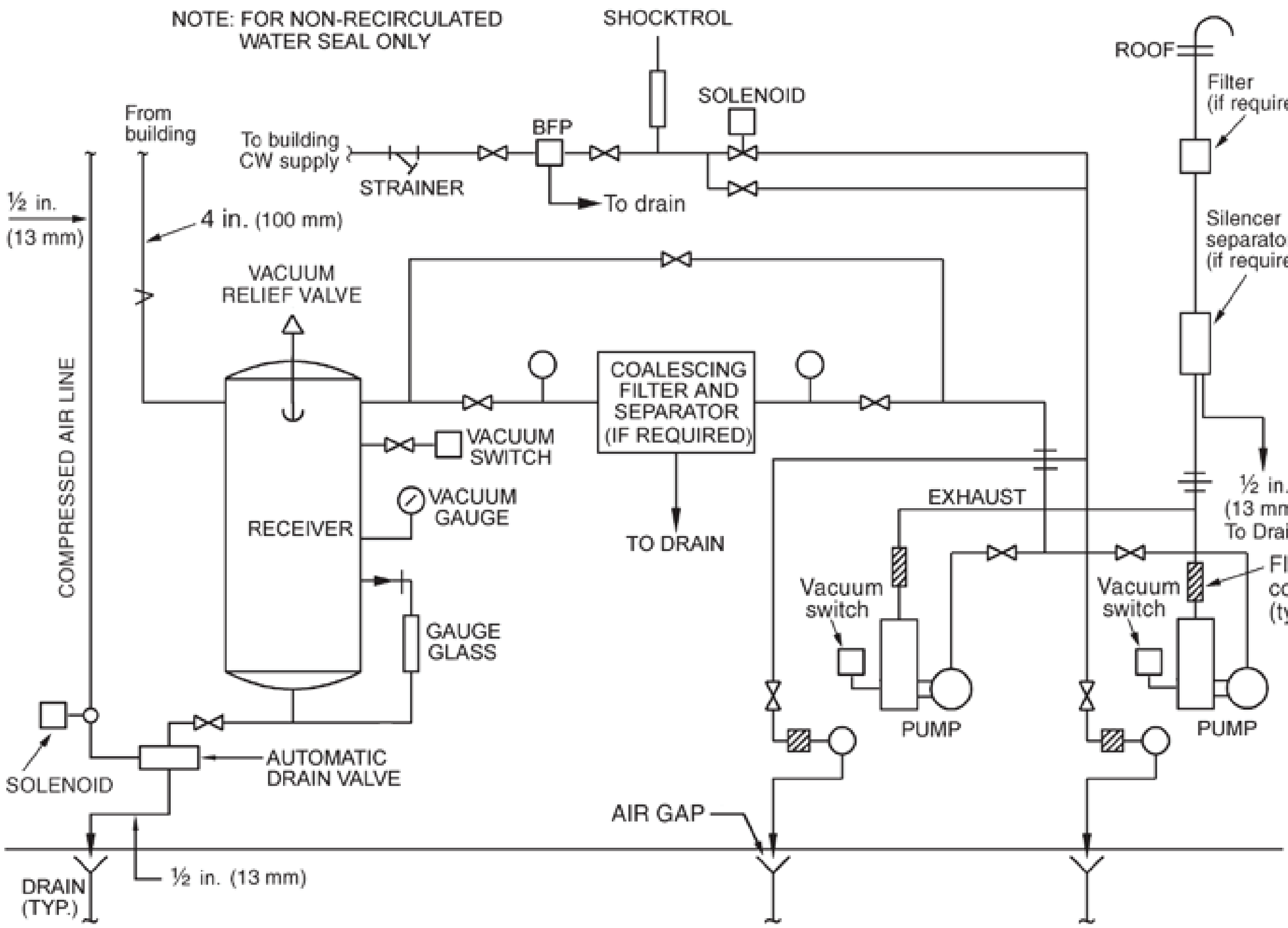

Figure 5-2 Typical Laboratory Vacuum Source

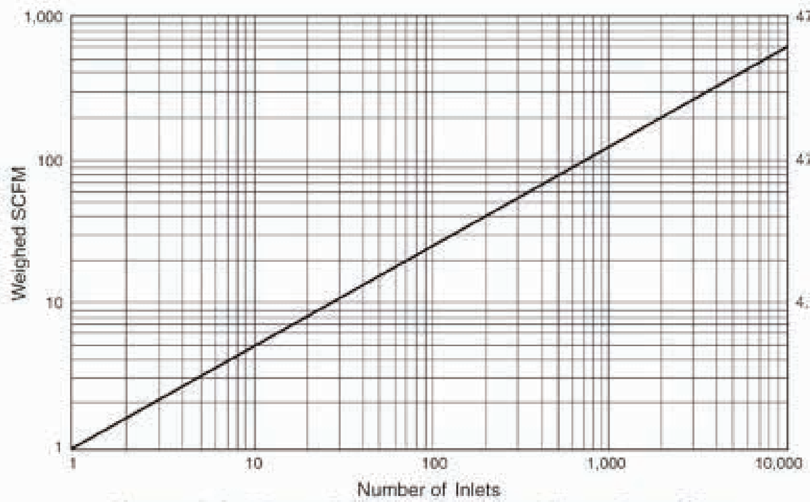

Figure 5-3 Direct Reading Vacuum Flow Rate Chart

Table 5-11 Vacuum Pipe Sizing, Type L Copper Tubing

Maximum Velocity: 5000 fpm (25 m/s)		Pipe Diameter, in. (DN)							
		¾ (20)	1 (25)	1¼ (32)	1½ (40)	2 (50)	2½ (65)	3 (80)	4 (100)
scfm	sL/s	Pressure Drop, in. Hg / 100 ft[a]							
1	0.472	0.08							
2	0.944	0.27	0.08						
3	1.41	0.53	0.15						
4	1.9	0.88	0.25	0.09					
5	2.36	1.3	0.36	0.14					
6	2.83	1.8	0.50	0.19					
7	3.30		0.65	0.24	0.11				
8	3.77		0.82	0.30	0.13				
9	4.25		1.01	0.37	0.16				
10	4.72		1.22	0.45	0.20				
15	7.0			0.91	0.40	0.11			
20	9.5				0.66	0.18			
25	11.8					0.26	0.09		
30	14.1					0.36	0.13		
35	16.5					0.47	0.17		
40	18.9						0.21	0.09	
45	21.2						0.26	0.11	
50	23.6						0.32	0.14	
60	28.3						0.44	0.19	
70	33.0							0.25	0.06
80	37.7							0.31	0.08
90	42.5								0.10
100	47.2								0.12
125	59.0								0.18
150	71.0								0.25

a 1 in. Hg = 3.37 kPa

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 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.

CODES AND STANDARDS

There are no codes and 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 multi-stage centrifugal type units powered by an electric motor. The housing can be constructed of various materials to handle special chemicals and of non-sparking aluminum for potentially explosive dust. The discharge of the unit can be positioned at various points to accommodate the 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 type systems, tubular bag and centrifugal type 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 cannot be removed. They function as air filters 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 is 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 by motor operation. 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, dry compressed air can be used to blow through the bags and remove the dirt without requiring a shutdown.

The centrifugal type separator is designed to remove coarser, dry particles from the airstream. It is also recommended when more than six simultaneous operators are anticipated to remove the bulk of the dirt. 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 drain. This type of separator can be equipped with an automatic overflow shut-off that stops the system if the water level reaches a pre-determined high-water level and with automatic emptying features.

Immersion type separators are used to collect explosive or flammable material in a water compartment. If there is a potential for explosion, such as exists 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, a High Efficiency Particulate Air (HEPA) filter must be installed in the discharge line to eliminate the possibility of contami-nation of the outside air. The recommended location is between the separator and vacuum producer, but an alternate location immediately prior to penetration of the building wall or roof is also acceptable.

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 air flow will require special design considerations. Connection to silencers shall be made with flexible connections. Additional support for silencers is recommended. Filters and silencers can be economically combined into a single, integral unit. Inlets Inlets are female inlet valves and are equipped with self-closing covers. They pro-vide a quick connection for any male hose or equipment. The cover can be locked as an option. Many different inlet types are available, in sizes ranging from 1½ to 4 in. and in various materials.

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 used only fully open or closed, they are generally referred to as "blast gates." When used as regulating valves, they are called wafer "butterfly valves." A less costly substitute for a blast gate is an air-gate valve, which operates using a sliding plate in a channel. An air gate is illustrated in Figure 15-16B. 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 only be used in low-pressure systems and are generally available in sizes ranging from 2 to 6 in.

Air-Bleed Device

If the exhauster is constantly operated with low or no inlet air, there is a possibil-ity 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 exhauster that will automatically allow air to enter the piping system. If the facil-ity indicates that this may be a possibility, the manufacturer of the unit should be consulted to determine the need for this device for the system selected.

Table 5-12 Vacuum Pipe Sizing, Sched. 40 Steel Pipe

Maximum Velocity: 5000 fpm (25 m/s)		Pipe Diameter, in. (DN)							
		¾ (20)	1 (25)	1¼ (32)	1½ (40)	2 (50)	2½ (65)	3 (80)	4 (100)
scfm	sL/s	Pressure Drop, in. Hg / 100 ft[a]							
1	0.472	0.07							
2	0.944	0.22	0.07						
3	1.41	0.45	0.14						
4	1.9	0.75	0.24	0.06					
5	2.36	1.1	0.35	0.09					
6	2.83	1.56	0.48	0.13					
7	3.30		0.63	0.17	0.08				
8	3.77		0.81	0.21	0.10				
9	4.25		1.00	0.26	0.13				
10	4.72		1.21	0.32	0.15				
15	7.0			0.66	0.31	0.09			
20	9.5				0.52	0.15			
25	11.8				0.78	0.23	0.10		
30	14.1					0.32	0.14		
35	16.5					0.42	0.18		
40	18.9					0.54	0.23	0.08	
45	21.2						0.28	0.10	
50	23.6						0.34	0.12	
60	28.3						0.47	0.16	
70	33.0							0.22	0.06
80	37.7							0.28	0.07
90	42.5							0.34	0.09
100	47.2								0.11
125	59.0								0.17
150	71.0								0.23

a 1 in. Hg = 3.37 kPa

Pipe and Fittings

The most often-used pipe 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 specially 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 hose not being able to be stretched to the absolute end of its 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 frequent spot clean-ing 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 a reduction in the 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 another major consideration for design purposes because an under-de-signed 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 department 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 prac-tice in order to produce 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, which are based on experience, can be used to estimate simultaneous use based on productivity. These figures consider the greater efficiency of a central system compared to portable units, often in the order of 25%. They must be verified and based on actual methods anticipated.

1. For carpets, 1 operator is expected to cover 20,000 ft 2 of area for regular carpeting in an 8-hr shift. For long or shag carpets, the figure is about 15,000 ft
2. Another generally accepted figure for short time periods is 3000 ft 2 /hr for standard floors and 2500 ft 2 /hr for shag and long carpets. 2. For hotels, an average figure of 100 rooms, including adjacent corridors, per 8-hr shift is 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, 12 classrooms/day is an average figure for a custodian to clean in addition to other duties normally accomplished.

Inlet Valve and Hose Sizing

Experience has shown that 1½ in. is the most practical size for hose and tools used for cleaning floors, walls, and ceilings. Smaller, 1-in. size tools are used for clean-ing production tools, equipment, and benches.

Table 5-13 Recommended Sizes of Hand Tools and Hose

Nominal Size in.	Nominal Size DN	Average Floor Cleaning and Moderate Spills	Close Hand Work	Removing Heavy Sills or Large Quantities of Materials	Overhead Vacuum Cleaning	Standard Hose Length ft	Standard Hose Length m
1	25	Not used	Yes	Inadequate	Not used	8	2.4
1½	40	Excellent	Yes	Fair	Preferred	25 and 50	7.5 and 15
2	50	Good	No	Good	Poor	25 and 50	7.5 and 15
2½	65	Not used	No	Excellent	Not used	25 and 50	7.5 and 15

Source: Courtesy of Hoffman.

Table 5-14 Flow Rate and Friction Loss for Vacuum-Cleaning Tools and Hoses

Use	Nominal Size of Tools and Hose	Minimum Volume and Pressure Drop[a] Volume, scfm	Minimum Volume and Pressure Drop[a] Pressure Drop, in. Hg	Maximum Volume and Pressure Drop[a] Volume, scfm	Maximum Volume and Pressure Drop[a] Pressure Drop, in. Hg
Bench use	1-in. diam., 8-ft 1-in. flexible hose	40	1.20	50	1.90
White rooms or areas with very low dust content	1½-in. diam., 50-ft 1½-in. flexible hose	60	2.25	90	4.10
Usual industrial	1½-in. diam., 50-ft 1½-in. flexible hose	70	2.80	100[b]	4.80
Fissionable materials or other heavy metallic dusts and minute particles of copper, iron, etc.	1½-in. diam., 50-ft 1½-in. flexible hose	100	2.50	120	4.20
Heavy spills, cleaning railroad cars and ship holds	2-in. diam., 50-ft 2-in. flexible hose	120	2.60	150	3.80

Source: Courtesy of Hoffman.
Note: 1 scfm = 0.5 sL/s; 1 in. Hg = 3.4 kPa
a The pressure drop in flexible hose is 2½ times the pressure drop for the same length and size of Schedule 40 pipe.
b Can be exceeded by 10% if necessary.

Table 5-15 Recommended Velocities for Vacuum-Cleaning Systems

Nominal Tubing Size in.	Nominal Tubing Size DN	Horizontal Runs of Branches and Mains and Vertical Down-Flow Risers Minimum Velocity, ft/min	Horizontal Runs of Branches and Mains and Vertical Down-Flow Risers Recommended Max. Velocity, ft/min	Vertical Up-Flow Risers Minimum Velocity, ft/min	Vertical Up-Flow Risers Recommended Max. Velocity, ft/min
1½	40	1800	3000	2600	3800
2	50	2000	3500	3000	4200
2½	65	2200	3900	3200	4700
3	75	2400	4200	3800	5100
4	100	2800	4900	4200	6000
5	125	3000	5400	4800	6500
6	150	3400	6000	5000	7200

Source: Courtesy of Hoffman.
Note: 1 ft/min = 0.3 m/min

Larger hose and tools are used for picking up large spills and cleaning large tanks, boxcars, and the holds of ships. Refer to Table 5-13 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 a maximum of 50 ft 0 in. of hose. This represents a labor savings by halving the times an operator has to change outlets with a 25-ft hose. 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 when 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 they are to be installed.
2. An ideal location is on the floor below the lowest inlet of the building or facil-ity and centrally located 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 is required.
4. Enough room around the separators shall be provided to allow for easy in-spection, and, where the dirt bins must be emptied, room must be provided for the carts needed to move it. Dry separators could also be located outside the building for direct truck disposal of the dirt if they are sufficiently pro-tected.

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 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 sizes for hand tools and hose are given in Table 5-13.

Vacuum-Pressure Requirements and Hose cfm In order to achieve the neces-sary air velocity, the minimum recommended vacuum pressure for ordinary use is 2 in. Hg. For hard-to-clean and industrial type materials, 3 in. Hg vacuum pressure is required. The flow rate must be enough to bring the dirt into the tool nozzle. Refer to Table 5-14 to determine the minimum and maximum recommended flow rates 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

Table 5-16 Pipe Diameter Based on Simultaneous Operators

Line Diam. in.	DN	Number of Operators 70 scfm, 1½-in. hose	Number of Operators 140 scfm, 2-in. hose
2	50	1	—
2½	65	2	1
3	75	3	2
3½	90	4	2
4	100	5	3
5	125	8	4
6	150	12	6
8	200	20	10

Source: Courtesy of Spencer Turbine.
Note: 1 scfm = 0.5 sL/s

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 within the recommended range. Refer to Table 5-15, which in-dicates recommended velocity based on pipe size and the horizontal or vertical orientation of the pipe. 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 Simultaneous Number of Outlets in Use* — Facilities may have many inlet valves, but only a few will be used at once. Under normal operating conditions, these inlets are chosen at random by the operators. As an aid in the determination of simultaneous usage, the following conditions should be expected:

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

Sizing the Piping Network — Refer to Table 5-16 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, the term "line" refers to permanently installed pipe from inlet to separator and "hose" is the hose connecting the tool to the inlet. One-and-a-half-in. 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 5-17 Equivalent Length of Vacuum Cleaning Pipe Fittings

Nominal Pipe Size in.	DN	Equivalent Length of Pipe Fittings (ft)[a] 90° Change in Direction	45° Change in Direction
1¼	32	3	1½
1½	40	4	2
2	50	5	2½
2½	65	6	3
3	75	7	4
4	100	10	5
5	125	12	6
6	150	15	7½
8	200	20	10

Notes: 1) For smooth-flow fittings, use 90% of these values.
2) 1 ft = 0.3 m
a Lengths based on use of cast-iron drainage fittings.

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 determined using Figure 5-4. 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 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 the 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 in. Hg, to size the exhauster. This is calculated by adding together all of the following values, starting from the inlet that is most remotely located from the exhauster and continuing to the source.

1. Initial level of vacuum required. For average conditions the generally ac-cepted figure is 2 in. Hg. For hard-to-clean material, industrial applications, and long shag type carpet, the initial vacuum should be increased to 3 in. Hg.
2. Pressure drop through the hose and tool. Refer to Table 5-14 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 Figure 5-4. Fittings are fig-ured separately, using an equivalent length of pipe to be added to the straight run. Refer to Table 5-17 to determine the equivalent length of run for each type and size of fitting. Starting from the farthest inlet, use the cfm, the pipe size, the fitting al-lowance, and the pipe length along the entire run of pipe to find the total friction loss.
4. Loss through the separator. A gener-ally accepted figure is 1 in. Hg 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 in. Hg as an average figure for a run of 100 ft.

Vacuum-Producer (Exhauster) Sizing

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

The vacuum pressure required from the exhauster is the total necessary to over-come 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 to the source. These include the initial inlet vacuum level required; the pressure lost through the tool and hose selected; the friction loss of air flowing through the pip-ing 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.

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

Separator Selection and Sizing The separator is sized based on the cfm of the vacuum producer and the type of material expected to be collected. Refer to Table 5-18 for classification of the material that is expected to be collected.

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

Some automatic separator cleaning systems use compressed air to aid in dislodg-ing the dust. The air pressure recommended is generally in the range of 100 to 125 psig.

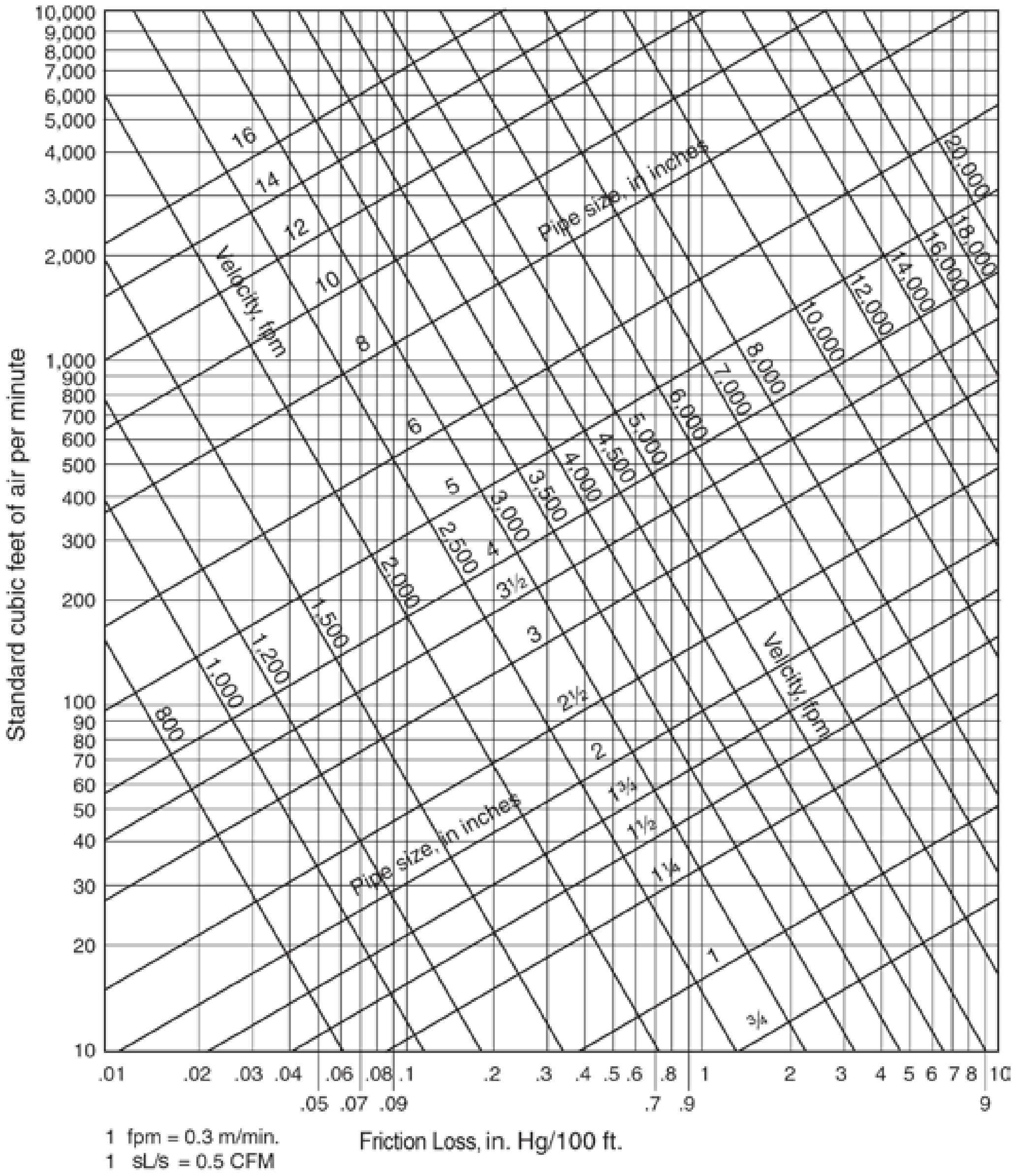

Figure 5-4 Vacuum Cleaning Pipe Sizing Chart Friction loss, in in. of mercury per 100 ft of line with inlet air at 70°F and 14.7 psia

Source: Courtesy of Spencer Turbine.

Exhauster Discharge The discharge from the exhauster is usually steel pipe routed outside the building. It is also possible to route the exhauster discharge into an HVAC exhaust duct, which is routed directly 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 1 size larger than the size of the 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 ex-hauster must overcome. For short runs of about 20 ft 0 in., this can be ignored.

Exhauster Rating Adjustments

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

In order to establish the adjusted cfm, it is necessary to calculate separately the total system friction loss for the branch lines containing the inlets nearest and farthest from the exhauster. Following the procedures previously explained will result in minimum and maximum system friction loss figures. The following formula is used to calculate the adjusted cfm:

Equation 5-6 adjusted

cfm = farthest inlet friction loss (in. Hg) × selected cfm closest inlet friction loss (in. Hg)

The adjusted cfm figure is used instead of the selected cfm and is multiplied by the number of simultaneous operators to size the exhauster.

Adjustment Due to Elevation — All of the above calculations are based on scfm. If the project location is above sea level, the scfm should be adjusted to allow for the difference in barometric pressure. Refer to Table 5-8 for the correction factor. This factor shall be multiplied by the scfm figure to calculate the adjusted cfm, which is used in sizing the exhauster.

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

To convert scfm to acfm, refer to Equation 5-1.

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 in the direction of the pipe, such as at elbows and tees and under the 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 of extra cfm to ensure that additional capacity is available from the exhauster without its affecting the available vacuum. This safety factor should not exceed 5% of the total cfm and is used only when se-lecting the exhauster, not for sizing the piping system. Select the exhauster size and

then add the safety factor. The unit selected should have the extra flow available.

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

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 1⁄8in./ft. All drops should be no larger than 2 in. in size and only 1 inlet shall be placed on a single drop. Each drop should terminate in a plugged tee facing down. This allows 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.

A typical schematic of a wet vacuum-cleaning source is illustrated in Figure 5-5.

Table 5-18 Classification of Material for Separator Selection

Size of Material	Very Fine		Fine		Granular		Lumpy		Irregular
	Recommended Sep. (S)	Ratio Vol. Bag Area	Recommended Sep. (S)	Ratio Vol. Bag Area	Recommended Sep. (S)	Ratio Vol. Bag Area	Recommended Sep. (S)	Ratio Vol. 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. and TB	6:1	Cent.	Not appl.	Cent.	Not appl.	
Large	Cent. and TB	3:1	Cent. and TB	6:1	Cent. and TB	6:1	Cent.	Not appl.	

Source: Courtesy of Spencer Turbine.

Notes: 1) Centrifugal separators do not utilize bags.

2) Definition of terms:

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

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

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

Fine: 100 mesh to 8 in. (3.2 mm).

Very fine: Less than 100 mesh.

Granular: 8 to ½ in. (3.2 to 12.7 mm).

Lumpy: Lumps ½ in. (12.7 mm) and over.

Irregular: Fibrous, stringy, and so on.

3) Abbreviations: Cent. = centrifugal; TB = tubular bag.

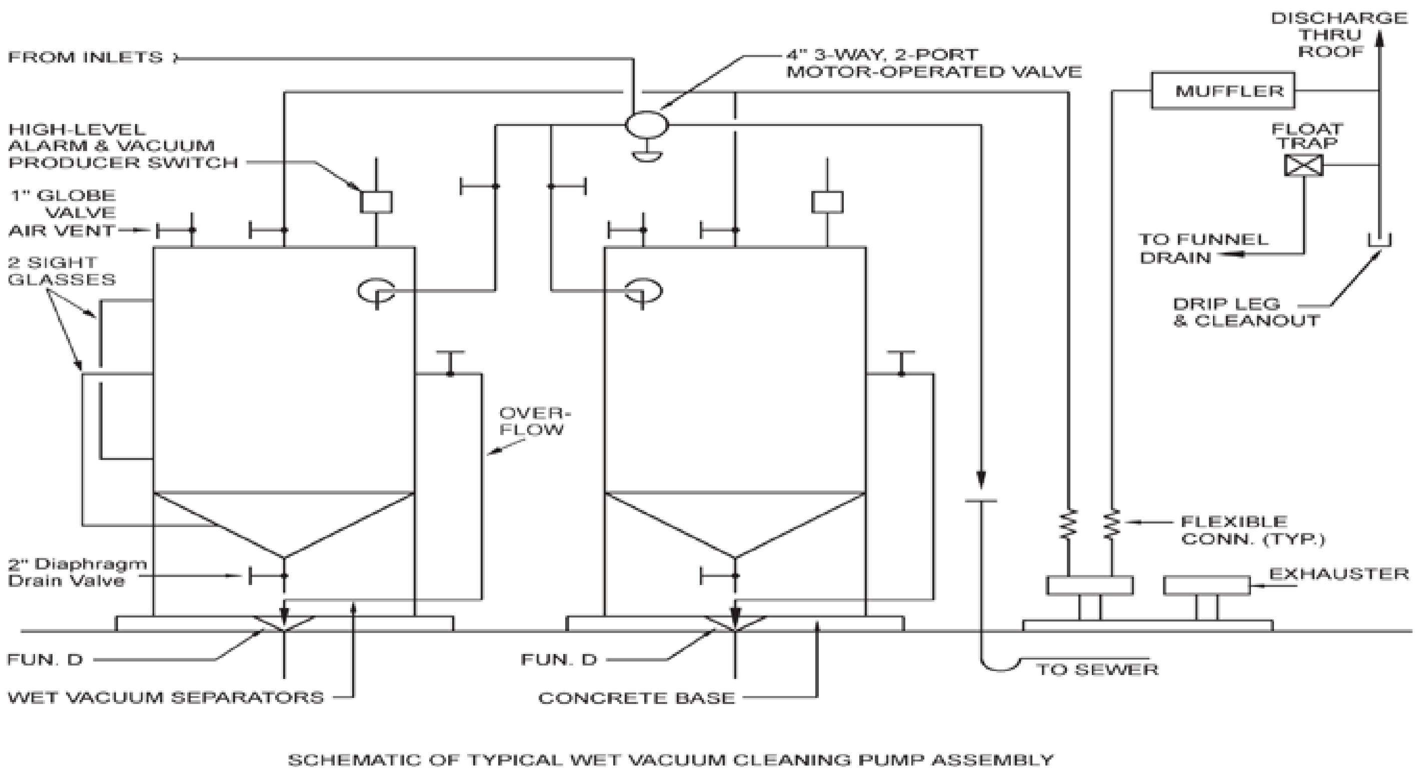

Figure 5-5 Schematic of a Typical Wet-Vacuum Cleaning Pump Assembly

Source: Courtesy of Spencer Turbine.

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Expiration date: Continuing education credit will be given for this examination through **March 31, 2014.**

CE Questions — "Vacuum-Air Systems" (CEU 197)

1. **Vacuum-air system performance is based on the _______.**
   a. flow volume
   b. maximum vacuum maintained in the system
   c. capacity of the pump
   d. both a and b
2. **10 torr equals ________ mm Hg.**
   a. 0.1
   b. 1
   c. 10
   d. 100
3. **The time a given pump will take to reach its rated vacuum pressure depends on what?**
   a. volume of the system
   b. capacity of the pump
   c. altitude above sea level
   d. both a and b
4. **To find the total force of the vacuum system acting on a load, multiply the vacuum pressure by the _______.**
   a. volume of the system
   b. surface area on which the vacuum is acting
   c. capacity of the pump
   d. altitude above sea level
5. **_______ is an example of a gas-transfer pump.**
   a. liquid ring
   b. screw
   c. diaphragm
   d. all of the above
6. **What is the most widely used type of gauge to measure the difference between the system vacuum pressure and local barometric pressure?**
   a. manometer
   b. Bourdon
   c. diaphragm
   d. strain
7. **What size Type L copper tube should be used for a 40-scfm system with a pressure drop of 0.21 in. Hg/100 ft?**
   a. 2 inches
   b. 2.5 inches
   c. 3 inches
   d. 4 inches
8. **_______ is a type of permanent vacuum cleaning system.**
   a. dry
   b. wet
   c. combination
   d. all of the above
9. **A valve for a vacuum cleaning system that is used only fully open or closed is referred to as a _______.**
   a. blast gate
   b. regulating valve
   c. butterfly valve
   d. none of the above
10. **To clean floors, walls, and ceilings, with a vacuum cleaning system, a ______ hose is recommended.**
    a. 1-inch
    b. 1½-inch
    c. 2-inch
    d. 2½-inch
11. **In a vacuum cleaning system using 3-inch tubing, what is the maximum recommended velocity in the vertical up-flow risers?**
    a. 4,200 ft/min
    b. 4,700 ft/min
    c. 5,100 ft/min
    d. 6,000 ft/min
12. **The generally accepted initial vacuum level for average cleaning conditions is _______.**
    a. 1 in. Hg
    b. 2 in. Hg
    c. 3 in. Hg
    d. 4 in. Hg