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Plumbing Engineering Design Handbook

A Plumbing Engineer's Guide to System Design and Specifications

Volume 3

Special Plumbing Systems

American Society of Plumbing Engineers
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American Society of Plumbing Engineers
2980 S. River Rd.
Des Plaines, IL 60018
(847) 296-0002 • Fax: (847) 296-2963
E-mail: info@aspe.org • Internet: www.aspe.org

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Fire Protection Systems

As the role of the plumbing engineer has evolved, many have become responsible for the engineering of fire protection systems within the buildings they design. It is their responsibility to be knowledgeable about the applicable fire protection system types, design methods, relevant adopted codes, insurance regulatory requirements, and general installation methods.

The two main purposes for fire protection systems within built environments are life safety and property protection. Equal consideration must be given to attempt to contain a fire while protecting a building's occupants during their evacuation. Absolute safety from fire is not attainable, but means must be provided to minimize the potential for fire and the damage done by fire. The systems and methods used today are constantly changing and improving to meet the requirements of project variations and challenges. This chapter provides a basic outline for establishing the needed criteria to ensure fire safety via fire suppression within a building environment.

HISTORY AND OBJECTIVE

The primary system encountered is the water-based sprinkler system. This type of system dates back to the 1850s. The original sprinkler system was first introduced as lengths of perforated pipe that were manually activated. These types of systems were predominantly installed in mill buildings in the era from 1850 to approximately 1880.

In 1874, Henry S. Parmalee of New Haven, Connecticut obtained U.S. patent No. 154076 for an automatic sprinkler head. This device was a perforated sprinkler head containing a valve that was held closed against water pressure by a heavy spring made of low-fusing material. In 1874, he installed his fire sprinkler system in the piano factory that he owned. With the introduction of the first true heat-actuated automatic sprinkler, known as the "Parmalee head," in 1878, the automatic sprinkler system as we know it today was born.

Fast forward 60 years. Following fires with large losses of life (Coconut Grove Nightclub, Boston, 1942, 492 dead; LaSalle Hotel, Chicago, 1946, 61 dead; Winecoff Hotel, Atlanta, 1946, 119 dead), fire and building officials searched for a means to provide life safety for building occupants. They found that factories and other buildings equipped with automatic sprinklers had an amazingly good life safety record compared to similar buildings without sprinklers, and thus dawned the new age of providing sprinklers in commercial buildings.

The predominant source for fire suppression guidance is the National Fire Protection Association (NFPA). Established in 1896, the NFPA's mission is to reduce the worldwide burden of fire and other hazards on the quality of life by providing and advocating scientifically based consensus codes and standards, research, training, and education. NFPA publishes many codes and standards and also compiles records on fires in buildings protected with fire suppression systems. NFPA statistics show that properly designed sprinkler systems rarely fail to control the spread of or extinguish a fire. The organization has no record of a fire killing more than two people in a completely sprinklered building where a sprinkler system was properly operating, except in an explosion or flash or where industrial fire brigade members or employees were killed during fire suppression operations. The major cause of sprinkler system failure is inadequate water supply due to under-designed systems or closed water control valves.

(Note: NFPA standards refer to the authority having jurisdiction (AHJ), which is the organization or individual responsible for approving equipment, materials, installations, and procedures. NFPA standards typically are adopted by our model building codes and local governments. Each authority may choose different versions of NFPA published standards or provide their own amended versions. It is important to investigate what applicable codes and standards are to be used for each project.)

FIRE HAZARD EVALUATION

The first step in the design of an automatic sprinkler system is the determination of the overall fire hazard. The key factors affecting the overall fire hazard are:

- Class of fire
- Classification of occupancy and commodities
- Type of building construction
- Fire growth rate

Classes of Fires

A generally accepted method of classification separates combustible materials into five types:

- Class A Fires: Ordinary combustible materials such as wood, cloth, paper, rubber, and many plastics (typical for wet-based sprinkler systems)
- Class B Fires: Flammable liquids, combustible liquids, petroleum greases, tars, oils, oil-based paints, solvents, lacquers, alcohols, and flammable gases
- Class C Fires: Fires that involve energized electrical equipment
- Class D Fires: Combustible metals such as magnesium, titanium, zirconium, sodium, lithium, and potassium
- Class K Fires: Fires in cooking appliances that involve cooking oils and fats

Note: Class B, C, D, and K fires require specialized suppression systems based on the material that needs to be extinguished. The correct selection of an extinguishing agent is critical to controlling and extinguishing these types of fire.

Classification of Occupancy

The criteria for occupancy classification is defined in NFPA 13: *Standard for the Installation of Sprinkler Systems*. The categories are broken into five areas based on building use type:

- Light hazard: Low quantity of combustibles with low heat release (e.g., churches, hospitals, museums)
- Ordinary hazard 1: Moderate quantity of combustibles with moderate heat release and 8-foot stockpiles (e.g., mechanical rooms, restaurant kitchens, laundry facilities)
- Ordinary hazard 2: Moderate quantity of combustibles with moderate heat release and 12-foot stockpiles (e.g., stages, large library stack rooms, repair garages)
- Extra hazard 1: High quantity of combustibles with high heat release and no flammable or combustible liquids (e.g., aircraft hangers, saw mills)
- Extra hazard 2: High quantity of combustibles with high heat release and flammable and combustible liquids (e.g., plastics processing, flammable liquids spraying)

If the building includes storage, whether in stockpiles, racks, or pallets, the materials and methods of storage must be known. NFPA 13 provides specific guidelines regarding stored goods within the building environment.

The different building uses and stored materials require different hydraulic demand requirements. It is imperative to obtain this information during the information-gathering process.

Type of Building Construction and Use

The general construction and occupancy use classification of the building must be understood to determine if the building is required to be provided with a sprinkler system by code. In some instances, the model building codes make exceptions to allow increased building area if fully protected by an automatic sprinkler system (which should be confirmed during code review).

Fire Load and Resistance Ratings

The nature and potential magnitude of a fire in a building are related directly to the amount, composition, and physical arrangement of combustibles, either as contents of the building or as materials used in its construction. The total amount of combustibles is referred to as the fire load of a building and is expressed in pounds per square foot (lb/ft^2), with an assumed calorific value for ordinary cellulosic materials of 7,000 to 8,000 British thermal units per pound (Btu/lb). If this Btu content is applied when organic materials are present in large proportions, the weights must be adjusted accordingly.

The temperatures used in standard fire tests of building components are indicated by the nationally recognized time/temperature curve shown in Figure 1-1. The fire resistance of the construction of building assemblies, such as walls, floors, and ceilings (determined by standard fire tests), is expressed in hours.

WATER SOURCE

The primary agent for most fire-extinguishing systems is water. The availability of municipal water supplies of sufficient pressure and quantity to meet the design demands of the fire protection sprinkler system must be addressed. The points to be considered for the water supply include:

- Quantity, static pressure at no flow and residual pressure at design flow, and availability of water
- Overall fire demand, including duration of flow
- Makeup and reliability of the source
- Size, material of construction, and age of mains

Refer for NFPA 24: *Standard for the Installation of Private Fire Service Mains and their Appurtenances* for more information.

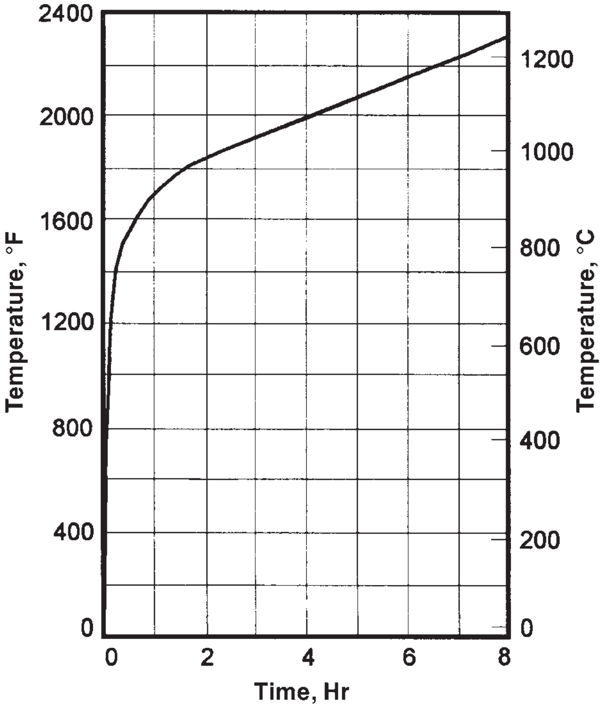


Figure 1-1 Time/Temperature Curve for Standard Fire Test

Quantity and Availability

The amount of water available from a network of underground water mains, whether they be private yard mains or the public water supply, can be determined in several ways. (Refer to NFPA 291: *Recommended Practice for Fire Flow Testing and Marking of Hydrants*.) The simplest method is to consult the history of fire flow tests in the area, available through the local water and fire departments or plant personnel for private systems. If test results are not current or the water supply might have changed since the most recent hydrant flow test, a new hydrant flow test should be requested through the local authorities (i.e., water department, fire department, or plant management).

Hydrant Flow Test

To conduct a fire flow test, the following equipment and information are necessary:

- Hydrant butt cap, with dial-spring gauge
- Pitot tube and blade with an attached dial-spring pressure gauge
- Hydrant wrench
- Nozzle pressure flow tables
- Knowledge of the water main's sizing and piping layout

Once all of the necessary equipment is assembled, a minimum of two operable fire hydrants should be selected. It is recommended practice that the residual pressure hydrant (test hydrant) be as close as possible to the structure under design and downstream of the flow hydrant. After the hydrants for the test have been selected, the hydrant butt cap with its pressure gauge should be placed on the test hydrant. The water department or maintenance personnel should operate the hydrants to limit the liability for damage. Special provisions may be required to accommodate the large volume of water that will discharge during a test.

Once the butt cap is in place, the test hydrant should be opened slightly to allow the air in the hydrant barrel to bleed off past the open bleed cock on the hydrant butt. After the air is bled off, the hydrant can be opened fully, and the bleed cock can be closed. The pressure that registers on the gauge at this time is the static pressure (pressure with no flow). The second hydrant now can be approached.

To start the test, one flow hydrant butt should be opened. The coefficient of discharge should be determined by considering the construction and roughness of the inside lip of the hydrant butt. In addition, the actual inside diameter of the butt should be measured to confirm its diameter. After this data has been recorded, the flow hydrant now can be opened fully. Some caution should be exercised when opening the hydrant. It should never be opened rapidly, and the path of discharge should be investigated to ensure that personnel will not be injured and that property will not be damaged by the stream or the residual standing water.

After the flow hydrant has been opened, it should be allowed to flow for two to five minutes to allow debris to clear the hydrant barrel and to stabilize the water flow before the pitot tube is inserted into the stream. When the pitot tube is inserted into the water stream, it should be placed in the centerline of the stream, at approximately one-half of the diameter of the butt opening (see Figure 1-2). The reading on the pressure gauge attached to the pitot tube then can be read. Simultaneously, the residual pressure (flowing pressure) must be read on the test hydrant (see Figure 1-3).

The pitot reading and residual pressure now should be recorded. For best results, the pitot reading

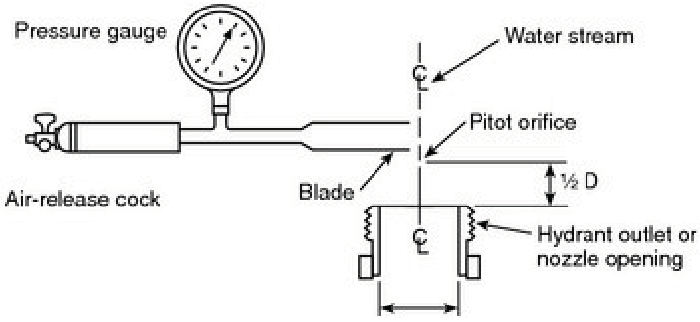


Figure 1-2 Pitot Tube Position

Source: NFPA 291

should not be less than 10 pounds per square inch (psi) or greater than 30 psi; similarly, the static pressure should drop 25 to 50 percent under the test conditions. In addition, it is a good idea to flow a quantity at least equal to the fire demand.

Now the data gathered during this test can be used to determine the quantity of water flowed and the amount of water available for firefighting operations. First, to determine the quantity of water flowed, the pitot pressure, hydrant butt size, and discharge coefficient are used. Using the pitot pressure and hydrant butt size from a given table (supplied by the manufacturer), a theoretical flow can be found, using the following formula. This formula allows computation of the gallons per minute (gpm) flowing from a nozzle, hydrant outlet, or orifice (see Figure 1-4).

Equation 1-1

$$Q = (29.83)(c)(d^2)(\sqrt{p})$$

where
Q= Flow discharge, gpm
c= Coefficient of discharge
d= Diameter of outlet, inches
p= Pitot (velocity) pressure, psi

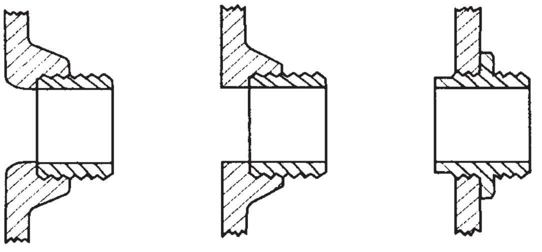
The flow available at any pressure along the established flow curve can be found using the following equation:

Equation 1-2

$$Q_A = (Q_T)((P_S - P_A)/(P_S - P_R))^{0.54}$$

where
Q_A= Flow available at some residual pressure (P_A)
Q_T= Actual flow measured during the test
P_S= Measured static pressure
P_R= Measured residual pressure
P_A= Pressure of interest

The results of a hydrant flow test can be plotted on a graph to develop the characteristic flow curve for the piping network (water supply) for the test location. A typical water supply is shown in Figure 1-5. Either the formula method discussed above or the graph method can be used to determine water availability.



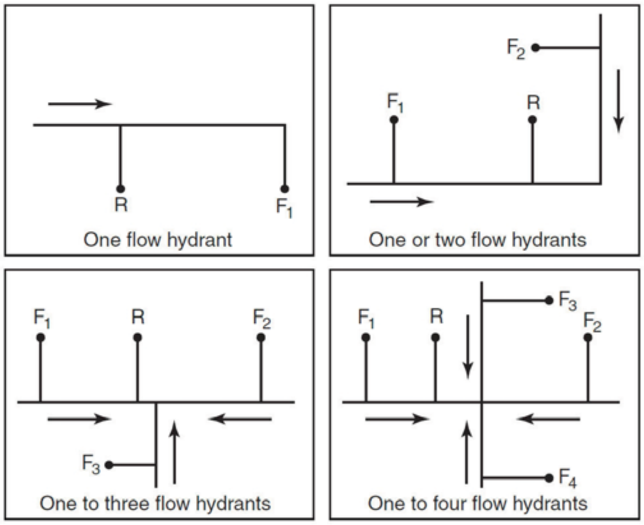
Outlet Smooth and Rounded Coef. 0.90

Outlet Square and Sharp Coef. 0.80

Outlet Square and Projecting into Barrel Coef. 0.70

Figure 1-4 Three General Types of Hydrant Outlets and Their Coefficients of Discharge

Source: NFPA 291



One flow hydrant

One or two flow hydrants

One to three flow hydrants

One to four flow hydrants

Arrows indicate direction of flow: R – residual hydrant; F – flow hydrant

Figure 1-3 Method of Conducting Flow Tests

Example 1-1

Determine the water demand at the desired residual pressure given the following flow test conditions:

- Static pressure: 70 psi
- Residual pressure: 50 psi
- Pitot reading: 24 psi
- Hydrant butt: 2½ inches
- Coefficient: 0.9

From Table 1-1, the theoretical flow can be found to be 914 gpm. By multiplying by the coefficient of 0.9, the actual flow is found.

$Q_F = 0.9 \times 914$ gpm
$Q_F = 822.6$ gpm
$Q_F = 823$ gpm

By plotting this on the water supply graph, the characteristic flow curve can be established.

Similarly, using Equation 1-2, the flow available at 20-psi residual pressure can be found:

$Q_A = (Q_T)((P_S - P_A)/(P_S - P_R))^{0.54}$
$Q_T = 914$ gpm
$P_S = 70$ psi
$P_R = 50$ psi
$P_A = 20$ psi
$Q_A = (823)((70-20)/(70-50))^{0.54}$
$Q_A = (823)(50/20)^{0.54}$
$Q_A = (823)(2.5^{0.54})$
$Q_A = 1{,}350$ gpm

Overall Fire Demand (Flow, Pressure, and Duration)

The overall fire demand is established by hydraulic calculations performed by the engineer, by code, or by the insurance rating organization. The end result is the amount of flow required (gpm) at a calculated pressure (psi). The flow duration requirement is typically mandated by NFPA 13. For example, light hazard occupancies typically require a reliable water supply with a 30-minute duration capability.

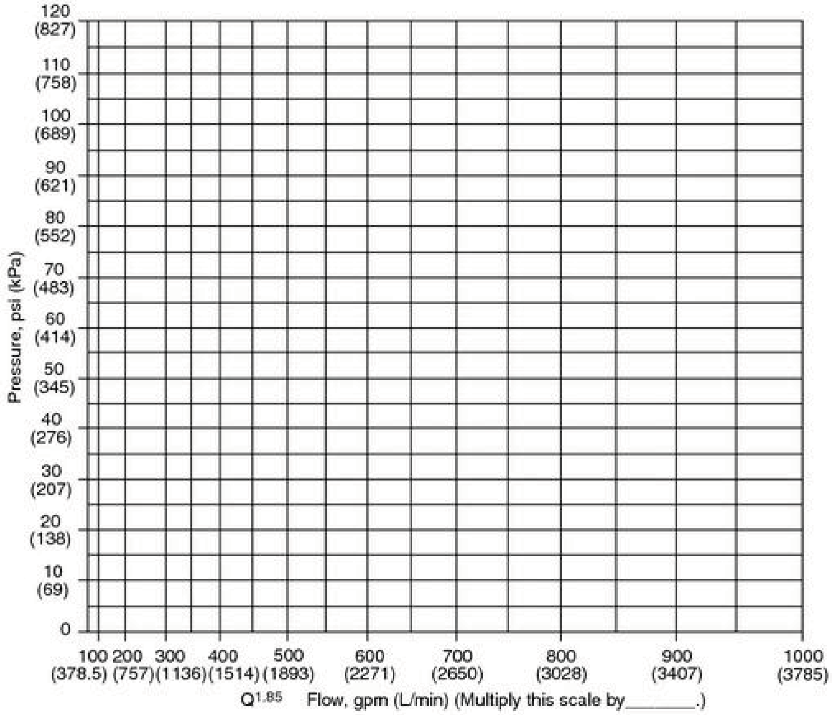


Figure 1-5 Water Supply Graph

Source: NFPA 13

Table 1-1 gpm Flow Table

Pitot Pressure* (psi)	Feet	Velocity Discharge (ft/sec)	Orifice Size (in.)											
			2	2.25	2.375	2.5	2.625	2.75	3	3.25	3.5	3.75	4	4.5
1	2.31	12.20	119	151	168	187	206	226	269	315	366	420	477	604
2	4.61	17.25	169	214	238	264	291	319	380	446	517	593	675	855
3	6.92	21.13	207	262	292	323	356	391	465	546	633	727	827	1047
4	9.23	24.39	239	302	337	373	411	451	537	630	731	839	955	1209
5	11.54	27.26	267	338	376	417	460	505	601	705	817	938	1068	1351
6	13.84	29.87	292	370	412	457	504	553	658	772	895	1028	1169	1480
7	16.15	32.26	316	400	445	493	544	597	711	834	967	1110	1263	1599
8	18.46	34.49	338	427	476	528	582	638	760	891	1034	1187	1350	1709
9	20.76	36.58	358	453	505	560	617	677	806	946	1097	1259	1432	1813
10	23.07	38.56	377	478	532	590	650	714	849	997	1156	1327	1510	1911
11	25.38	40.45	396	501	558	619	682	748	891	1045	1212	1392	1583	2004
12	27.68	42.24	413	523	583	646	712	782	930	1092	1266	1454	1654	2093
13	29.99	43.97	430	545	607	672	741	814	968	1136	1318	1513	1721	2179
14	32.30	45.63	447	565	630	698	769	844	1005	1179	1368	1570	1786	2261
15	34.61	47.22	462	585	652	722	796	874	1040	1221	1416	1625	1849	2340
16	36.91	48.78	477	604	673	746	822	903	1074	1261	1462	1679	1910	2417
17	39.22	50.28	492	623	694	769	848	930	1107	1300	1507	1730	1969	2491
18	41.53	51.73	506	641	714	791	872	957	1139	1337	1551	1780	2026	2564
19	43.83	53.15	520	658	734	813	896	984	1171	1374	1593	1829	2081	2634
20	46.14	54.54	534	676	753	834	920	1009	1201	1410	1635	1877	2135	2702
22	50.75	57.19	560	709	789	875	964	1058	1260	1478	1715	1968	2239	2834
24	55.37	59.74	585	740	825	914	1007	1106	1316	1544	1791	2056	2339	2960
26	59.98	62.18	609	770	858	951	1048	1151	1369	1607	1864	2140	2434	3081
28	64.60	64.52	632	799	891	987	1088	1194	1421	1668	1934	2220	2526	3197
30	69.21	66.79	654	827	922	1022	1126	1236	1471	1726	2002	2298	2615	3310
32	73.82	68.98	675	855	952	1055	1163	1277	1519	1783	2068	2374	2701	3418
34	78.44	71.10	696	881	981	1087	1199	1316	1566	1838	2131	2447	2784	3523
36	83.05	73.16	716	906	1010	1119	1234	1354	1611	1891	2193	2518	2865	3626
38	87.67	75.17	736	931	1038	1150	1268	1391	1656	1943	2253	2587	2943	3725
40	92.28	77.11	755	955	1065	1180	1300	1427	1699	1993	2312	2654	3020	3822
42	96.89	79.03	774	979	1091	1209	1333	1462	1740	2043	2369	2719	3094	3916
44	101.51	80.88	792	1002	1116	1237	1364	1497	1781	2091	2425	2783	3167	4008
46	106.12	82.70	810	1025	1142	1265	1395	1531	1821	2138	2479	2846	3238	4098
48	110.74	84.48	827	1047	1166	1292	1425	1563	1861	2184	2533	2907	3308	4186
50	115.35	86.22	844	1068	1190	1319	1454	1596	1899	2229	2585	2967	3376	4273

Source: NFPA 291

Water Supply Makeup and Reliability

A water supply's reliability can be determined by evaluating the method by which the pipe network is fed. Municipal water supplies consist of three types: elevated reservoirs (water towers), direct pump, or combined. The distribution of the water supply can be a dead end, grid, or loop pipe system or a combination of all three.

The elevated reservoir is reliable as it does not depend on electrical power to provide the water pressure. The same reasoning holds true for private supplies. With reliability in mind, an automatic fire protection system should be designed to function properly without the introduction of a booster fire pump. If this cannot be accomplished, then a fire pump will need to be added to provide the water supply. (See the discussion under "Fire Pumps" later in this chapter.)

A water supply piping system that consists of one large supply line feeding a series of dead-ended branch mains is far less efficient than a system of pipes that are looped and gridded together. For example, an 8-inch main flowing 2,000 gpm that is fed from one direction will have a friction loss of 4.62 psi per 1,000 feet of pipe. If that same main were fed from two directions, the flow could be balanced to 1,000 gpm from each side (assuming equivalent pipe characteristics and lengths). The friction loss would then be reduced to 1.128 psi per 1,000 feet, or reduced by a factor of 4.

Size and Age of Mains

The size and age of the fire mains play an important part in the ability of the water supply to produce adequate fire flows for fire protection systems. What may not be obvious to the casual observer, however, is how time and the corrosiveness of the water can affect the inside diameter of the supply mains. For example, with moderately corrosive water a 30-year-old cast iron pipe will have friction factors higher than new cast iron pipe.

AUTOMATIC SPRINKLER SYSTEMS

Once the fire hazard and water supply have been evaluated, the type of sprinkler system to be installed can be selected. The basic types of sprinkler systems are:

- Wet pipe
- Dry pipe
- Preaction
- Deluge
- Combined dry pipe and preaction
- Antifreeze

Wet Pipe Systems

Wet pipe sprinkler systems are installed more often than all other types by a wide margin. The wet pipe system employs automatic (fusible link, glass bulb, or closed type) sprinklers attached to piping containing water under pressure at all times. When a fire occurs, individual sprinklers are actuated by the heat, and water flows immediately. The starting point for all wet-based sprinkler systems is the water source.

The wet pipe system is controlled by an alarm check valve (see Figure 1-6). When a sprinkler activates, the flow of water raises the alarm valve clapper from its seat, thereby lifting the pilot valve disc from the nozzle. This permits water to enter the alarm line. A water motor gong is actuated by the flow. An optional pressure switch may be attached on the alarm line to provide an electric signal to an outdoor alarm bell or to the building's main fire alarm control panel.

The alarm valve is typically installed vertically in the main water supply to the wet pipe sprinkler system (see Figure 1-7). A variable-pressure water supply, which is the most common type of water supply encountered, requires the use of a retard chamber with the alarm valve to prevent false alarms.

Where the water supply has constant pressure, the alarm valve is used without the retard chamber. In cases where a local alarm is adequate, water is admitted directly to a water motor-driven gong. If no water motor gong is required, a vane-type water flow indicator can be inserted in the supply pipe to indicate, electrically, a water flow (see Figure 1-8).

Should a pressure surge occur, which will raise the clapper momentarily and lift the pilot valve disc from the nozzle, a small amount of water will pass into the retard chamber. If only a relatively small amount of water enters the retard chamber, the water will drain off through the retard chamber drain. However, should water escape through a sprinkler or from damaged piping, sustained water flow through the alarm valve will result. The clapper will move from its seat and lift the pilot valve disc, allowing a large volume of water to flow through the nozzle and into the retard chamber. The bleeding capacity through the retard chamber drain cannot keep up with the incoming volume. The retard chamber will fill, and water will flow through the alarm line to actuate the water motor gong and the optional alarm pressure switch, if used.

After a fire operation or test, the water in the alarm line will drain out through the retard chamber drain.

Dry Pipe Systems

Dry pipe systems are used in spaces in which the ambient temperature may be cold enough to freeze the water in a wet pipe system, rendering the system inoperable. This type of system is used most often in unheated buildings, in outside canopies attached to heated buildings (in which a wet pipe system would be provided), or in refrigerated coolers.

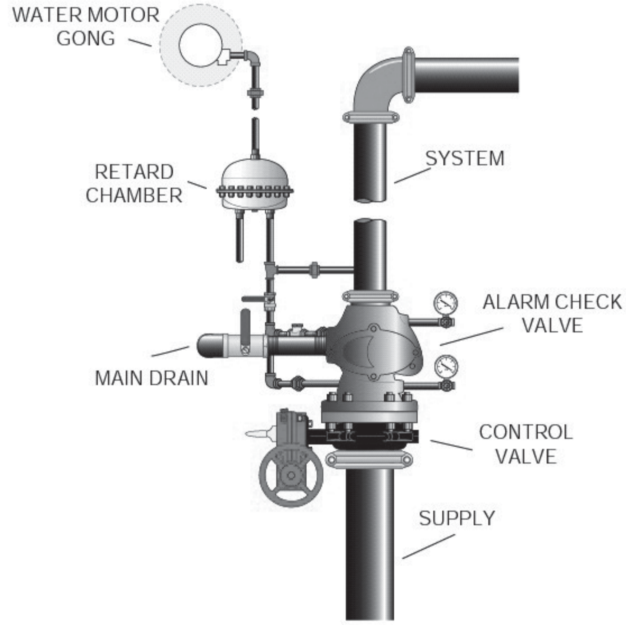
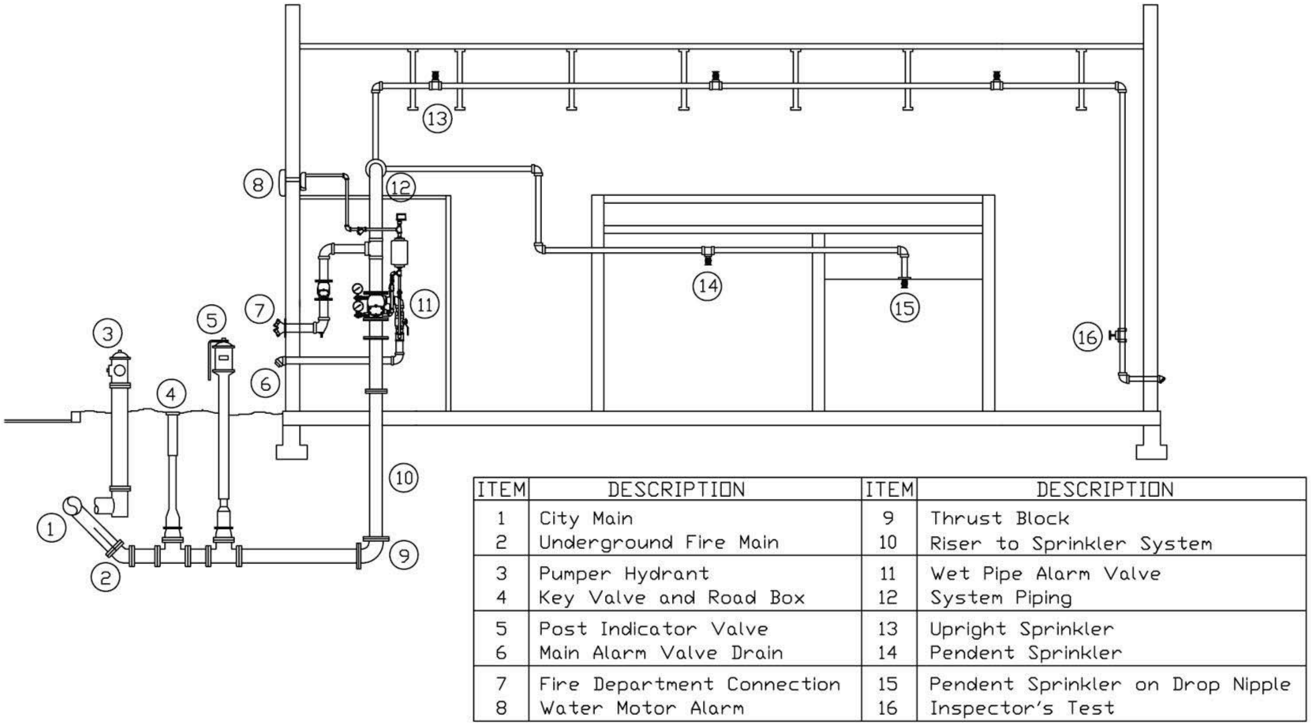


Figure 1-6 Typical Alarm Check Valve Riser
Source: Tyco Fire

Water is not present in the piping until the system operates. The sprinkler piping is pressurized with air at a maintenance pressure that is relatively low compared to the water supply pressure. To prevent the higher water supply pressure from forcing water into the piping, the design of the dry pipe valve intentionally includes a larger valve clapper sectional area exposed to the maintenance air pressure, as compared to the water pressure. Operation of the dry pipe equipment occurs when fire temperature fuses a sprinkler, allowing sprinkler piping air pressure to escape. This destroys the pressure differential that normally keeps the dry valve closed and allows water to flow into the sprinkler piping. The air pressure required to keep the clapper in a closed position varies directly with the water supply pressure.

Typically, the dry valve is installed in a heated area or in an insulated, heated valve enclosure protected against any occurrence of freezing temperatures. When one or more of the automatic sprinklers is exposed to sufficient heat, it operates, allowing the maintenance air to vent from that sprinkler. As the air pressure in the piping drops, the pressure differential across the dry pipe valve changes, allowing water to enter the piping system (see Figures 1-9 and 1-10). Water flow from sprinklers needed to control the fire is delayed until the air is vented from the sprinklers. For this reason, dry pipe systems are usually not as effective as wet pipe systems in fire control during the initial stages of the fire. To compensate for the time delay, dry sprinkler system hydraulic area requirements are typically greater than that of a traditional wet system.

A hydraulically operated fire alarm is standard; however, many installations also have an electric fire alarm gong that sounds when water flow into the sprinkler piping system actuates the alarm switch. This electric switch can also be used to signal the building's main fire alarm control panel.



ITEM	DESCRIPTION	ITEM	DESCRIPTION
1	City Main	9	Thrust Block
2	Underground Fire Main	10	Riser to Sprinkler System
3	Pumper Hydrant	11	Wet Pipe Alarm Valve
4	Key Valve and Road Box	12	System Piping
5	Post Indicator Valve	13	Upright Sprinkler
6	Main Alarm Valve Drain	14	Pendent Sprinkler
7	Fire Department Connection	15	Pendent Sprinkler on Drop Nipple
8	Water Motor Alarm	16	Inspector's Test

Figure 1-7 Wet Pipe Sprinkler System

Large dry pipe systems are typically installed with an accelerator, a device that accelerates dry valve operation. The accelerator is actuated by a drop in piping pressure. It then functions to apply remaining pressure from the sprinkler piping to the intermediate chamber of the dry valve. Added to the water pressure below the clapper, this quickly eliminates the differential to open the clapper. Exhausters are also available to assist in the quick discharge of air prior to operation. The time of water flow in dry pipe systems is based on system volume, generally not more than 750 gallons for any one dry pipe valve. This volume can be exceeded if water is delivered in 60 seconds or less. (Refer to NFPA 13 for system size and volume limitations.)

Under normal conditions, the dry pipe sprinkler system has sealed automatic sprinklers retaining air pressure in the sprinkler piping. Only after a sprinkler seal fuses and opens to release the air (under pressure) in the sprinkler piping does the dry valve clapper open, and water from the water supply main then flows through it into the sprinkler piping. The dry valve has two functions:

- To keep the clapper closed and withhold water from the sprinkler piping until fire fuses a sprinkler seal
- To trigger a fire alarm when the clapper opens

When set, the rubber-faced dry valve clapper rests with the rubber facing in contact with two concentric seat rings. The annular chamber, or intermediate chamber, is connected to the alarm devices such as the water motor gong and alarm switch. The clapper area against which the water exerts its force is the diameter of the inner seat ring. The clapper area against which the compressed air exerts its force is the diameter of the outer seat ring, which is considerably larger than the inner diameter. This difference in area enables the lesser air pressure (over a greater area) above the clapper to overcome the clapper. Priming water is added to some dry valves to provide a positive system through the intermediate chamber and its alarm outlets.

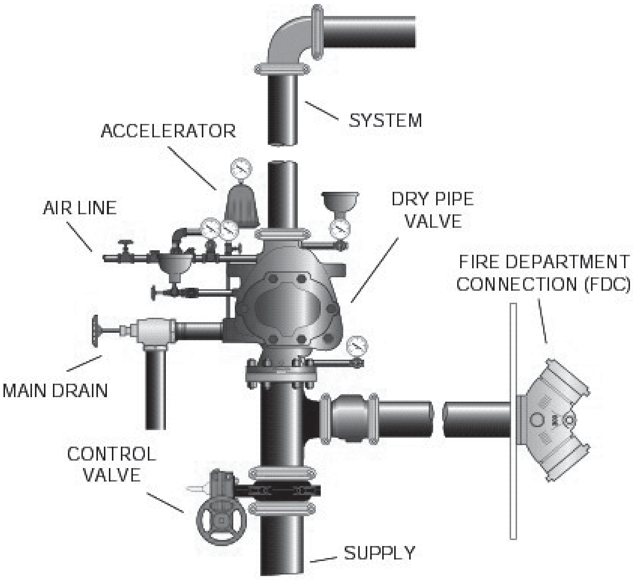


Figure 1-10 Typical Dry Pipe Valve Riser

Source: Tyco Fire

Figure 1-8 Vane-type Water Flow Indicator

Electric Air Compressor

For dry pipe systems, the piping water capacity must be calculated to determine air capacity, which is used in the selection of the correct-size air compressor.

NFPA standards require air compressors to be capable of restoring normal air pressure in a system within 30 minutes. FM Global standards require compressors to be capable of restoring normal air pressure plus 25 percent pressure within 30 minutes.

To calculate a system's capacity in gallons, determine the total pipe footage for each size pipe, and then multiply by the corresponding factor from Table 1-2. When the total capacity in gallons is determined, multiply by 0.012 to obtain the free-air delivery in cubic feet per minute (cfm).

(Note: Where one air compressor supplies more than one dry pipe system, the largest-capacity system shall determine the compressor size.)

Accelerator

An accelerator is an accessory device used on large dry pipe systems to hasten dry valve operation. NFPA 13 requires each standard dry valve controlling a

Table 1-2 Factors for Determining Water Capacity per Foot of Pipe

Capcaity & Weight of Water-filled Pipe				
Size inches	Sch 40 gal/ft	Sch 40 lb/ft	Sch 10 gal/ft	Sch 10 lb/ft
1	0.045	2.05	0.049	1.81
1¼	0.078	2.93	0.085	2.52
1½	0.106	3.61	0.115	3.04
2	0.174	5.13	0.190	4.22
2½	0.248	7.89	0.283	5.89
3	0.383	10.82	0.433	7.94
3½	0.513	13.48	0.576	9.78
4	0.660	16.40	0.740	11.78
5	1.040	23.47	1.144	17.30
6	1.501	31.69	1.649	23.03
8	2.660	47.70	2.776	40.08

system with a capacity of more than 500 gallons to be provided with an accelerator, with the following exception: the 60-second limit does not apply to dry systems with a capacity of 750 gallons or less when equipped with a quick-opening device.

In a fire condition, the accelerator redirects air pressure from the system piping into the intermediate chamber of the dry pipe valve. This air pressure assists the water pressure differential and opens the dry pipe valve more quickly.

Water Delivery

NFPA 13 requires dry sprinkler systems to deliver water in a prescribed time frame for different hazard applications. For example, a dry system used in a residential application is required to deliver water to the most remote sprinkler initially open in 15 seconds. This requirement was established to address the time interval between the operation of the sprinklers and the heat release and growth of the fire.

Preaction Systems

Preaction sprinkler systems are specialized for use in locations where accidental activation is undesired, such as in museums, data centers, or electrical rooms. A preaction system is installed where there is a need to counteract the operational delay of a conventional dry pipe system and to eliminate the danger of water discharge resulting from accidental damage to automatic sprinklers or piping. In a preaction system, the water supply (deluge) valve is actuated independently of the opening of sprinklers (i.e., the valve is opened by the operation of an automatic fire detection system and not by the fusing of sprinklers).

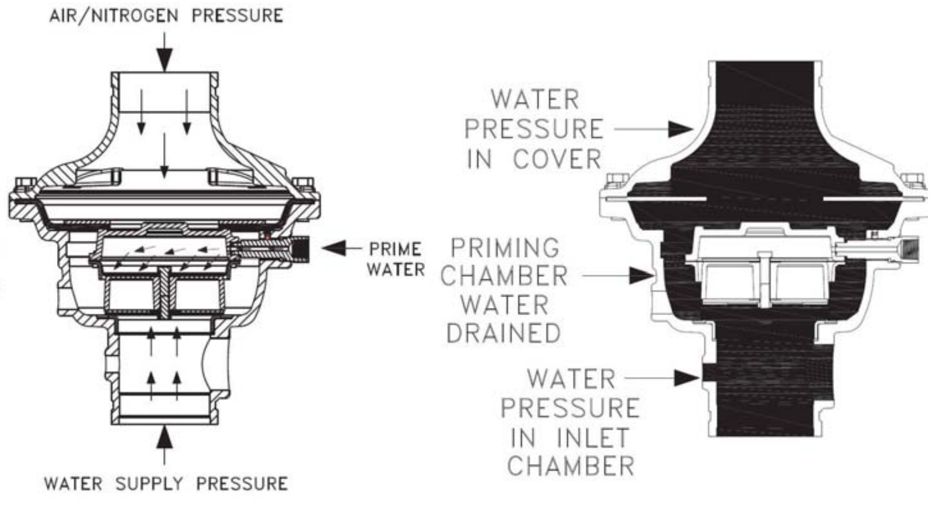


Figure 1-9 Dry Pipe Valve
(left) air pressure maintains clapper closed
(right) venting of air allows clapper to open and water to flow

Preaction systems are hybrids of wet, dry, and deluge systems, depending on the exact system goal. The three subtypes of preaction systems are single interlock, double interlock, and non-interlock. The operation of single interlock systems is similar to dry systems, except that these systems require a preceding and supervised event (typically the activation of a heat or smoke detector) to take place prior to the action of water introduction into the system's piping by opening of the preaction valve (which is a mechanically latched valve). Once the fire is detected by the fire alarm system, the system is essentially converted from a dry system into a wet system. If an automatic sprinkler operated prior to the fire being detected by the fire alarm system, water will be allowed into the piping, which will discharge water from the sprinkler.

The operation of non-interlock systems, much like the single interlock, admits water to sprinkler piping upon operation of either detection devices or automatic sprinklers.

The operation of double interlock systems is similar to deluge systems, except that automatic sprinklers are used. These systems require both a preceding and supervised event (typically the activation of a heat or smoke detector) and an automatic sprinkler activation to take place prior to the action of water introduction into the system's piping.

Preaction valves (see Figure 1-11) are typically located near the hazard they serve and are provided with an addressable control panel. Preaction systems operate faster and result in less fire and water damage compared to conventional dry pipe systems. They are limited to 1,000 sprinklers.

Deluge Systems

The purpose of a deluge system is to deliver sprinkler water coverage to the entire area of a fire in the least

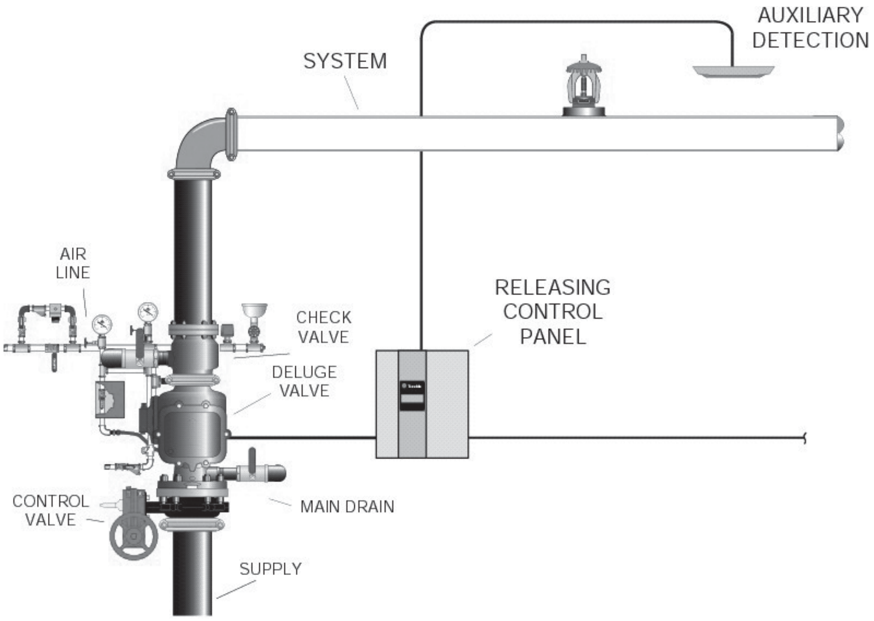


Figure 1-11 Typical Preaction Valve Riser

Source: Tyco Fire

amount of time possible. It accomplishes this by admitting water to sprinklers or spray nozzles that are open at all times. By using automatic fire detection devices of the type used in preaction systems or controls designed for individual hazards, a deluge system can apply water to a fire more quickly than a system whose operation depends on the opening of sprinklers as the fire spreads. Deluge systems are suitable for extra hazard occupancies in which flammable liquids are handled or stored and where a fire may flash ahead of the operation of ordinary automatic sprinklers.

Water is not present in the piping until the system operates. Because the sprinkler orifices are open, the piping is at ambient air pressure. To prevent the water supply pressure from forcing water into the piping, a deluge valve, which is a mechanically latched valve, is used in the water supply connection. It is a nonresetting valve and stays open once tripped.

Because the sprinklers are of the open type, the deluge valve must be opened as signaled by a specialized fire alarm system. The type of fire alarm-initiating device (e.g., smoke detectors, heat detectors, or optical flame detection) is selected mainly based on the hazard. The initiation device signals the fire alarm panel, which in turn signals the deluge valve to open. Activation can also be manual, depending on the system goals. Manual activation is usually via an electric or pneumatic fire alarm pull station.

Activation of a fire alarm-initiating device or a manual pull station signals the fire alarm panel, which in turn signals the deluge valve to open, allowing water to enter the piping system. Water flows from all sprinklers simultaneously. Where high values of discharge are involved or where spray nozzles, foam water sprinklers, or other foam applicators are used, the system should be supervised.

Deluge systems are used for fast, total application of water in extra-hazardous areas and in water-spray systems. Deluge valves are essentially check valves with a clapper latched in the closed position (see Figure 1-12). The actuating system unlatches the valve, allowing water to enter the piping system and flow out the heads. The more common design of the deluge valve employs a single differential diaphragm in which the water pressure bears on both sides, while the top side adjoins a closed chamber (see Figure 1-13). The actuating system opens the closed chamber, allowing the water to push the diaphragm up and off the water seat, releasing water to the system.

A modification of the valve uses a pressure regulator that maintains (on the outlet side) any predetermined pressure less than the available system pressure (see Figure 1-14). This allows the system to discharge at a constant rate.

Combined Dry Pipe and Preaction Systems

A combined dry pipe and preaction sprinkler system is one that employs automatic sprinklers attached to a piping system containing air under pressure and has

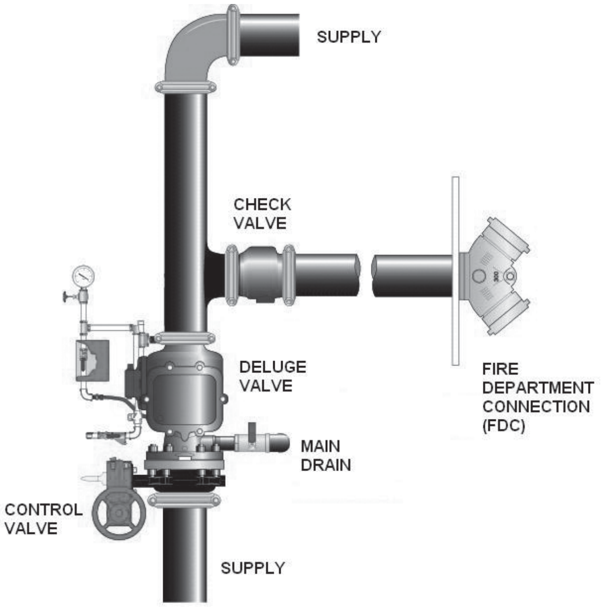


Figure 1-12 Typical Deluge Valve Riser

Source: Tyco Fire

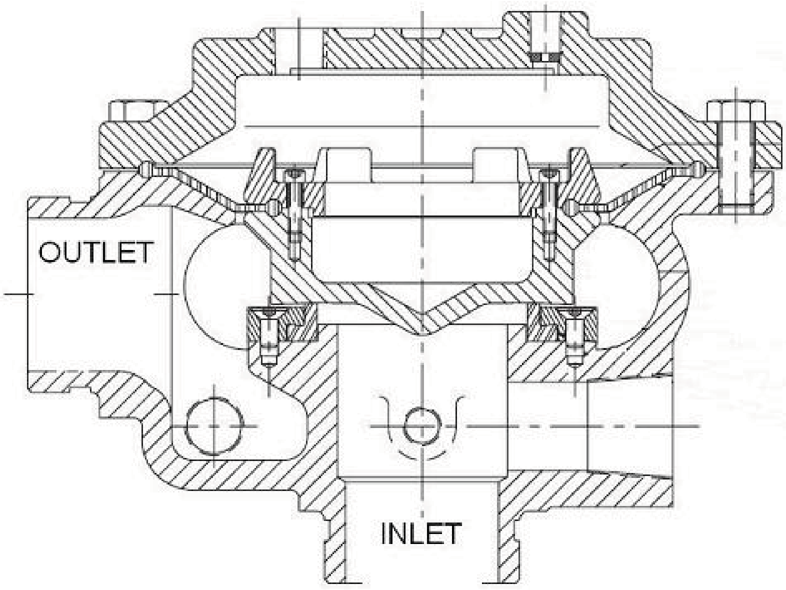


Figure 1-13 Deluge Valve with Single Differential Diaphragm
Source: Reliable Sprinkler

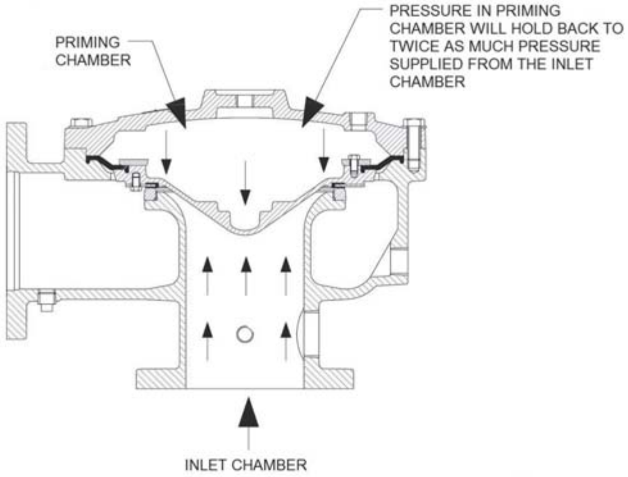


Figure 1-14 Deluge Valve with Outlet Pressure Regulator

a supplemental fire detection system installed in the same areas as the sprinklers. Operation of the fire detection system, as by a fire, actuates tripping devices that open dry pipe valves simultaneously and without loss of air pressure in the system. Operation of the fire detection system also opens approved air-exhaust valves at the end of the feed main, which facilitates the filling of the system with water, usually preceding the opening of sprinklers. The fire detection system also serves as an automatic, early warning fire alarm system. These systems are intended to be applied to unusual structures, such as piers or wharves that require unusually long runs of pipe.

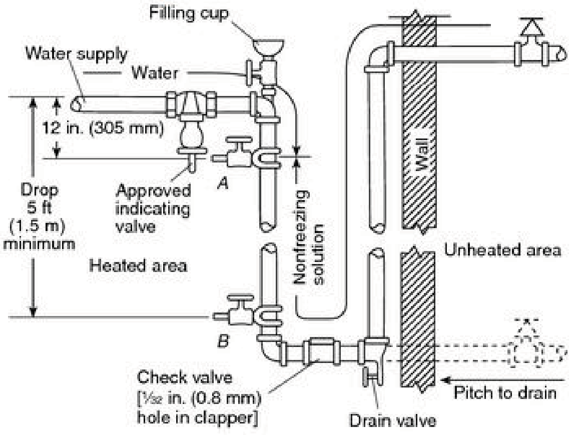
Antifreeze Systems

Antifreeze systems are typically used as subsystems to wet-based sprinkler systems. These systems are intended to protect small areas that could be exposed to freezing temperatures. Typically, antifreeze systems are used for rooftop cooling tower equipment or, most commonly, residential construction. The sprinkler distribution piping in an antifreeze system (see Figure 1-15) is filled with a mixed antifreeze solution prepared with a freezing point below the expected minimum temperature for the locality.

Note: Confer with your local AHJ and insurer for the allowed use of antifreeze systems.

SPRINKLER SYSTEM HYDRAULICS

Most sprinkler systems installed today are designed using an area and density approach. As described earlier, first the building use and building contents must be analyzed to determine the level of fire hazard. After determining the hazard classification, a design area and density can be found by referencing tables in NFPA 13 (see Figure 1-16). The design area is a theoretical area of the building representing the worst-case area where a fire could burn. The design density is a measurement of how much water (in gpm) per square foot of floor area should be applied to the design area. Through tests and studies, NFPA, FM Global, Industrial Risk Insurers, and



Notes:
1. Check valve shall be permitted to be omitted where sprinklers are below the level of valve *A*.
2. The 1/32 in. (0.8 mm) hole in the check valve clapper is needed to allow for expansion of the solution during a temperature rise, thus preventing damage to sprinklers.

Figure 1-15 Antifreeze System Piping Arrangement
Source: NFPA 13

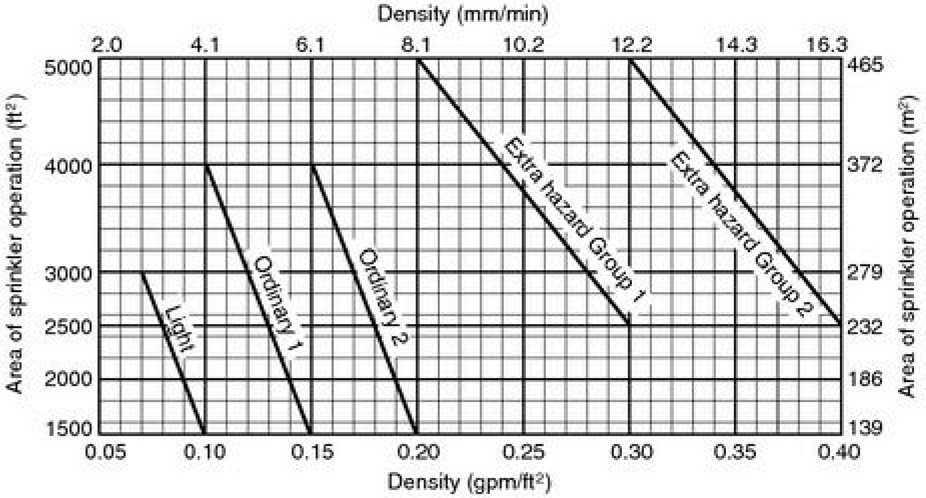


Figure 1-16 Density Area Curve Example

Source: NFPA 13

other organizations have established design densities that are appropriate for a wide range of occupancy classifications.

After the design area and density have been determined, fabrication drawings can be developed along with supporting hydraulic calculations, which are generated to prove that the designed pipe system can deliver the required amount of water to the required design area. These calculations account for all of the pressure that is lost or gained between the water supply source and the sprinklers that would operate in the design area. This includes pressure that is lost due to friction inside the piping and pressure that is lost or gained due to elevation differences between the source and the discharging sprinklers.

Another critical concept that must be understood in hydraulic calculations is that all of the sprinklers in the sprinkler system being designed are not expected to discharge simultaneously. Each selected remote area has a calculated number of sprinklers that are to be included in the hydraulic calculations. The number of sprinklers can be calculated by the following equation:

Equation 1-3

$$\text{Calculated sprinklers} = \frac{\text{Remote area}}{\text{Sprinkler coverage area}}$$

Example 1-2

If the remote area in an ordinary group 1 hazard application is 1,500 square feet, how many sprinklers should be calculated?

Calculated sprinklers = 1,500 ft^2/130 ft^2 = 11.5 sprinklers = 12 sprinklers

The required size of the remote area varies among occupancy classifications. NFPA 13 allows some flexibility in the sizing of the design area, usually permitting an area between 1,500 and 5,000 square feet. Other authorities have different ranges. In many cases, the insurance industry or government authorities require a specific design area based on a specific hazard classification. Otherwise, any area within the acceptable range can be chosen. It must be noted that the required minimum design density will vary with the hazard classification and the size of the design area.

The design area is to be located in the most hydraulically remote part of the fire area. In essence, the design area must be composed of the most demanding portion of the sprinkler system. If the calculations prove that the water supply available is adequate for the most demanding part of the system, then it logically follows that the water supply will be adequate for any part of the system. The most hydraulically remote area is not always easy to identify. In a non-loop and non-grid system (i.e., a conventional tree system), the hydraulically most remote area is usually the area most physically remote from the water supply source. However, it is important to understand that physical remoteness is not a fail-safe criterion for hydraulic remoteness, particularly when dealing with looped or gridded piping systems.

Pipe Schedule System

The essential difference between a hydraulically calculated sprinkler system and a pipe schedule sprinkler system lies in the regulation of pipe sizing. For a pipe schedule sprinkler system designed in accordance with NFPA 13, only a limited number of sprinklers may be supplied by a given pipe size. The pipes can become oversized based on available water supply and pressure, which make the system more costly than necessary. In a hydraulically calculated system, there is no limit to the number of sprinklers that can be supplied by any size pipe; the size is dictated by the rate of flow and pressure loss.

The pipe schedule design method is limited to additions or modifications to existing pipe schedule systems, to new installations of 5,000 square feet or less or to new installations exceeding 5,000 square feet where required flows are available with a minimum residual pressure of 50 psi at the highest sprinkler elevation.

System Size

The total square footage covered by a single fire zone is restricted, normally to 52,000 square feet for light and ordinary hazard occupancies and 40,000 square feet for extra hazard and storage occupancies.

Information Required for Hydraulic Calculations

The following information is necessary to obtain before performing hydraulic calculations.

Water Supply Information

- Static pressure, psi
- Residual pressure, psi
- Flow rate, gpm
- Location and elevation of test
- Total supply available

Hazard Classification (occupancy)

- Classification by insurance company or NFPA standards
- Density and area requirements
- Duration of flow requirements
- Hose stream allowance
- Pressure allowance

Piping Material

- Friction loss for selected piping type (e.g., lightwall pipe, Schedule 40 pipe, copper, cement-lined pipe)

Sprinkler Heads

- Sprinkler head K factor from technical data sheets
- Temperature rating
- Special coating requirements

STEPS TO FIRE SPRINKLER SYSTEM DESIGN

1. Estimate the minimum water demand for the sprinkler system. This can be obtained by calculating the product of the density and design area (see Equation 1-4). The density and design are normally specified by NFPA 13 or the fire insurance underwriter, and both relate to the type of hazard to be protected.

Equation 1-4

System demand = Density × Design area

Example 1-3

Given that a sprinkler system has a design density of 0.2 gpm/ft^2 and a design area of 3,000 ft^2, determine the system demand.

System demand = 0.2 × 3,000 = 600 gpm

2. Estimate the total demand for the sprinkler system and hose outlets. This can be determined by adding the sprinkler system demand to the hose demand (see Equation 1-5). The hose demand is normally specified by NFPA 13 or an insurance underwriter. (Typical combined hose demands are 100 gpm for light hazard; 250 gpm for ordinary hazard, and 500 gpm for extra hazard.)

Equation 1-5

Total demand = System demand + Hose demand

Example 1-4

If the minimum hose demand shall be 250 gpm, determine the total demand for Example 1-3.

Total demand = 600 gpm + 250 gpm = 850 gpm

3. Establish the pressure available at the water supply with the total demand flowing. This can be determined from a graph of the water supply characteristics (flow and pressure) at the water supply point. Refer to the "Water Source" section of this chapter.

4. Calculate the end-head flow that is required to provide the minimum specified water density to the most remote sprinkler head (see Equation 1-6). The end-head sprinkler pressure at its required minimum flow can be determined by using Equation 1-7 or from sprinkler head characteristic tables.

Equation 1-6

Q = Design area × Design density

Equation 1-7

$$P = (Q / K)^2$$

where

Q = End-head flow, gpm
P = End-head sprinkler pressure, psi
K = K factor

Example 1-5

Determine the end-head sprinkler flow and the head sprinkler pressure given the following conditions:

- Occupancy = Machine shop
- Hazard= Ordinary group 2
- Maximum spacing = 130 ft^2
- K factor = 5.6 (for a nominal ½-inch orifice size)
- Density = 0.20 gpm/ft^2
- Area =1,500 ft^2

Step 1: Calculate the end-head sprinkler flow or gpm head using Equation 1-6:

Q = 130 ft^2 × 0.20 gpm = 26 gpm

Step 2: Calculate the end-head pressure using Equation 1-7:

$P = (26/5.6)^2$
$P = (4.64)^2$
P = 21.52 psi

This is the end-head starting pressure. The starting pressure may be reduced by using a large orifice head (K = 8.0).

$P = (26/8)^2$
$P = (3.25)^2$
$P = 10.56$ psi

For systems where the end pressure has been established, use the following formula to calculate the end flow requirement.

Equation 1-8

$$Q = K\sqrt{P}$$

5. Size the sprinkler piping system. The hydraulic pipe schedule is a table of standard sprinkler system pipe sizes with associated flows that will produce the average friction loss per foot allowed in the system under consideration. (See Tables 1-3A through 1-3G for hydraulic values in sprinkler pipe sizes up to 4 inches.)
6. Calculate the average pressure loss per foot of piping and fittings. This is the unit pressure loss that may be expended in friction losses as the water travels through the sprinkler piping and sprinklers. It is determined by dividing the pressure available for the system by the system equivalent pipe length. (Refer to Table 1-4 for equivalent pipe lengths for fittings.)
7. Calculate the system head and pressure loss associated with the vertical distance traveled.

Equation 1-9

$$\text{Pressure} = (\text{Head} \times \text{Specific gravity}) / 2.31$$

$$\text{Head} = (\text{Pressure} \times 2.31) / \text{Specific gravity}$$

The specific gravity for water in this case is 1.00.

8. Calculate the total pressure loss associated with the system for the single most remote sprinkler. This is an estimating exercise. Full remote area design calculations should be developed when available pressure is a factor or when sizing a fire pump.

Equation 1-10

$$\text{Total pressure} = \text{Sprinkler pressure requirement} + \text{Average piping pressure loss} + \text{Head loss} + 10\%\ \text{safety factor}$$

USE OF SPRINKLERS

Automatic fire sprinklers operate at a predetermined temperature. These sprinklers utilize a fusible link, a portion of which melts, or a frangible glass bulb containing liquid that breaks, allowing the plug in the sprinkler orifice to be pushed out by the water pressure in the fire sprinkler piping, resulting in water flow. The water stream impacts a deflector, which produces a specific spray pattern designed in support of the goals of the sprinkler type. Most of today's sprinkler heads are designed to direct a spray downward (see Figure 1-17).

Table 1-3A Water Flow Tables
WATER FLOWING IN 1-INCH SCHEDULE 40 STEEL PIPE
I.D. = 1.049 inches

Q (gpm)	Pf (psi/ft)		Velocity (fps)
	C=100	C=120	
10	0.051	0.036	3.71
11	0.060	0.043	4.08
12	0.071	0.051	4.46
13	0.082	0.059	4.83
14	0.094	0.067	5.20
15	0.107	0.076	5.57
16	0.121	0.086	5.94
17	0.135	0.096	6.31
18	0.150	0.107	6.68
19	0.166	0.182	7.05
20	1.820	0.130	7.43
21	0.200	0.142	7.80
22	0.217	0.155	8.17
23	0.236	0.169	8.54
24	0.255	0.182	8.91
25	0.276	0.197	9.28
26	0.296	0.211	9.65
27	0.318	0.227	10.02
28	0.340	0.243	10.40
29	0.363	0.259	10.77
30	0.386	0.276	11.14
31	0.410	0.293	11.51
32	0.435	0.310	11.88
33	0.460	0.329	12.25
34	0.487	0.347	12.62
35	0.513	0.366	12.99
36	0.541	0.386	13.37
37	0.569	0.406	13.74
38	0.598	0.427	14.11
39	0.627	0.448	14.48
40	0.657	0.469	14.85
41	0.688	0.491	15.22
42	0.719	0.513	15.59
43	0.751	0.536	15.96
44	0.784	0.56	16.34
45	0.817	0.583	16.71
46	0.851	0.608	17.08
47	0.886	0.632	17.45
48	0.921	0.657	17.82
49	9.57	0.683	18.19
50	0.993	0.709	18.56
51	1.03	0.735	18.93
52	1.068	0.762	19.31
53	1.106	0.79	19.68
54	1.145	0.817	20.05

Table 1-3B Water Flow Tables

WATER FLOWING IN 1 1/4-INCH SCHEDULE 40 STEEL PIPE
I.D. = 1.049 inches

Q (gpm)	Pf (psi/ft) C=100	Pf (psi/ft) C=120	Velocity (fps)
10	0.013	0.009	2.14
11	0.016	0.011	2.36
12	0.019	0.013	2.57
13	0.022	0.015	2.79
14	0.025	0.018	3.00
15	0.028	0.020	3.21
16	0.032	0.023	3.43
17	0.036	0.025	3.64
18	0.039	0.028	3.86
19	0.044	0.031	4.07
20	0.048	0.034	4.29
21	0.052	0.037	4.50
22	0.057	0.041	4.71
23	0.062	0.044	4.93
24	0.067	0.048	5.14
25	0.072	0.052	5.36
26	0.078	0.056	5.57
27	0.084	0.060	5.79
28	0.089	0.064	6.00
29	0.095	0.068	6.21
30	0.102	0.072	6.43
31	0.108	0.077	6.64
32	0.114	0.082	6.86
33	0.121	0.086	7.07
34	0.128	0.091	7.29
35	1.135	0.096	7.50
36	0.142	0.102	7.71
37	0.150	0.107	7.93
38	0.157	0.112	8.14
39	0.165	0.118	8.36
40	0.173	0.123	8.57
41	0.181	0.129	8.79
42	0.189	0.135	9.00
43	0.198	0.141	9.21
44	0.206	0.147	9.43
45	0.022	0.153	9.64
46	0.224	0.160	9.86
47	0.233	0.166	10.07
48	0.242	0.173	10.29
49	0.252	0.180	10.50
50	0.261	0.186	10.71
51	0.271	0.193	10.93
52	0.281	0.200	11.14
53	0.291	0.208	11.36
54	0.301	0.215	11.57
55	0.312	0.222	12.00
56	0.322	0.230	12.21
57	0.333	0.238	12.43
58	0.344	0.245	12.64
59	0.355	0.253	12.86
60	0.366	0.261	13.07
61	0.377	2.690	13.07
62	0.389	0.278	13.29
63	0.401	0.286	13.50
64	0.412	0.294	13.71
65	0.424	0.303	13.93
66	0.437	0.312	14.14
67	0.449	0.320	14.36
68	0.461	0.329	14.57
69	0.474	0.338	14.79
70	0.487	0.347	15.00
71	0.500	0.357	15.21
72	0.513	0.366	15.43
73	0.526	0.375	15.64
74	0.540	0.385	15.86
75	0.553	0.395	16.07
76	0.567	0.405	16.29
77	0.581	0.414	16.50
78	0.595	0.424	16.71
79	0.609	0.435	16.93
80	0.623	0.445	17.14
81	0.638	0.455	17.36
82	0.652	0.466	17.57
83	0.667	0.476	17.79
84	0.682	0.487	18.00
85	0.697	0.498	18.21
86	0.712	0.508	18.43
87	0.728	0.519	18.64
88	0.743	0.531	18.86
89	0.759	0.542	19.07
90	0.775	0.553	19.29
91	0.791	0.565	19.50
92	0.807	0.576	19.71
93	0.823	0.588	19.93
94	0.840	0.599	20.14

Table 1-3C Water Flow Tables

WATER FLOWING IN 1 1/2-INCH SCHEDULE 40 STEEL PIPE
I.D. = 1.61 inches

Q (gpm)	Pf (psi/ft) C=100	Pf (psi/ft) C=120	Velocity (fps)
10	0.006	0.004	1.57
12	0.009	0.006	1.89
14	0.012	0.008	2.20
16	0.015	0.011	2.52
18	0.019	0.013	2.83
20	0.023	0.016	3.15
22	0.027	0.019	3.46
24	0.032	0.023	3.78
26	0.037	0.026	4.09
28	0.042	0.030	4.41
30	0.048	0.034	4.75
32	0.054	0.039	5.04
34	0.060	0.043	5.35
36	0.067	0.048	5.67
38	0.074	0.053	6.98
40	0.082	0.058	6.30
42	0.089	0.064	6.61
44	0.097	0.069	6.93
46	0.106	0.075	7.24
48	0.114	0.082	7.56
50	0.123	0.088	7.87
52	0.133	0.095	8.19
54	0.142	0.101	8.50
56	0.152	0.109	8.82
58	0.162	0.116	9.13
60	0.173	0.123	9.45
62	0.184	0.131	9.76
64	0.195	0.139	10.08
66	0.206	0.147	10.39
68	0.218	0.155	10.71
70	0.23	0.164	11.02
72	0.242	0.173	11.34
74	0.255	0.182	11.65
76	0.359	0.191	11.97
78	0.281	0.200	12.28
80	0.294	0.210	12.59
82	0.308	0.220	12.91
84	0.322	0.230	13.22
86	0.336	0.240	13.54
88	0.351	0.250	13.85
90	0.366	0.261	14.17
92	0.381	0.272	14.48
94	0.396	0.283	14.80
96	0.412	0.294	15.11
98	0.428	0.306	15.43
100	0.445	0.317	15.74
102	0.461	0.329	16.06
104	0.478	0.341	16.37
106	0.495	0.353	16.69
108	0.513	0.366	17.00
110	0.530	0.378	17.32
112	0.548	0.391	17.63
114	0.566	0.404	17.95
116	0.585	0.418	18.26
118	0.604	0.431	18.58
120	0.623	0.445	18.89
122	0.642	0.458	19.21
124	0.662	0.472	19.52
126	0.682	0.487	19.84
128	0.702	0.501	20.15

Table 1-3D Water Flow Tables

WATER FLOWING IN 2-INCH SCHEDULE 40 STEEL PIPE
I.D. = 2.067 inches

Q (gpm)	Pf (psi/ft) C=100	Pf (psi/ft) C=120	Velocity (fps)
30	0.014	0.010	2.87
35	0.019	0.010	3.35
40	0.024	0.017	3.82
45	0.030	0.021	4.30
50	0.037	0.026	4.78
55	0.044	0.031	5.26
60	0.051	0.037	5.74
63	0.056	0.040	6.02
66	0.061	0.044	6.31
69	0.066	0.047	6.60
72	0.072	0.051	6.88
75	0.077	0.055	7.17
78	0.083	0.059	7.46
81	0.089	0.064	7.75
84	0.095	0.068	8.03
87	0.102	0.073	8.32
90	0.108	0.077	8.61
93	0.115	0.082	8.89
96	0.122	0.087	9.18
99	0.129	0.092	9.47
102	0.137	0.097	9.78
105	0.144	0.103	10.04
108	0.152	0.108	10.33
111	0.160	0.144	10.61
114	0.168	0.120	10.90
117	0.176	0.126	11.19
120	0.184	0.132	11.47
123	0.193	0.138	11.76
126	0.202	0.144	12.05
129	0.211	0.150	12.33
132	0.220	0.157	12.62
135	0.229	0.164	12.91
138	0.239	0.170	13.20
141	0.249	0.177	13.48
144	0.258	0.184	13.77
147	0.269	0.192	14.06
150	0.279	0.199	14.34
152	0.288	0.206	14.60
154	0.295	0.211	14.80
156	0.304	0.217	15.00
158	0.311	0.222	15.20
160	0.318	0.227	15.30
162	0.325	0.232	15.50
164	0.333	0.238	15.70
166	0.340	0.243	15.90
168	0.349	0.249	16.10
170	0.355	0.254	16.30
172	0.364	0.260	16.50
174	0.371	0.265	16.70
176	0.378	0.270	16.90
178	0.386	0.276	17.00
180	0.395	0.282	17.20
185	0.416	0.297	17.70
190	0.437	0.312	18.20
195	0.458	0.327	18.70
200	0.480	0.343	19.10
205	0.502	0.359	19.60
210	0.526	0.376	20.10

Table 1-3E Water Flow Tables

WATER FLOWING IN 2 1/2-INCH SCHEDULE 40 STEEL PIPE
I.D. = 2.469 inches

Q (gpm)	Pf (psi/ft) C=100	Pf (psi/ft) C=120	Velocity (fps)
40	0.010	0.007	2.68
45	0.013	0.009	3.02
50	0.015	0.011	3.35
55	0.018	0.013	3.69
60	0.022	0.015	4.02
65	0.025	0.018	4.36
70	0.029	0.020	4.69
75	0.033	0.023	5.03
80	0.037	0.026	5.36
85	0.041	0.029	5.70
90	0.046	0.033	6.03
95	0.050	0.036	6.37
100	0.055	0.040	6.70
103	0.059	0.042	6.90
106	0.062	0.044	7.10
109	0.065	0.046	7.30
112	0.068	0.049	7.51
115	0.072	0.051	7.71
118	0.075	0.054	7.91
121	0.079	0.056	8.11
124	0.082	0.059	8.31
127	0.086	0.066	8.51
130	0.090	0.064	8.71
133	0.094	0.067	8.91
136	0.098	0.070	9.11
139	0.102	0.073	9.32
142	0.106	0.076	9.52
145	0.110	0.079	9.72
148	0.114	0.082	9.92
151	0.119	0.085	10.12
154	0.123	0.088	10.32
157	0.128	0.091	10.52
160	0.132	0.094	10.72
163	0.137	0.098	10.92
166	0.142	0.101	11.12
169	0.146	0.104	11.33
172	0.151	0.108	11.53
175	0.156	0.111	11.73
178	0.161	0.115	11.93
179	0.164	0.117	12.00
180	0.166	0.118	12.10
182	0.169	0.120	12.20
184	0.172	0.123	12.30
186	0.176	0.125	12.40
188	0.179	0.128	12.60
190	0.183	0.131	12.70
192	0.187	0.133	12.90
194	0.190	0.136	13.00
196	0.194	0.138	13.20
198	0.197	0.141	13.30
200	0.201	0.144	13.40
202	0.205	0.146	13.50
204	0.209	0.149	13.60
206	0.213	0.152	13.70
208	0.216	0.154	13.80
210	0.200	0.157	13.90
212	0.224	0.160	14.10
214	0.228	0.163	14.20
216	0.232	0.166	14.40
218	0.236	0.168	14.60
220	0.240	0.171	14.70
222	0.244	0.174	14.90
224	0.248	0.177	15.10
226	0.252	0.180	15.30
228	0.257	0.183	15.60
230	0.261	0.186	15.80
235	0.271	0.194	16.00
240	0.282	0.201	16.10
245	0.293	0.209	16.40
250	0.304	0.217	16.90
255	0.316	0.225	17.10
260	0.327	0.234	17.40
265	0.339	0.242	17.70
270	0.351	0.250	18.10
275	0.363	0.259	18.50
280	0.375	0.268	18.80
285	0.388	0.227	19.00
290	0.401	0.286	19.40
295	0.414	0.296	19.80
300	0.427	0.305	20.10

Table 1-3F Water Flow Tables

WATER FLOWING IN 3-INCH SCHEDULE 40 STEEL PIPE
I.D. = 3.068 inches

Q (gpm)	Pf (psi/ft)		Velocity (fps)
	C=100	C=120	
30	0.002	0.001	1.30
40	0.004	0.003	1.74
50	0.005	0.004	2.17
60	0.007	0.005	2.60
70	0.010	0.007	3.04
80	0.013	0.009	3.47
90	0.016	0.011	3.91
100	0.019	0.014	4.34
110	0.023	0.016	4.77
120	0.027	0.019	5.21
130	0.031	0.022	5.64
140	0.036	0.026	6.08
150	0.041	0.029	6.51
155	0.043	0.031	6.73
160	0.046	0.033	6.94
165	0.049	0.035	7.16
170	0.051	0.037	7.38
175	0.054	0.039	7.60
180	0.057	0.041	7.81
185	0.060	0.043	8.03
190	0.063	0.045	8.25
195	0.066	0.047	8.46
200	0.069	0.049	8.68
205	0.073	0.052	8.90
210	0.076	0.054	9.11
215	0.079	0.057	9.33
220	0.083	0.059	9.55
225	0.086	0.062	9.77
230	0.090	0.064	9.98
235	0.093	0.067	10.20
240	0.097	0.069	10.42
245	0.101	0.072	10.63
250	0.011	0.075	10.85
255	0.109	0.078	11.07
260	0.113	0.080	11.28
265	0.117	0.083	11.50
270	0.121	0.086	11.72
275	0.125	0.089	11.94
280	0.129	0.092	12.15
285	0.134	0.095	12.37
290	0.138	0.098	12.59
295	0.142	0.102	12.80
300	0.147	0.105	13.02
305	0.151	0.108	13.24
310	0.156	0.111	13.45
315	0.161	0.115	13.67
320	0.165	0.118	13.89
325	0.170	0.122	14.11
330	0.175	0.125	14.32
335	0.180	0.129	14.54
340	0.185	0.132	14.76
345	0.190	0.136	14.97
350	0.195	0.139	15.19
355	0.200	0.143	15.41
360	0.206	0.147	15.62
365	0.211	0.151	15.84
370	0.216	0.154	16.06
375	0.222	0.158	16.28
380	0.227	0.162	16.49
385	0.233	0.166	16.71
390	0.239	0.170	16.93
395	0.244	0.174	17.14
400	0.250	0.178	17.36
405	0.256	0.183	17.58
410	0.262	0.187	17.79
415	0.268	0.191	18.01
420	0.274	0.195	18.23
425	0.280	0.200	18.45
430	0.286	0.204	18.66
435	0.292	0.208	18.88
440	0.298	0.213	19.10
445	0.305	0.217	19.31
450	0.311	0.222	19.53
455	0.317	0.226	19.75
460	0.324	0.231	19.96
465	0.330	0.236	20.18

Table 1-3G Water Flow Tables

WATER FLOWING IN 4-INCH SCHEDULE 40 STEEL PIPE
I.D. = 4.026 inches

Q (gpm)	Pf (psi/ft)		Velocity (fps)
	C=100	C=120	
100	0.005	0.004	2.52
125	0.008	0.006	3.15
150	0.011	0.008	3.78
175	0.014	0.010	4.41
200	0.018	0.013	5.04
225	0.023	0.016	5.67
250	0.028	0.020	6.30
275	0.033	0.024	6.93
300	0.039	0.028	7.56
325	0.045	0.032	8.19
350	0.052	0.037	8.82
375	0.059	0.042	9.45
400	0.067	0.048	10.08
425	0.074	0.053	10.71
450	0.083	0.059	11.34
475	0.091	0.065	11.97
500	0.101	0.072	12.60
510	0.104	0.074	12.85
520	0.108	0.077	13.11
530	0.112	0.080	13.36
540	0.116	0.083	13.61
550	0.120	0.086	13.86
560	0.124	0.089	14.11
570	0.128	0.091	14.37
580	0.132	0.094	14.62
590	0.137	0.097	14.87
600	0.141	0.101	15.12
610	0.145	0.104	15.37
620	0.150	0.107	15.63
630	0.154	0.110	15.88
640	0.159	0.113	16.13
650	0.163	0.117	16.38
660	0.168	0.120	16.63
670	0.173	0.123	16.89
680	0.178	0.127	17.14
690	0.183	0.130	17.39
700	0.187	0.134	17.64
710	0.192	0.137	17.89
720	0.197	0.141	18.15
730	0.203	0.145	18.40
740	0.208	0.148	18.65
750	0.213	0.152	18.90
760	0.218	0.156	19.16
770	0.224	0.160	19.41
780	0.229	0.163	19.60
790	0.234	0.167	19.91

Table 1-4 Equivalent Pipe Lengths for Fittings

Fittings and Valves	Fittings and Valves Expressed in Equivalent Feet of Pipe									
	0.5	0.75	1	1.25	1.5	2	2.5	3	3.5	4
45° elbow	x	1	1	1	2	2	3	3	3	4
90° standard elbow	1	2	2	3	4	5	6	7	8	10
90° long-turn elbow	0.5	1	2	2	2	3	4	5	5	6
Tee or cross (flow turned 90°)	3	4	5	6	8	10	12	15	17	20
Butterfly valve	x	x	x	x	x	6	7	10	x	12
Gate valve	x	x	x	x	x	1	1	1	1	2
Swing check*	x	x	5	7	9	11	14	16	19	22

*Due to the variation in design of swing check valves, the pipe equivalents indicated in this table are considered average.

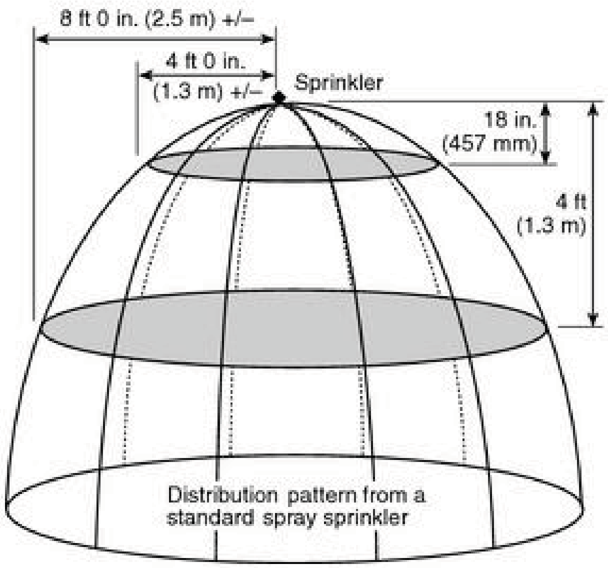


Figure 1-17 Example Sprinkler Flow Pattern

Source: NFPA 13

Many automatic fire sprinklers utilizing glass bulbs follow a standardized color-coding convention indicating their operating temperature, as shown in Table 1-5. Activation temperatures correspond to the type of hazard against which the sprinkler system protects. For example, residential occupancies are provided with a special type of fast-response sprinkler with the unique goal of life safety.

The selection of sprinklers will vary by occupancy. The types of sprinklers that may be used are standard spray upright and pendent, sidewall spray, concealed, extended coverage, open, residential, early suppression fast-response, large drop, quick response, and special application sprinklers. Sprinkler spacing is based on the rating and listing of the sprinkler in addition to the requirements set forth in NFPA 13.

Residential Sprinklers

Residential sprinklers, listed by Underwriters Laboratories (UL), are now available. They are designed to respond to a fire much faster than currently available standard commercial and industrial sprinkler systems. Typical residential sprinkler systems are installed in accordance with NFPA 13D: *Standard for the Installation of Sprinkler Systems in One- and Two-Family Dwellings and Manufactured Homes* and NFPA 13R: *Standard for the Installation of Sprinkler Systems in Residential Occupancies Up to and Including Four Stories in Height*. Residential fire sprinkler systems provide coverage throughout the entire home, excluding small bathrooms (less than 55 square feet), small closets (less than 24 square feet), attics, and garages.

Table 1-5 Maximum Sprinkler Temperature Rating and Temperature Classification Color Code (with glass bulb fusible link)

Maximum Ceiling Temperature	Temperature Rating	Temperature Classification	Color Code (with Fusible Link)	Glass Bulb Color
100°F	135-170°F	Ordinary	Uncolored or Black	Orange (135°) or Red (155°)
150°F	175-225°F	Intermediate	White	Yellow (175°) or Green (200°)
225°F	250-300°F	High	Blue	Blue
300°F	325-375°F	Extra High	Red	Purple
375°F	400-475°F	Very Extra High	Green	Black
475°F	500-575°F	Ultra High	Orange	Black
625°F	650°F	Ultra High	Orange	Black

Source: NFPA 13

PIPE HANGERS

Sprinkler systems can be made up of many different types of piping. NFPA 13 requires pipe used in sprinkler systems to have chemical properties, physical properties, and dimensions of material at least equivalent to the standards shown in Table 1-6. The pressure limitations of these piping systems and their components must be understood when specifying pipe materials.

Each sprinkler system shall be supported and installed in accordance with the requirements of NFPA 13 (see Figure 1-18). Pipe hangers shall be UL-listed. Hangers shall be arranged to maintain the required pitch for free expansion and contraction. Sprinkler piping or hangers shall not be used to support non-system components. Each vertical line shall be supported at its base using a hanger placed in the horizontal line near the riser. Hangers shall meet seismic requirements in areas prone to seismic movement.

STANDPIPE SYSTEMS

The purpose of installing a standpipe system is to provide a readily accessible water supply for use by fire department personnel and/or trained occupants during fire situations. A standpipe is a type of rigid water pipe to which firehoses can be connected that is built into multistory buildings in a vertical position. Standpipe systems can be classified into three system types as defined by NFPA 14: *Standard for the Installation of Standpipe and Hose Systems*.

- Class I system: A system that provides 2½-inch hose connections to supply water for use by fire

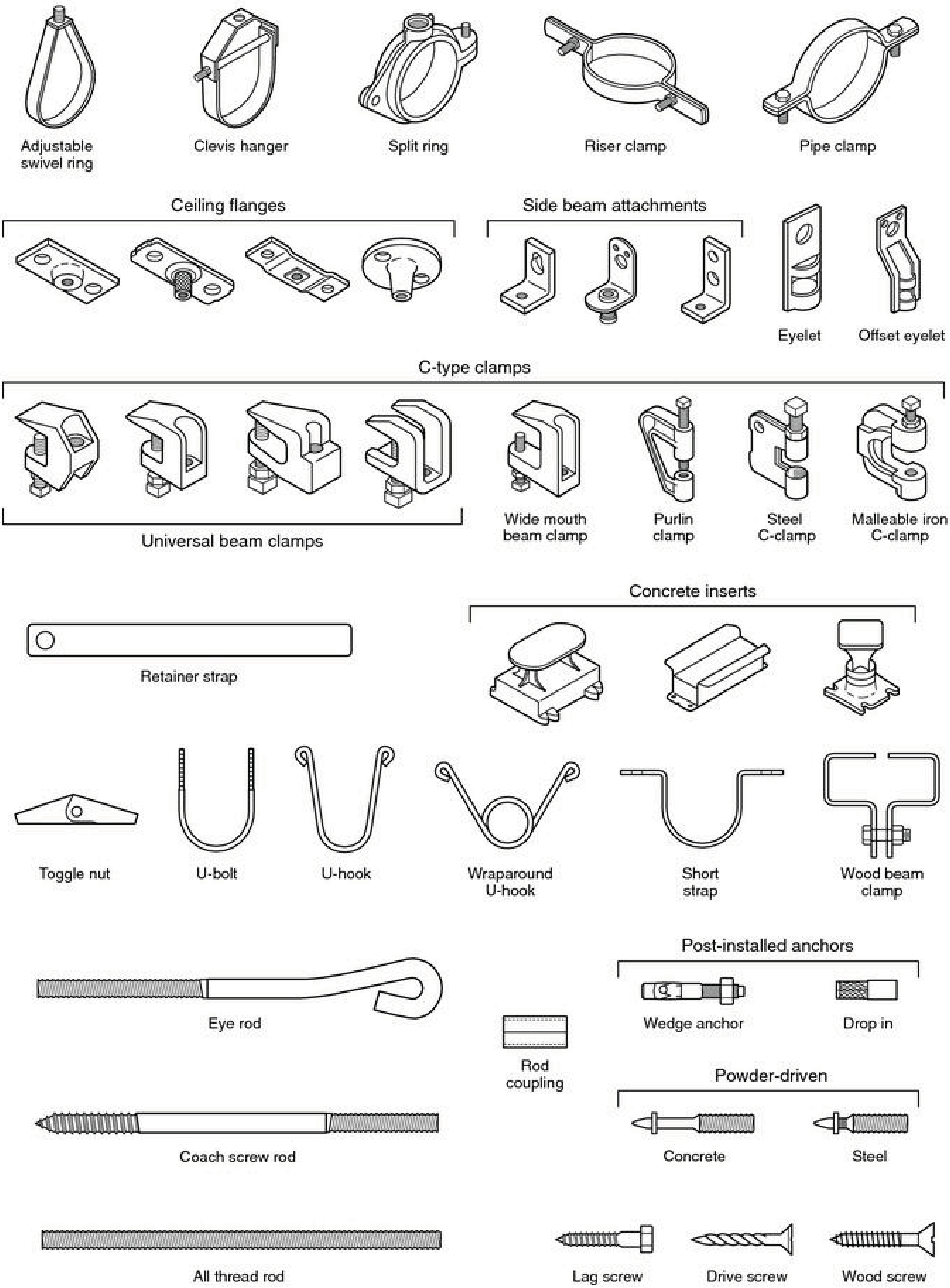


Figure 1-18 Common Types of Acceptable Hangers

Source: NFPA 13

Table 1-6 Approved Pipe Materials

Materials and Dimensions	Standard
Ferrous Piping (Welded and Seamless) Specification for black and hot-dipped zinc-coated (galvanized) welded and seamless steel pipe for fire protection use	ASTM A 795
Specification for welded and seamless steel pipe	ANSI/ASTM A 53
Wrought steel pipe	ANSI/ASME B36.10M
Specification for electric-resistance-welded steel pipe	ASTM A 135
Copper Tube (Drawn, Seamless)	
Specification for seamless copper tube	ASTM B 75
Specification for seamless copper water tube	ASTM B 88
Specification for general requirements for wrought seamless copper and copper-alloy tube	ASTM B 251
Fluxes for soldering applications of copper and copper-alloy tube	ASTM B 813
Brazing filler metal (classification BCuP-3 or BCuP-4)	AWS A5.8
Solder metal, Section 1: Solder alloys containing less than 0.2% lead and having solidus temperatures greater than 400°F	ASTM B 32
Alloy materials	ASTM B 446
Plastic Pipe	
Nonmetallic piping specification for special listed chlorinated polyvinyl chloride (CPVC) pipe	ASTM F442

Source: NFPA 13

departments and those trained in handling heavy fire streams

- Class II system: A system that provides 1½-inch hose connections to supply water for use by trained building personnel or fire departments during initial response
- Class III system: A system that provides 1½-inch hose connections to supply water for use by trained personnel and 2½-inch hose connections to supply a larger volume of water for use by fire departments and those trained in handling heavy fire streams

Standpipes may be either wet type or dry type, depending on the application. The subtypes of each are as follows:

- An automatic wet standpipe contains water at all times, is attached to a water supply capable of providing the system demand (flow and pressure), and requires no action other than opening a hose valve to provide water at hose connections.
- A manual wet standpipe contains water at all times but relies exclusively on the fire department connection to supply the system demand.
- An automatic dry standpipe contains air or nitrogen at pressure but is attached to a water supply capable of providing the system demand. The water supply is held at a dry pipe valve until a hose valve is opened, releasing the air or nitrogen and allowing water to flow into the standpipe system.
- A semiautomatic dry standpipe is an empty, non-pressurized system attached to a water supply capable of providing the system demand. The water supply is held at a deluge valve and requires activation of a remote control device to provide water flow into the standpipe system.
- A manual dry standpipe has no attached water supply and relies exclusively on the fire department connection to supply the system demand.

Locating and Determining the Number of Standpipe Risers

Our model building codes establish whether or not a building is required to be provided with a standpipe system. Typically, standpipes are required in a building where the floor level of the highest story is located more than 30 feet above the lowest level of fire department vehicle access or where the floor level of the lowest story is located more than 30 feet below the highest level of fire department vehicle access. Separate standpipes shall be provided in each required exit stairway where required by code. Additional hose connections may be required where travel distances exceed the code-mandated limits or where identified by the local fire department or authority having jurisdiction. Most building codes and NFPA require the risers and 2½-inch hose valves for Class I and III standpipe systems to be located inside fire-rated stairs or smoke-proof

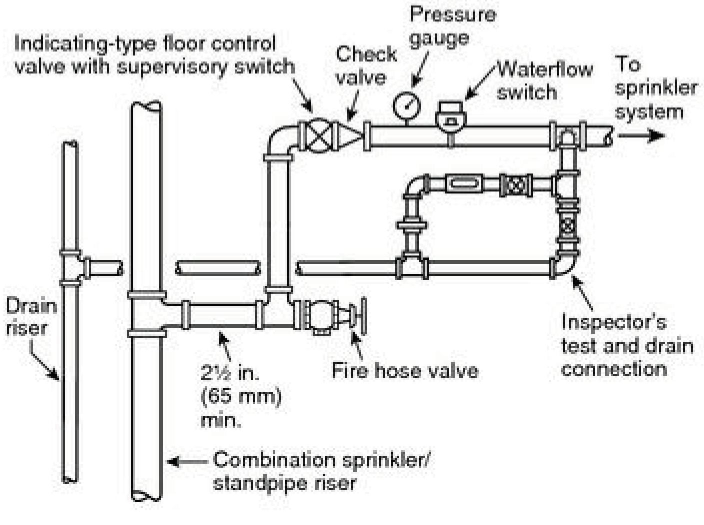


Figure 1-19 Acceptable Piping Arrangement for Combined Sprinkler/ Standpipe Systems

Source: NFPA 14

towers to allow the fire department the opportunity to make its connection to the riser inside a protected area prior to entering the floor under the fire condition.

Standpipe System Design

The design of standpipe risers and branch mains, if applicable to the installation, varies according to the system configuration, local and state building code requirements, the building hazard, and the size of the building. Typically, Class I and Class III standpipes shall be at least 4 inches in size. Standpipes that are part of a combined system (a system that supplies water to both fire department personnel and the building sprinkler system) shall be at least 6 inches in size (see Figure 1-19). (Exception: Where the building is protected throughout by an approved automatic sprinkler system, the minimum standpipe size may be 4 inches for hydraulically calculated systems.) Since several factors are involved in the standpipe system, it is recommended to check with the local and state codes as well as the NFPA standards to ensure that the system will meet local requirements.

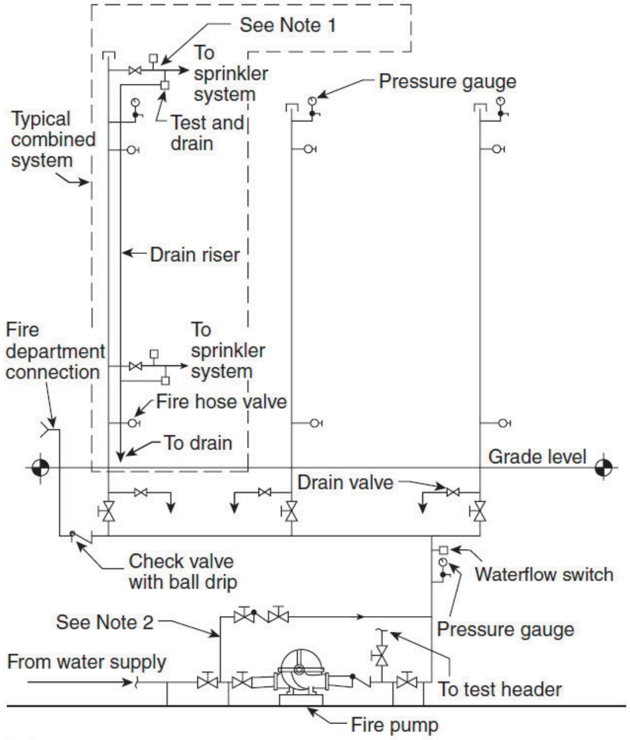
The standpipe design flow and pressure requirements from NFPA 14 are as follows:

- For Class I and Class III systems, the minimum flow rate for the hydraulically most remote standpipe shall be 500 gpm. Where a horizontal standpipe on a Class I and Class III system supplies three or more hose connections on any floor, the minimum flow rate shall be 750 gpm. The minimum flow rate for additional standpipes shall be 250 gpm per standpipe, with the total not exceeding 1,250 gpm or 1,000 gpm for buildings sprinklered throughout.
- Hydraulically designed standpipe systems shall be designed to provide the water flow rate (see above) at a minimum residual pressure of 100 psi at the outlet of the hydraulically most remote 2½-inch hose connection and 65 psi at the outlet of the hydraulically most remote 1½-inch hose station.

If the water supply to the standpipes cannot provide the required volume and pressure, the system must be upgraded to ensure an adequate supply or a fire pump must be added to the system (see Figure 1-20).

FIRE PUMP SYSTEMS

A fire pump usually is connected to the municipal or fire protection water supply at the intake and to the building's sprinkler system risers at the discharge (see Figure 1-21). Fire pumps are listed specifically for fire service by a listing agency such as UL or FM Global. The main standard that governs fire pump installations is NFPA 20: *Standard for the Installation of Stationary Fire Pumps for Fire Protection*.



Notes:
1. Sprinkler floor assembly in accordance with NFPA 13, *Standard for the Installation of Sprinkler Systems.*
2. Bypass in accordance with NFPA 20, *Standard for the Installation of Stationary Pumps for Fire Protection.*

Figure 1-20 Schematic Diagram of Fire Pump with Bypass
Source: NFPA 20

The fire pump becomes active when the pressure in the fire sprinkler system drops below a set threshold. This threshold is typically the performance value of the jockey pump. Once operating, the fire pump provides additional water pressure to the sprinkler system.

The types of pumps used for fire service include horizontal split case, vertical split case, vertical inline, vertical turbine, and end suction.

Labeled fire pumps are made in specific sizes ranging from 25 gpm to 5,000 gpm. Pressure selections may range from 40 to 475 psi for fire pumps.

Per NFPA 20, the fire pump must meet the following requirements:

- The net pump shutoff (churn) plus the maximum static suction pressure shall not exceed the pressure for which the system components are rated.
- At 150 percent of the rated capacity, it shall develop at least 65 percent of its rated head and shall not exceed 140 percent of the rated head at zero capacity.
- Suction size and test components shall be per Table 1-7.
- The maximum pump brake horsepower must not exceed the rating of the particular driver.

Table 1-7 Partial Summary of Centrifugal Fire Pump Data

Minimum Pipe Sizes (nominal)								
Pump Rating (gpm)	Suction (inches)	Discharge (inches)	Relief Valve (inches)	Relief Valve Discharge (inches)	Meter Device (inches)	Number of Hose Valves (inches)	Size of Hose Valves (inches)	Hose Header Suppy (inches)
250	3½	3	2	2½	3½	1	2½	3
300	4	4	2½	3½	3½	1	2½	3
400	4	4	3	5	4	2	2½	4
450	5	5	3	5	4	2	2½	4
500	5	5	3	5	5	2	2½	4
750	6	6	4	6	5	3	2½	6
1000	8	6	4	8	6	4	2½	6
1250	8	8	6	8	6	6	2½	8
1500	8	8	6	8	8	6	2½	8
2000	10	10	6	10	8	6	2½	8

Source: NFPA 20

- Each fire pump must have listed pressure gauges and be fitted with a suitable air-relief valve. With certain exceptions, a ¾-inch casing relief valve is required to prevent overheating of the pump when it operates against a closed valve. Where the pump pressure may exceed the safe working pressure of the system, and always when a diesel driver or variable-speed driver is used, a listed main relief valve must be furnished.

Fire Pump Drivers

Fire pumps are driven by either electric motors or diesel engines.

If the fire pump is electric, power must be uninterruptible with properly protected power cabling and emergency power. Alarms should sound if normal power is interrupted (i.e., loss of phase or phase reversal). All fire pump motor drivers are required to be rated for continuous duty and must not be used at voltages in excess of 110 percent of the rated voltage. At rated voltage and frequency, the full load ampere rating must not be exceeded under any pumping conditions.

If the fire pump is diesel, provisions must be made for a day tank for fuel storage, engine cooling, exhaust pipe discharge location, and sufficient airflow for cooling, combustion, and ventilation.

The performance requirements and accessories for pumps, whether motor or engine driven, are basically the same. The related components of the specific drivers, however, vary in installation, operation, and maintenance.

The motor-control equipment must be factory assembled, wired, and tested, as well as specifically approved for fire service.

Jockey Pump

A jockey pump is normally required in all pressurized systems. This automatic electric pump has a capacity of 5 to 10 gpm or less. The intent is to maintain pressure when it is lost due to minor leaks, not to keep up with sprinkler discharge. Its controller is set to start at about 5 psi above the start signal for the fire pump and to stop at full pressure.

Equation 1-11: Fire Pump Estimate Sizing

$$\begin{array}{c}\text{Brake horsepower}\\ \text{(BHP)}\end{array} = \frac{\text{Head} \times \text{gpm} \times \text{Specific gravity}}{3{,}960 \times \text{Efficiency}}$$

$$\begin{array}{c}\text{Brake horsepower}\\ \text{(BHP)}\end{array} = \frac{(\text{psi} \times 2.13) \times \text{Specific gravity}}{3{,}960 \times \text{Efficiency}}$$

Example 1-6

Calculate the brake horsepower given the following conditions:

- Standpipes = 3
- Fully sprinklered = Yes
- Flow demand = 1,000 gpm
- Building height = 50 feet
- Efficiency = 65%
- Specific gravity = 1.0

BHP = (50 × 1,000 × 1.0) / (3,960 × 0.65)
BHP = (50,000) / (2,574)
BHP = 19.42

Additional losses to consider are internal pipe loss, pump loss, backflow prevention equipment, and safety factors.

SPECIAL EXTINGUISHING SYSTEMS

Special extinguishing systems focus on the specific elements of a fire: oxygen, heat, and fuel. All three elements must be present at the same time for fire to occur.

Oxygen, heat, and fuel are frequently referred to as the "fire triangle" (see Figure 1-22). Take any of these three things away, and fire will not occur or

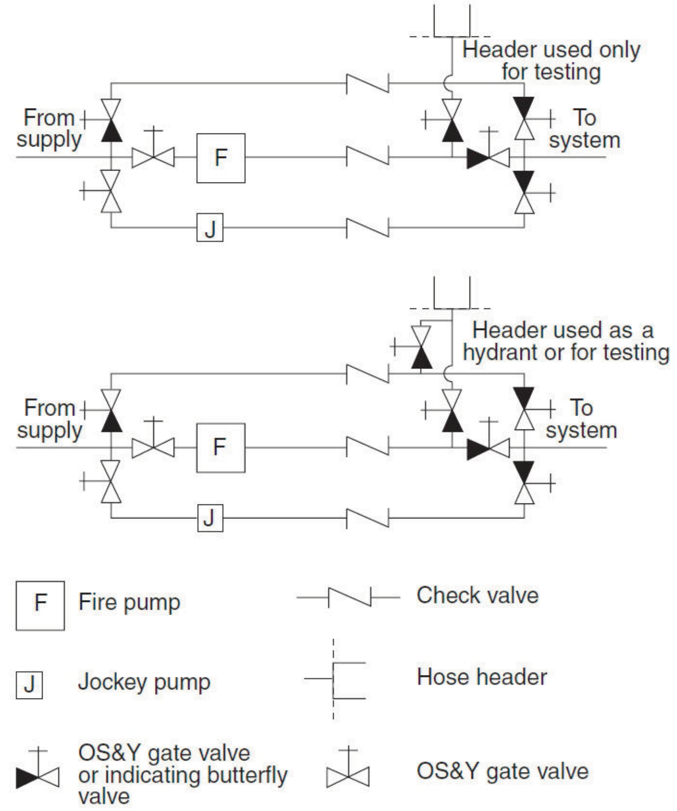


Figure 1-21 Fire Pump System

will be extinguished. Fire suppression systems put out fires by taking away one or more elements of the fire triangle.

Without sufficient heat, a fire cannot begin, and it cannot continue. Heat can be removed by the application of a substance that reduces the amount of heat available to the fire reaction. This is often water. Introducing sufficient quantities and types of powder or gas in the flame reduces the amount of heat available for the fire reaction in the same manner.

Without fuel, a fire will stop. Fuel can be removed naturally, as where the fire has consumed all of the burnable fuel, or manually, by mechanically or chemically removing the fuel from the fire.

Without sufficient oxygen, a fire cannot begin, and it cannot continue. With a decreased oxygen concentration, the combustion process slows.

(Note: The fire tetrahedron adds another requirement: the presence of a chemical reaction. If the chemical reaction is inhibited, the fire will extinguish.)

Dry Chemical Extinguishing Systems

Dry chemical systems utilize dry powder mixtures as the fire extinguishing agent. They are intended for application by means of portable extinguishers, hand hose-line systems, or fixed systems. The five basic varieties of dry chemical extinguishing agents currently are borax and sodium bicarbonate, sodium bicarbonate, urea potassium bicarbonate, monoammonium phosphate base, and potassium bicarbonate. When introduced directly into the fire area, dry chemicals cause almost immediate extinguishment. The major effect of dry chemicals is that they break the chain reaction of combustion. The minimum requirements for the design, installation, maintenance, and testing of dry chemical extinguishing systems can be found in NFPA 17: *Standard for Dry Chemical Extinguishing Systems*.

Dry chemical extinguishing systems originally were used to extinguish Class B fires. They consisted of a sodium bicarbonate base with additives to prevent caking and to improve the fluid flow characteristics. Later, multipurpose dry chemicals, effective on Class A, B, and C fires, were developed. When dry chemical systems are specified for use in a Class A fire area, they may not produce a lasting effect on the fire area. Twin-agent units using dry chemicals for early flame knockdown, followed by a foam application to prevent re-flash, are becoming a more common means of fire suppression.

Dry chemicals are most effective and most often used on surface fires, especially on flammable liquids. They can be discharged by handheld extinguishers, wheeled portable equipment, nozzles on fixed piping, or hose lines in local applications where the hazard is not enclosed or where the enclosure does not form an effective fire boundary. Chemical application may be tank side, overhead, or a combination of both.

Dry chemical systems also may be total flooding. The total flooding system consists of a predetermined supply of dry chemical permanently connected to a fixed discharge piping system, with fixed nozzles discharging into an enclosed space or an enclosure around a hazard. Upon actuation of the system by a heat detector, nitrogen is discharged into the storage container, and dry chemical is expelled

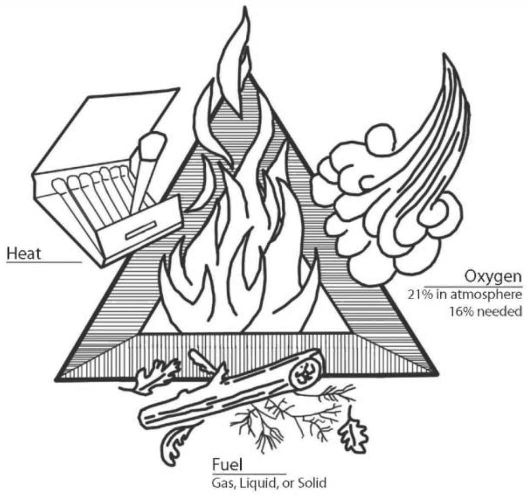


Figure 1-22 The Fire Triangle

through the system nozzles. The system may be either of the following:

- Engineered: These systems are based on known factors of chemical flow, pressure, friction losses, and pressure drops. Detection and activation are by automatic operation using electric, electronic, or mechanical detection and discharge. Many authorities require a full discharge test after installation for verification of the effectiveness of such a system or require a room air pressure test.
- Pre-engineered: These systems have been fire tested for a listing with a recognized laboratory. The manufacturer's instructions are specific regarding installation, pipe size, nozzle pressures, and types and quantities of chemicals to be used. Most pre-engineered systems are designed for automatic operation, using electric, electronic, or mechanical detection and discharge. A manual pull station is required to be installed at an exit.

Hand hose-line systems consist of a hose and nozzle connected to a dry chemical supply by direct connection to the storage container or by fixed piping. One or more hose reels can be supplied by the same chemical supply.

Dry Powder Extinguishing Systems

Dry powder extinguishing agents are different from dry chemical extinguishing agents and are effectively used to put out Class D fires, which are metal fires. Certain metals, such as sodium, titanium, magnesium, potassium, uranium, lithium, plutonium, and calcium, are flammable. Magnesium and titanium fires are common. When one of these combustible metals ignites, it can easily and rapidly spread to surrounding Class A materials.

To be effective on any type of Class D fire, the extinguishing agent must suppress the fire without reacting physically or chemically with the combustible materials. Water and other common firefighting materials can excite metal fires and make them worse. Thus, NFPA recommends that Class D fires be fought with dry powder extinguishing agents, which work by smothering and heat absorption. The two more familiar dry powder extinguishing agents for controlling combustible metal fires are graphite and sodium chloride (salt). Dry powder systems should not be confused with dry chemical systems, which normally are associated with extinguishing agents suitable for use on flammable liquid fires. Some dry chemical agents may create an explosive reaction when applied to combustible metal fires.

Several proprietary dry powders are currently available; however, none should be used without first consulting the manufacturer. The applicable NFPA standard for combustible metals is NFPA 484: *Standard for Combustible Metals*.

Wet Chemical Extinguishing Systems

Wet chemical fire-extinguishing agents consist of organic or inorganic salts mixed with water to form an alkaline solution that is typically discharged though a piping and nozzle system when activated. The minimum requirements for the design, installation, maintenance, and testing of wet chemical extinguishing systems can be found in NFPA 17A: *Standard for Wet Chemical Extinguishing Systems*.

Wet chemical agents are listed for suppression of fires in commercial cooking equipment (Class K), such as deep-fat fryers, griddles, range tops, and broilers. These agents are considered to be nontoxic and noncarcinogenic.

When wet chemical extinguishing agents are sprayed on a grease fire, they interact immediately with the grease, forming a blanket of foam over the surface on which they are sprayed. This creates a smothering and cooling effect on the fire.

Wet chemical systems typically are pre-engineered systems, defined by predetermined flow rates, nozzle pressures, and quantities of agent required. Wet chemicals are usually stored in cylinders adjacent to the hazard and are activated by either manual or automatic means. Automatic actuation is provided by either a fusible link or heat detector operation. Manual actuation occurs by the use of a pull station. Actuation of the system opens the seal on the gas cylinder, and the gas flows to the agent cylinder and expels the liquid through the distribution piping and nozzles. Once the system is actuated, all sources of fuel and power to the equipment that produces heat are required to be shut down.

Water Spray Fixed Systems

Water spray systems are operationally identical to a deluge system, but the piping and discharge nozzle spray patterns are designed to protect a uniquely configured hazard, usually being three-dimensional components or equipment. Fixed water spray systems are most commonly used to protect equipment from exposure fires such as flammable liquid and gas tanks, piping and equipment, and electrical equipment such as oil-filled transformers. The nozzles used may not be listed fire sprinklers and are usually selected for a specific spray pattern to conform to the three-dimensional nature of the hazard. The minimum requirements for the design, installation, maintenance, and testing of these systems can be found in NFPA 15: *Standard for Water Spray Fixed Systems for Fire Protection*.

Water Mist Systems

Water mist systems utilize water as the extinguishing, suppression, or control medium, but they do so in a nontraditional manner. Water mist systems were introduced in the 1940s and were utilized for maritime applications such as on passenger ferries. The systems were designed to discharge less water using small-diameter piping, thus having less overall weight than a standard sprinkler system. The minimum requirements for the design, installation, maintenance, and testing of these systems can be found in NFPA 750: *Standard on Water Mist Fire Protection Systems*.

When a fire condition is detected in the protected hazard area via a heat or smoke detector, the system control panel sends a signal to the releasing module to operate the water mist suppression system. Small water mist systems contain nitrogen cylinders and a water cylinder, and large systems use pressure pumps. The nitrogen storage cylinder provides pressure to drive the water to the system nozzles. When the system is operated, valves on the nitrogen tanks open, and the resulting air pressure drives the water through the opened water valve and to the system nozzles. The specifically designed nozzles create specific water droplet characteristics for the applied hazard, and the resulting water mist contains a variety of droplet sizes. The larger droplets produced by the nozzle provide the necessary energy and momentum to carry the smaller droplets to the base of the fire where the mist vaporizes and extinguishes the fire. The simple theory behind this development is that a large amount of small droplets has a greater surface area than the same volume of large droplets, therefore absorbing more heat.

Water mist systems extinguish fires using the following basic principles:

- Cooling: As the mist is converted into vapor, it removes heat from the fire source.
- Inerting: As the water mist turns to steam, it expands approximately 1,700 times, forcing oxygen away from the flame front, thus denying the fire the oxygen necessary to support combustion.
- Wetting: Primarily for incidental Class A fires, wetting of the surface helps extinguish the fire as well as contain it.

Foam Extinguishing Systems

A foam-water fire sprinkler system is a special application system discharging a mixture of water and foam concentrate, resulting in a foam spray from the sprinkler. These systems are usually used with special hazard occupancies associated with high-challenge fires, such as airport hangars and flammable liquids.

Foam, mostly a mass of air- or gas-filled bubbles formed by chemical or mechanical means, is most useful in controlling fires involving flammable liquids with a low flash point and specific gravity that are lighter than water. The mass of bubbles forms a cohesive blanket that extinguishes the fire by excluding air and cooling the surface and by separating the fuel from the fire.

Foam is not suitable for use on fires involving compressed gases or on live electrical equipment. Because of the water content, 94 to 97 percent, foam cannot be used on fires involving burning metals and is not effective on oxygen-containing materials. For fires involving water-soluble liquids, such as polar solvents, a special alcohol-resistant aqueous film-forming foam concentrate must be used. Foam can be applied to the fire surface or to the subsurface, such as in petrochemical tanks. Polar solvents must be surface applied. Systems can be fixed or semi-fixed.

Foams are defined by their expansion ratio:

- Low-expansion foam: Expansion up to 20:1
- Medium-expansion foam: Expansion from 20 to 200:1
- High-expansion foam: Expansion from 200 to 1,000:1

The minimum requirements for the design, installation, maintenance, and testing of foam extinguishing systems can be found in NFPA 11: *Standard for Low-, Medium-, and High-Expansion Foam* and NFPA 16: *Standard for the Installation of Foam-Water Sprinkler and Foam-Water Spray Systems*.

Mechanical Foam

A number of foam concentrates are available, some of which are designed for specific applications. Mechanical foam is made by the mechanical mixing of water and the synthetic foam concentrates. Examples include aqueous film-forming foam (AFFF), fluoroprotein foaming (FP), film-forming fluoroprotein (FFFP), protein foaming (P), low-temperature foam, alcohol-resistant foam (AR), and high-expansion foam.

Protein and fluoroprotein foams are the most cost-effective and have excellent burn-back resistance, but they do not knock down the fire as quickly as AFFF, which drains quickly but is not as heat resistant or as stable. Alcohol-resistant foams are somewhere between the two, but cost twice as much as protein foams.

High-expansion foam can be generated in volumes that are 1,000 times that of the water used. The foam is formed by the passage of air through a screen constantly wetted by a solution of chemical concentrate, which usually has a detergent base. The foam can be conducted by ducts, either fixed or portable, and can be manually applied by portable generators. High-expansion foam is useful for extinguishing fires by totally flooding indoor confined spaces, such as mine tunnels, or by local application. It extinguishes by displacing air from the fire and by the heat-absorbing effect of converting the foam water into steam. The foam forms an insulating barrier for exposed equipment or building components. However, high-expansion foam is generally not reliable when used outdoors, where it is subject to wind currents, and although it is nontoxic, it can have a disorienting effect on people.

Mechanical foam can be conducted through pipelines and discharged through a fixed chamber mounted in a bulk-fuel storage tank, or it can be conducted through hoses and discharged manually through special nozzles. This foam can also be distributed through a specially designed sprinkler system.

The type of discharge device (nozzle) that should be used with a specific type of foam is based on the listing from the manufacturer. Foam can be supplied from a diaphragm (bladder) tank using water pressure to make and distribute foam or from an inline pressure-proportioning system that utilizes an atmospheric tank with a supply-pressure pump.

Foam disposal after discharge can cause problems. Although most foams are biodegradable, because their biological oxygen demand (BOD) is high, they cannot be directly discharged to the sewer or storm water system. A holding tank with a treatment system may be required.

Carbon Dioxide Extinguishing Systems

Carbon dioxide is an effective fire extinguishing agent that can be used on many types of fires, such as surface fires, flammable liquids, and most solid combustible materials. For fire suppression, the discharge is designed to raise the carbon dioxide concentration in the hazard area. This displaces the air containing oxygen, which results in fire extinguishment. (It should be noted that because of the displacement of oxygen, a carbon dioxide system will fail to support life; thus, care should be exercised in its application.) In addition, carbon dioxide cools fire areas. Typical applications for a high-pressure carbon dioxide system include spray booths, commercial fryers, dip tanks, dust collectors and bag houses, electrical cabinets, printing presses, and storage vaults. The minimum requirements for the design, installation, maintenance, and testing of these systems can be found in NFPA 12: *Standard on Carbon Dioxide Extinguishing Systems*.

Carbon dioxide is an odorless, colorless gas at ordinary temperatures. Carbon dioxide as used for fire protection systems is available in high-pressure or low-pressure equipment. High-pressure systems (850 psi at 70°F) use gas compressed in standard cylinders. Low-pressure systems use carbon dioxide stored at 300 psi at 0°F in refrigerated, insulated tanks. Low-pressure systems are capable of multiple discharges since the duration of discharge is limited, and several hazards may be simultaneously protected through the use of multidirectional valves.

Under normal conditions, the gas is compressed into a liquid. When a carbon dioxide system is discharged, the pressure in the storage container acts as the propellant, forcing the stored liquid through pipelines to discharge nozzles. Each pound of carbon dioxide will expand to approximately 8 cubic feet of vapor at atmospheric pressure. Most of the liquid expands to a gas, but a portion forms particles of dry ice. This "snow" increases the mass of the discharge, allowing it to be projected for some distance. It absorbs heat and reduces temperature.

A minimum concentration of 34 percent by volume will handle most common materials; others may require an inerting atmosphere up to 100 percent. Some burning materials, such as stacked paper, furs, electrical insulation, and baled cotton, contain so much oxygen in pores or other internal spaces that they must be "soaked" in a smothering atmosphere for periods ranging from several minutes to several hours.

Carbon dioxide may be applied by either total flooding or local application. Total flooding is used where the hazard is contained in a room, compartment, or other enclosure that will allow the carbon dioxide atmosphere to remain in contact with the burning materials for a sufficient period to extinguish the fire and prevent its reigniting.

Local application is used where a hazard cannot be readily enclosed. The rate and duration of discharge, length of piping, and usable capacity of storage containers are critical factors, as the discharge of carbon dioxide is soon dissipated and has no continuing effect. System design for this type of application is considerably more complex than it is for flooding an enclosure. The types of nozzles to be used and their locations and discharge rates must be determined within accurate limits. Local application is commonly used for the largest and most valuable industrial processes, such as for oil quench tanks, flow-coating paint machines, steel and aluminum mills, printing presses, and power-generating equipment.

Clean Agent Fire Suppression Systems

For many years, halogenated agent (Halon 1211 and Halon 1301) fire suppression systems were utilized to protect high-value equipment, materials, and buildings. Halon 1301 was a particularly good extinguishing agent, as it interfered with the chain reaction of fire, left no residue, and was nontoxic. Halons contain compounds that consist of chlorine, bromine, fluorine, and carbon, which are commonly known as chlorofluorocarbons (CFCs). CFCs are extremely stable compounds that do not break down chemically until reaching the Earth's upper atmosphere. In September 1987, 24 nations of the United Nations signed an agreement to phase out production of refrigerants and halons that are detrimental to the Earth's ozone layer. This agreement is commonly referred to as the Montreal Protocol. Both Halon 1211 and Halon 1301 were phased out of production in 1994, except for essential uses, and CFCs were phased out in 1996. Some halons still exist in manufacturers' inventories and are still in service as a suppression system.

The current replacement fire suppression gases for Halon 1301 are halocarbon clean agents. Halocarbon replacements include compounds containing carbon, hydrogen, bromine, chlorine, fluorine, and iodine. They are grouped into five categories: hydrobromofluorocarbons (HBFCs), hydrofluorocarbons (HFCs), hydrochlorofluorocarbons (HCFCs), perfluorocarbons (PFCs), and fluoroiodocarbons (FICs).

The descriptions and design requirements for all of these replacement agents are given in detail in NFPA 2001: *Standard on Clean Agent Fire Extinguishing Systems*. Halon 1301 information may be found in NFPA 12A: *Standard on Halon 1301 Fire Extinguishing Systems*.

Clean agent systems are designed to be chemical inhibitors that react with the transient products of combustion, terminating the combustion chain reaction and thereby stopping the flame propagation. They reduce the oxygen content below the point necessary to maintain combustion. Although inert gases have a low level of toxicity, the decomposition products generated by their breaking down in the presence of very high amounts of heat may be dangerous. They may be used in occupied areas if the design concentration does not exceed the "no observed adverse effect level" (NOAEL) of 43 percent.

NFPA 2001 has set exposure limits for inert gases. Unnecessary exposure to inert gas agent systems resulting in low oxygen atmospheres shall be avoided. The maximum exposure in any case shall not exceed five minutes. It is advised that evacuation from the protected areas be done during the countdown period between the verification of a fire and the release of any of these agents.

Clean Agent System Design Procedure

Modern concepts of fire protection for buildings of various occupancies include consideration of a clean agent extinguishing system as either an alternative or an addition to a traditional fire protection sprinkler system for rooms or areas considered special in nature from a fire protection point of view or of high value because of the equipment and/or materials housed in those areas. Specific applications must be reviewed with the local fire authorities having jurisdiction and the owner's insurance underwriter, but the following steps could be considered as a basis for further, detailed design.

1. Determine if the authority having jurisdiction and the owner's insurance underwriter will allow a clean agent in addition to a sprinkler system. If a clean agent system is installed in addition to a fire protection sprinkler system to protect the same floor area, the sprinkler system should be designed to release water after the clean agent system has been exhausted.
2. Determine the quantity of agent necessary, which depends on the following:
   - Calculate the square footage and the volume (cubic feet) of the space to be protected, including any under-floor (raised-floor) areas or plenum (above-ceiling) areas. According to the specific application, the under-floor area may be on a separate zone than the room space.
   - Determine the minimum agent concentration required for the hazard classification, as established by NFPA 2001, NFPA 12A, or the authority having jurisdiction. Subtract the volume of fixed structures that will be impervious to clean agent vapor.
   - Determine the specific volume of the agent vapor at the room's set temperature.
   - Evaluate minimum agent hold requirements and evaluate compartment for leakage.
   - Establish the maximum discharge time (10 to 60 seconds).

Equation 1-12: Clean Agent Weight Calculation

$$W = V / S\,(C / (100 - C))$$

where
W = Weight of clean agent, pounds
V = Net volume of hazard
S = Specific volume of agent at set temperature
C = Agent design concentration (per NFPA 2001 or authority having jurisdiction)
t = Minimum anticipated temperature of the protected room volume

   The connected standby is an integral part of the system. Connected standby (reserve) is sometimes required by the jurisdictional authority or owner in important systems or continually operated areas, such as telephone exchanges, data processing rooms, or mainframe computer rooms. The reserve system is arranged to discharge on a delayed basis after the primary bank of cylinders has released or failed to release. Normally, the requirement for 100 percent connected reserve is established by the owner or insurance underwriter for the building or equipment as an extra precaution against building loss, but it is not a requirement of the NFPA standards.

3. Locate the cylinder(s). The agent equipment supplier should be consulted at this point regarding standard cylinder sizes, required clearances between cylinders and walls, access for cylinder replacement from an outside supply truck, weight of the equipment (for structural engineering design), and anchoring and support methods for attaching cylinders or spheres to walls or hanging from or above ceilings. Cylinders can be located within the hazard area or outside the hazard area.

4. Locate the pipe route from the cylinders to the discharge nozzles to ensure uniform discharge and design concentration of the agent throughout the protected space, generally within 10 to 60 seconds. If a separate agent storage room is to be used, it is particularly important that the length of piping between the storage room and the point of discharge is properly sized to ensure complete flooding of the room to the design concentration and within a maximum of 10 to 60 seconds. Longer pipe runs mean a longer time before the agent reaches the most remote nozzle on the system.
   - Pipe sizing is usually established by a fire protection engineer or the extinguishing agent equipment supplier based on computerized programs for pipe size determination, with proper data input related to room size and volume, air infiltration, the hazard being protected, and the specifics about the agent being used. Any such program must be listed or approved by a third-party agency, such as Underwriters Laboratories or FM Global.
   - Special precaution in design is necessary to ensure proper support and anchoring of the piping, as the force of the agent under pressure moving through the pipe systems can cause pipe movement, ruptured joints, or other dangerous conditions. Ceiling clips are recommended to hold down lay-in ceiling tiles during high-pressure agent discharge.
5. Define the method of initiating or triggering the system. Typical system initiating devices are ionization and/or photoelectric smoke detectors. These detectors are located within the protected area at ceilings, under raised floors, or in the plenum space. These devices are normally spaced at approximately 125 square feet to 900 square feet per detector based on the airflow through the space. The maximum area per detector is defined in NFPA 72: *National Fire Alarm and Signaling Code*. When the detector is triggered, the signal is sent to an agent control panel normally located near the exit door from the protected space, thus beginning the alarm sequence. The most common sequence of events for the control panel is as follows:
   - The first smoke detector activates. An alarm bell or horn rings in the protected area, and an alarm signal is sent to the building fire alarm control panel.
   - The second smoke detector activates. An alarm bell sounds, the countdown timer delay (30 seconds) starts, air-handling equipment shuts down, clean agent air dampers close, and an alarm signal is sent to the building's fire alarm control panel.
   - The time delay expires. The agent discharges immediately, electrical equipment shuts down, strobe lights and local discharge horns are activated, and an alarm signal is sent to the building's fire alarm control panel.

   An alternative to the above-described initiation sequence is counter zoning, which requires at least one detector to alarm from two different detector zones in the protected space before system discharge. This requires the establishment of multiple detection zones in the protected space.
6. The control panel is commonly equipped with a light indicating that the agent is discharging, a 30-second time delay relay, alarm relay, shutdown relay, abort station, and manual release station. In the event that the fire can be brought under control by other means or until the fire is confirmed, the abort station may be used to prevent the release of the agent.
7. Building fire alarm systems should be equipped with the ability to receive a signal from the clean agent extinguishing system control panel and indicate to fire department personnel where the fire is within the building. If the building's fire alarm control panel does not have this capability, a separate remote annunciator should be provided with the extinguishing agent control equipment.
8. Actual discharge testing of halon systems is no longer permitted, due to environmental considerations. It is common, however, for a complete functional test of the system to be required after installation to ensure proper operation of all mechanical and electrical equipment, detection system, discharge control, abort, power shutdown, air-handling unit shutdown, fire damper, and door closure circuits. A fan pressurization test of the space integrity and an acceptance test also may be required. Refer to NFPA 2001 for complete inspection, testing, and training requirements for clean agent extinguishing systems. Refer to NFPA 12A for halon system requirements.

Fire Extinguishers

A fire extinguisher is an active fire protection device used to extinguish or control a fire, typically in emergency situations. A fire extinguisher, in general, consists of a handheld cylindrical pressure vessel containing an agent that can be discharged to extinguish a fire. In selecting a fire extinguisher, consideration should be given to the type of hazard and the potential size of fire involvement. For the proper type, rating, and locations, refer to NFPA 10: *Standard for Portable Fire Extinguishers*.

Fire extinguishers are available to extinguish all Class A, B, C, D, and K fires and are available with specialty extinguishing agents: carbon dioxide, dry chemical, water, clean agent, foam, and special compounds for use with combustible metals.

Some extinguishers extinguish only one class of fire, and some may be suitable for two or three classes of fire; however, none are suitable for all classes. Rating numerals are used to provide the effectiveness of an extinguisher (i.e., a 4A extinguisher will discharge twice as much extinguishing agent as a 2A unit). The numerical rating for Class B extinguishers is based on the quantity of burning flammable liquid to be extinguished. Class C and D extinguishers do not have numerical ratings.

Class A extinguishers often are used for general building protection (paper, wood, cloth) and use water, AFFF, multipurpose dry chemical, and clean agent extinguishing agents. Class B extinguishers include carbon dioxide, dry chemicals, AFFF, and halogenated types for use on flammable liquid fires (gasoline, grease, oil, paint) and may be located in kitchens, laboratories, and generator rooms. Class C extinguishers include carbon dioxide, dry chemical, and clean agent types for use on electrical equipment fires. Class D extinguishing agents are special dry powder agents for use on combustible metals. It should be noted that multipurpose dry chemicals leave a residue when used. Delicate electrical or electronic equipment could be damaged if Class A, B, or C dry chemical extinguishing agents are used.

Extinguishers should be mounted with the top no more than 5 feet above the floor, but with the bottom a minimum of 4 inches above the floor. For units in excess of 40 pounds, the top should be 3.5 feet above the floor. Extinguishers shall be easily visible and accessible. The actual travel distance to extinguishers, including walking around partitions and equipment, becomes a critical factor for quick fire control. The maximum distance allowed is listed in NFPA 10. (For example, the maximum distance between extinguishers in a Class A hazard is 75 feet.) It is beneficial to locate extinguishers in normal paths of travel, near exits and entrances, where uniform distribution is possible, and where the units will be readily available. Wheeled extinguishers are usually intended for outdoor placement and use by trained personnel.

ELEVATOR SHAFT PROTECTION

ASME A17.1: *Safety Code for Elevators and Escalators* states that the mainline power supply to the elevator must be automatically disconnected prior to the application of water in the event of a fire. This is required because the electrical components and brakes in an elevator do not perform predictably when wet. This situation necessitates some special arrangement, such as a preaction system or inline flow switch to ensure that water does not flow in the elevator shaft until power has shut down.

Elevator Recall

Smoke detectors are provided at the top of the shaft. When the smoke detector is triggered, this alarms the system control panel and initiates elevator recall upon actuation.

Elevator Shut Down

Heat detectors are provided adjacent to each sprinkler installed in the elevator shaft and elevator machine room. The heat detector activation set point is set for less than the activation temperature of the sprinkler. When the heat detector is triggered, a signal is sent to the system control panel that disconnects power to the elevator without time delay. In the event of accidental damage to a sprinkler head, water flow shall activate either the preaction system or water flow switch and send a signal to the system control panel that disconnects power to the elevator.

Sprinklers and Piping

Sidewall sprinklers are to be installed at the bottom of each elevator hoistway not more than 2 feet above the floor of the pit. All sprinkler piping must be located outside the shaft, except for the short horizontal branch that feeds the sprinkler heads. An accessible and monitored isolation valve must be provided on the main line feeding the shaft sprinklers, outside the shaft.

NFPA 13 allows eliminating the sprinkler at the top of elevator hoistways, if two conditions are met: The elevator hoistway must be noncombustible, and the elevator car enclosure material must meet the requirements of ASME A17.1. Note that this exception is subject to the approval of the authority having jurisdiction.

DESIGN COORDINATION AND CONSIDERATIONS

Fire protection design extends beyond the installation of the suppression system. The entire building team becomes part of the design effort. The architect and the HVAC, plumbing, and electrical engineers are an integral part of the fire protection system design process. Following is a partial list of items that should be reviewed by the design team prior to final drawings and specifications being issued for construction.

- State and local building codes and ordinances
- Fire wall locations
- Fire door locations
- Fire damper locations
- Smoke door locations
- Smoke exhaust locations
- Smoke damper locations
- Smoke detector locations
- Heat detector locations
- Fire alarm notification devices
- Fire alarm panel location

- Fire alarm manual pull station locations
- Sprinkler flow switch locations
- Sprinkler valve pressure switch locations
- Sprinkler valve supervisory switch locations
- Standpipe and hose locations
- Fire department connection locations
- Fire pump locations
- Fire pump test header locations
- Fire water service locations
- Fire hydrant locations
- Specialty suppression system locations
- Emergency and/or standby power
- Available power

As a result of the size and complexity of today's structures, the entire fire protection team is required to supply a life safety system of detection, notification, and suppression with the ultimate goal of safety to the occupants of the structure and protection of the owner's investment.

REFERENCES

The documents or portions thereof listed are referenced within the information sections of this chapter. Check with federal, state, and local codes to determine which editions are in effect in the project's location.

- National Fire Protection Association (NFPA) *Fire Protection Handbook*
- NFPA 10: *Standard for Portable Fire Extinguishers*
- NFPA 11: *Standard for Low-, Medium-, and High-Expansion Foam*
- NFPA 12: *Standard on Carbon Dioxide Extinguishing Systems*
- NFPA 12A: *Standard on Halon 1301 Fire Extinguishing Systems*
- NFPA 13: *Standard for the Installation of Sprinkler Systems*
- NFPA 14: *Standard for the Installation of Standpipes and Hose Systems*
- NFPA 15: *Standard for Water Spray Fixed Systems for Fire Protection*
- NFPA 16: *Standard for the Installation of Foam-Water Sprinkler and Foam-Water Spray Systems*
- NFPA 17: *Standard for Dry Chemical Extinguishing Systems*
- NFPA 17A: *Standard for Wet Chemical Extinguishing Systems*
- NFPA 20: *Standard for the Installation of Stationary Pumps for Fire Protection*
- NFPA 24: *Standard for the Installation of Private Fire Service Mains and their Appurtenances*
- NFPA 72: *National Fire Alarm and Signaling Code*
- NFPA 291: *Recommended Practice for Fire Flow Testing and Marking of Hydrants*
- NFPA 484: *Standard for Combustible Metals*
- NFPA 750: *Standard on Water Mist Fire Protection Systems*
- NFPA 2001: *Standard on Clean Agent Fire Extinguishing Systems*

DISCLAIMER

The design of fire suppression systems should be performed only by experienced fire protection designers or engineers. Although this chapter provides a basic, systematic approach to fire protection systems design, it does not attempt to answer all of the questions concerning the subject.

APPENDIX

The following factors may be used to convert inch-pound measurement units to metric units.

- 1 inch = 25.4 millimeters
- 1 foot = 0.348 meters
- 1 gallon = 3.785 liters
- 1 square foot = 0.0929 square meter
- 1 gallon per minute = 0.063 liter per second
- 1 psi = 6.8948 kPa
- 1 gpm/ft^2 = 0.6781 L/s/m^2
- 1 foot per minute = 5.08 mm/s
- 1 cubic foot = 0.028 cubic meter
- 1 cubic foot per minute = 28.32 L/min

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Plumbing Design for Healthcare Facilities

Healthcare facilities, nursing homes, medical schools, and medical laboratories require plumbing systems that are more complex than those for most other types of buildings. The plumbing designer should work closely with the architect and facility staff and be involved in meetings and discussions to fully understand the plumbing requirements for any new or special medical equipment. The plumbing design must be coordinated with the civil, architectural, structural, mechanical, and electrical designs to ensure that adequate provisions have been made for utility capacities, the necessary clearances and space requirements of the piping systems and related plumbing equipment, and compliance with applicable codes. Healthcare facilities may have different requirements or be exempt from some codes and standards, such as water and energy conservation codes and regulations regarding the physically challenged. The plumbing engineer should consult with the administrative authority to ensure conformance with local ordinances.

This chapter discusses the provisions that may be encountered in the design of a healthcare facility, including the plumbing fixtures and related equipment, sanitary drainage system, water supply system, laboratory waste and vent systems, pure water systems, and medical gas systems.

TYPES OF HEALTHCARE FACILITIES

Healthcare facilities include hospitals, nursing homes, medical and dental offices, and clinics. These facilities fall into two general categories: short-term and long-term care. Short term is considered the typical acute care surgical- or medical-type hospital.

Hospitals

A hospital is defined as a building or part thereof that is used for medical, obstetrical, psychiatric, or surgical care on a 24-hour basis for four or more patients. These include general hospitals, mental hospitals, tuberculosis hospitals, children's hospitals, etc. and any facility providing inpatient care. Piping systems shall conform to levels (defined in the next section) as follows:

- Medical/surgical compressed gases and vacuum systems for direct patient care, pneumatic devices, or supplying-mechanical or assisted-mechanical ventilation equipment shall conform to Level 1.
- Waste anesthetic gas disposal (WAGD) systems shall conform to Level 1 requirements and may be produced by either a dedicated system or a connection to the medical/surgical vacuum system.
- High-pressure support gases (nitrogen or instrument air) for pneumatic devices, tools, etc. shall be Level 1 and also may be used for laboratory purposes if appropriate. They shall not be used for respiration.
- Level 2 systems are not permitted.
- A Level 3 gas (nitrous oxide and oxygen only) and vacuum system for dentistry shall be permitted if not connected to the hospital's Level 1 central system source. These gas systems shall not be used for patient or staff ingestion. Existing systems are permitted to be used, provided that they do not constitute a hazard to life as determined by the local authorities.

Nursing Homes

A nursing home is a facility providing long-term nursing care and housing on a 24-hour basis for patients who, because of physical or mental incapacity, may be unable to provide for their own needs without the assistance of another person. This type of facility includes nursing and convalescent facilities, skilled nursing homes, intermediate-care facilities, and infirmities with homes for the aged. Piping systems, if installed, shall conform to levels as follows:

- Medical gas and vacuum systems if provided for patients with mechanical or assisted-mechanical ventilation considered critical life support shall conform to Level 1 as well as any gas connected to Level 1 sources or distribution piping.
- Where patients are not dependent on medical gas or vacuum systems at any time for critical life

support, such systems, if provided, shall conform to Level 2.
- All other systems, if provided, shall conform to Level 3.

Limited-care Facilities

A limited-care facility is used on a 24-hour basis for the housing and care of four or more persons who are incapable of self-preservation due to illness, accident, mental retardation, or chemical dependency. If installed, piping systems shall conform to levels as follows:

- Where patients are provided with mechanical or assisted-mechanical ventilation, gas, or vacuum systems, these systems shall conform to Level 1.
- Systems shall meet Level 2 if they do not meet all of the above conditions.

Other Healthcare Facilities

Other facilities, or portions thereof, provide diagnostic and treatment services to patients other than those provided in hospitals, nursing homes, and limited-care facilities. This category is intended to encompass all other facilities without the need for specifically naming them, which in the past has resulted in misinterpretation and misapplication of standards. It includes small outpatient facilities and medical and dental offices. If installed, piping systems shall conform to levels as follows:

- Medical compressed gases and vacuum systems supplying mechanical or assisted-mechanical ventilation equipment and WAGD systems shall conform to Level 1. If general anesthesia is given, Level 1 systems are required.
- Where patients are not dependent on medical gas or vacuum systems at any time for critical life support, such systems, if provided, shall conform to Level 2.
- All other systems, if provided, shall conform to Level 3.

MEDICAL GAS AND VACUUM SYSTEM LEVELS

The term "level" represents a comparative degree of risk to patients and the facility in which they are installed. The levels are intended to define standards of purity, safety, and reliability. They indicate intended system uses and the potential risk to a patient if the system shall fail or malfunction. Systems conforming to different levels within the same building are permitted.

Level 1

Level 1 includes any dedicated, nonflammable compressed gas or vacuum system whose failure or interruption will be an immediate threat to life safety and the expectation that the patient outcome would result in death or permanent injury. The official definition is "imminent danger of morbidity or mortality." A Level 1 gas system shall be installed in critical areas and also serve patients who could be provided with mechanical ventilation or assisted-mechanical ventilation. The patients are dependent on such systems for critical life support while undergoing or recovering from invasive diagnostic, treatment, or surgical procedures. The Level 1 vacuum system shall serve any station inlets installed in critical care areas, including WAGD, and provide medical/surgical support for the patient population undergoing or recovering from invasive diagnostic, treatment, or surgical procedures. This level shall include all necessary alarms, operating controls, gauges, etc. High-pressure compressed gases more than 160 pounds per square inch gauge (psig) (1,103 kPa) used to serve pneumatic devices that are used for invasive procedures are Level 1, which also includes instrument (support) air that is used as a replacement for nitrogen. The supply and alarms must be redundant.

Level 2

Level 2 includes any nonflammable patient gas distribution system where patients are not dependent on such systems for critical life support and are not provided with mechanical ventilation or assisted-mechanical ventilation. The failure of this level system may result in death or permanent injury. This level is used where a patient is at manageable risk of morbidity or mortality if the system fails. This will serve any patient who is dependent on the piped medical gas and vacuum system for well-being and for recovery from invasive diagnostic, treatment, or surgical procedures, where a bottled gas could be substituted quickly for the failed service. This includes support air where applicable. The source supply, equipment, and alarms can be simplex. They shall not be connected to Level 1 central systems and are not permitted to be used in hospitals. The occupancy to be served and the function of that occupancy where Level 2 systems are installed shall be different from all other occupancies in a hospital.

Level 3

Level 3 systems are considered low risk to a patient and are found where interruption of the piped systems would allow termination of a procedure that would not place the patient at risk of mortality or conditions that would lead to death. Patients are not dependent on compressed gas or vacuum. Such systems are found in facilities such as dental offices and clinics. They include any nonflammable patient gas distribution system at a pressure of less than 160 psi (1,103 kPa) providing a source of power for orthopedic, pediatric, and plastic surgery devices and for dental services. The vacuum system can be either wet or dry and is used predominately for removal of liquids from any treatment area and from the oral cavity. Alarms and supplies need not be redundant. The systems installed shall not supply more than two adjoining treatment facilities.

PLUMBING FIXTURES AND RELATED EQUIPMENT

Selection Process

Meetings among the plumbing engineer, architect, and facility staff to discuss the general and specific requirements regarding the plumbing fixtures and related equipment usually are held after the architect has prepared the preliminary drawings. At these meetings, the plumbing designer should assist in the selection of plumbing fixtures. Following these sessions, the plumbing designer can prepare the preliminary drawings and coordinate the required piping systems and the plumbing fixture space requirements with the architect and facility staff. In detailing the piping system spaces and plumbing fixture locations, the plumbing engineer should refer to the framing drawings. It is common for the architect to locate the piping shafts and the spaces in direct conflict with the framing; it is the plumbing designer's responsibility to give the architect directions regarding the space requirements, fixture arrangements, and pipe shaft sizes and locations.

Following the meetings held with the architect and hospital staff and with the preliminary drawings available, the plumbing designer should prepare an outline specification for the plumbing fixtures and related equipment. A guide to the required plumbing fixtures and equipment for healthcare facilities is provided in Table 2-1 and is discussed later in this section.

A review of applicable code requirements regarding the quality and types of plumbing fixtures is always required. In addition to the local codes, it is necessary for the plumbing engineer to refer to the special hospital code requirements published by the local hospital authorities, state hospital or health department authorities, The Joint Commission, and the U.S. Department of Health and Human Services. The architect may investigate these special requirements; however, the plumbing designer must be familiar with them since they contain many other applicable requirements (in addition to the table indicating the plumbing fixtures necessary for a particular installation).

General Requirements

Plumbing fixtures in healthcare facilities should be of dense, impervious materials having smooth surfaces. Plumbing fixtures of vitreous china, enameled cast iron, and stainless steel are commonly used. Fixture brass—including faucets, traps, strainers, escutcheons, stops, and supplies—should be chromium plated in a manner approved by the administrative authority. Die-cast metals should not be used. Faucets should have a laminar flow device (no alternative) of brass, Monel metal, or stainless steel trim. Each plumbing fixture in a healthcare facility should be provided with individual stop valves. Each water service main, branch main, and riser shall have valves. Access shall be provided at all valves. All submerged inlets, faucets with hose adapters, and flush valves must be equipped with approved vacuum breakers. Backflow prevention devices shall be installed on hose bibbs and supply nozzles used for the connection of hoses or tubing and at other locations where the potable water supply must be protected from contamination.

All plumbing fixtures, faucets, piping, solder, and fluxes used in potential drinking water areas should comply with the latest maximum lead content regulations. Facilities for the physically challenged shall be in compliance with Americans with Disabilities Act (ADA) accessibility guidelines.

Fixtures for General Use in Staff and Public Areas

Water Closets

Vitreous china, siphon-jet water closets with an elongated bowl design and open-front seat, less cover, should be specified. Wall-hung water closets are preferred for easy cleaning; however, floor-set models are also acceptable by most local jurisdictions. All water closets should be operated by water-saver flush valves.

Lavatories and Sinks

Vitreous china, enameled cast iron, or stainless steel lavatories and sinks should be specified. The most commonly specified size is 20×18×7.5 inches (508×457.2×190.5 mm) deep. Hands-free (foot or knee) controls are generally employed for staff use and for scrub-up sinks. In public areas, codes should be checked for the requirement for self-closing valves and/or metered valves. Stops should be provided for all supply lines. Aerators are not permitted; laminar flow devices shall be used instead. Insulated and/or offset p-traps should be used for handicapped fixtures.

Faucets

Valves should be operable without hands (i.e., with wrist blades, foot controls, or electronically). If wrist blades are used, blade handles used by the medical and nursing staff, patients, and food handlers shall not exceed 4.5 inches (114.3 mm) in length. Handles on scrub sinks and clinical sinks shall be at least 6 inches (152.4 mm) long. Water spigots used in lavatories and sinks shall have clearances adequate to avoid contaminating utensils and the contents of carafes, etc.

Urinals

Vitreous china wall-hung urinals with flush valves shall be specified. Flush valves should be equipped with stops and may be of the exposed or concealed design.

Table 2-1 Recommended Plumbing Fixtures and Related Equipment

	Elongated Water Closet, Flush Valve	Urinal	Handwashing Lavatory	Shower	Drinking Fountain/Water Cooler	Mop Service Basin	Counter Sink, Single Compartment	Counter Sink, Double Compartment	Clinic Sink, Flushing Rim	Scrub-up Sink	Utility Sink	Sink, Triple Compartment	Plaster Sink, Plaster Trap	Cup Sink	Floor Drain	Floor Drain, Flushing Rim	Emergency Shower	Emergency Eyewash	Bathtub/Shower	Sitz Bath	Bedpan Washer	Waste Grinder	Ice Maker	Arm/Leg Bath	Immersion Bath	Glass Washer	Infant Bathtub
Public/Staff Restrooms	●	●	●	●	●	●									●												
Staff Lounge	●	●	●		●		●																●				
Patient Rooms	●		●	●																	●						
Isolation Rooms	●		●	●																	●						
Nurse Stations							●																				
Nursery			●																								●
Formula Room			●				●																			●	
Intensive Care Room	●		●								●																
Outpatient-Services Area	●		●		●										●												
Emergency Rooms	●		●		●				●		●																
Exam/Treatment Room	●		●				●																				
Labor Room	●		●	●																							
Janitor's Closet			●			●									●												
Clean Linen Holding							●																				
Soiled Linen Holding								●	●																		
Nourishment Station			●				●																●				
Patient Bathing Area	●		●	●											●				●								
Critical Care Area	●		●			●									●						●						
Pharmacy							●																				
Surgical Scrub-up										●																	
Anesthesia Workroom							●																				
Surgical Supply Services								●																			
Surgical Cleanup Room									●																		
Doctors' Locker Room	●	●	●	●																							
Nurses' Locker Room	●		●	●																							
Recovery Room			●						●												●						
Fracture Room			●										●														
Cleanup/Utility Room			●				●		●												●						
Sub-sterilizing Room							●																				
Medical Laboratory	●	●	●		●	●	●							●	●		●	●								●	
Physical Therapy Room	●		●				●								●					●				●	●		
Cystoscopic Room	●		●	●					●							●						●					
Autopsy Room	●		●	●		●	●		●							●						●					
Dietary Services	●	●	●			●	●	●				●			●							●	●				
Laundry Facility	●		●								●				●												
Family Waiting Room	●		●		●																						

Showers

The shower enclosure and floor specified by the plumbing engineer may be constructed of masonry and tile or prefabricated fiberglass. Showers and tubs shall have nonslip walking surfaces. The shower valve should automatically compensate for variations in the water supply pressure and temperature to deliver the discharge water at a set temperature that will prevent scalding.

Drinking Fountains and Water Coolers

Drinking fountains are available in vitreous china, steel, and stainless steel. Units for exterior installations are available in suitable materials. Refrigerated water coolers are available in steel and stainless steel. All of these materials are acceptable by most local administrative authorities. These units may be of the surface-mounted, semi-recessed, or fully recessed design.

Chilled water for drinking purposes should be provided between 45 and 50°F (7.2 and 10°C) and obtained by a refrigeration compressor, which may be enclosed in a cabinet with the dispenser (water cooler), installed in a wall cavity behind a grill adjacent to the dispenser, or remotely located for single or multiple dispensers. A remotely installed unit for multiple dispensers (central system) should have a recirculation system.

Mop-service Basins

Floor-mounted mop-service basins can be obtained in precast or molded-stone (terrazzo) units of various sizes. The plumbing engineer should specify the most suitable model. Rim guards typically are provided to protect the rims from damage, and wall guards are provided to protect walls from splashing and chemical stains. The water supply fixture is usually a two-handle mixing faucet mounted on the wall with a wall brace, vacuum breaker, and hose adapter.

Floor Drains

Floor drains in toilet rooms are optional in most cases; however, in many instances floor drains are required by the applicable codes. The plumbing designer should consider maintaining a trap seal in the floor drain through the use of deep-seal p-traps and/or trap primers. Floor drains shall not be installed in operating and delivery rooms.

Fixtures for Patient and Treatment Rooms

Patient Rooms

These rooms (private or semiprivate) usually are provided with a toilet room containing a water closet, lavatory, and shower or bathtub. (Some hospitals use common shower and bath facilities for a group of patient rooms.) The plumbing fixtures should conform with the following recommendations:

- The water closet should be vitreous china, wall hung or floor mounted, with an elongated bowl. All water closets should be operated by a flush valve. Water closets should have open-front seats, less cover. Bedpan lugs and bedpan washers often are required by the local codes. Bedpan-flushing devices shall be provided in each inpatient toilet room; however, installation is optional in psychiatric and alcohol-abuse units where patients are ambulatory.
- The lavatory should be a minimum of 20×18×7.5 inches (508×457.2×190.5 mm) deep. Lavatories should be installed at least 34 inches (863.6 mm) above the floor. Mixing faucets should be of the gooseneck-spout design and provided with wrist-blade handles or electronic or hands-free controls.
- The shower is usually constructed of masonry and tile, acrylics, or fiberglass. The shower base should be a nonslip surface. The shower valve should automatically compensate for variations in the water supply pressure and temperature to deliver the discharge water at a set temperature that will prevent scalding. Grab bars located within the shower enclosure are usually required by local codes. The plumbing engineer should always check with the local administrative authority regarding approved designs.
- Bathtubs can be constructed of cast iron, fiberglass, acrylics, or steel. Faucets should be as they are for showers. Showerheads may be of the stationary design, but in many locations handheld showerheads are required.
- A lavatory intended for use by doctors, nurses, and other hospital staff is sometimes required by local ordinances. This particular lavatory is usually located on the wall near the door with a gooseneck spout and hands-free controls.
- A water closet and lavatory, with a fixed or foldaway water closet made of stainless steel, may be considered. This concept, as well as the construction of the unit, must be accepted by the administrative authority.

Ward Rooms

Ward rooms are infrequently found in healthcare facilities, particularly in the private hospital field. These rooms require at least one lavatory, which should be a minimum 20×18 inches (508×457.2 mm) and be made of vitreous china or stainless steel. The faucet should be of the gooseneck-spout design and be provided with wrist-blade handles or hands-free controls.

Nurseries

A hospital's nursery is usually provided with a 20×18-inch (508×457.2-mm) minimum lavatory with hands-free controls and a high gooseneck spout. An infant's bathtub, wall- or counter-mounted with an integral large drain board and rinsing basin, is provided. The water supply fitting is a filler spout over the basin with separate hand-valve controls. The spout and the spray are usually supplied and controlled through a thermostatic mixing valve. Use a separate supply tank to ensure a safe water temperature.

Intensive Care Rooms

These rooms usually have utility sinks with hands-free controls and high gooseneck spouts. A water supply fitting equipped with a gooseneck spout and a provision for bedpan washing (either at an immediately adjacent water closet or at a separate bedpan-washing station within an enclosure in the room) should be provided. Newer designs include combination lavatory/water closets for patient use, especially in cardiac care units.

Emergency (Triage) Rooms

The plumbing fixtures provided in emergency rooms include a utility sink with an integral tray and a water supply fitting with a gooseneck spout and wrist-blade handles. A vitreous china clinic sink (or a flushing-rim sink) for the disposal of solids, with the water supply fitting consisting of a flush valve and a separate combination faucet with vacuum breaker mounted on the wall above the plumbing fixture, also should be provided.

Examination and Treatment Rooms

These rooms are usually provided with vitreous china or stainless steel lavatories. The water supply fitting should be a hands-free valve equipped with a high, rigid gooseneck spout. For a particular examination room or a group of patient rooms, an adjacent toilet room is provided containing a specimen-type water closet for inserting a specimen-collecting bedpan. The toilet room also requires a lavatory and a water supply with wrist-blade handles or hands-free controls and a gooseneck spout.

Physical Therapy Treatment Rooms

The plumbing fixtures and related equipment for these rooms usually include hydrotherapy immersion baths and leg, hip, and arm baths. These units are generally furnished with electric motor-driven whirlpool equipment. The water is introduced into the stainless steel tank enclosure by means of a thermostatic control valve to prevent scalding, usually wall mounted adjacent to the bath for operation by a hospital attendant. The water supply should be sized to minimize tub fill time. Immersion baths typically are provided with overhead hoists and canvas slings to help lift a completely immobile patient in and out of the bath. A hydrotherapy shower also is sometimes required. These showers usually consist of multiple showerheads, sometimes as many as 12 to 16, vertically mounted to direct the streams of water at a standing patient by means of a sophisticated control console operated by a hospital attendant.

Cystoscopic Rooms

Among the various plumbing fixtures required in cystoscopic rooms are wall-mounted clinic sinks equipped with flush valves, bedpan washer, and combination faucets; lavatories provided with water supply fittings and gooseneck spouts; and, in an adjacent room, specimen water closet and lavatory. If a floor drain is installed in a cystoscopy room, it shall contain a non-splash, horizontal-flow flushing bowl beneath the drain plate.

Autopsy Rooms

The autopsy room table is usually provided with cold and hot water supplies, with a vacuum breaker or backflow preventer, and a waste line. The plumbing designer must consult with the table manufacturer and the administrative authority regarding the requirements of the autopsy room table. Drain systems for autopsy tables shall be designed to positively avoid splatter and overflow onto floors or back-siphonage and for easy cleaning and trap flushing. The autopsy room also is usually equipped with a stainless steel or vitreous china sink with hands-free fittings, a clinic sink, and a blood-type floor drain. A water closet and shower room are usually provided adjacent to the autopsy room. Many autopsy rooms are equipped with waste disposal units integral with the sink.

Nourishment Stations

These stations are usually provided on each patient room floor near the nurse station for serving nourishment between regularly scheduled meals. A sink, equipped for hand washing with hands-free controls, an ice maker, and a hot water dispenser (optional) to provide for the patient's service and treatment should be provided.

Pharmacy and Drug Rooms

The plumbing fixtures for these rooms include medicine and solution sinks. These units can be counter-type or made of stainless steel or vitreous china with a mixing faucet and a swing spout. A solids interceptor should be considered for compounding areas.

Operating Room Areas

No plumbing fixtures or floor drains are required in the hospital's operating room. However, the scrubbing station located adjacent to the operating room should have at least two scrub sinks, usually made of vitreous china or stainless steel, furnished with hands-free water supply fittings, and equipped with gooseneck spouts. These sinks should be sufficiently large and deep to allow scrubbing of hands and arms to the elbow. A soiled workroom, designed for the exclusive use of the hospital's surgical staff, should be located near the operating room area. This workroom should contain a vitreous china, flushing-rim clinical sink for the disposal of solids, with the water supply fittings consisting of a flush valve bedpan washer and a separate faucet mounted on the wall above the fixture, as well as handwashing facilities consisting of a vitreous china or stainless steel lavatory with a gooseneck spout and equipped with wrist-blade handles. Substerile rooms should be equipped with an instrument sterilizer and general-purpose sink. The plumbing designer should consult with the instrument sterilizer manufacturer for any special requirements for the equipment. The general-purpose sink can be countertop mounted and equipped with a hands-free water supply fitting with a gooseneck spout.

Recovery Rooms

The rooms for the post-anesthesia recovery of surgical patients should include a handwashing facility, such as a vitreous china or stainless steel lavatory equipped with a gooseneck spout and wrist-blade handles, as well as a vitreous china, flushing-rim clinical sink for the disposal of solids, with the water supply fitting consisting of a flush valve and a separate faucet mounted on the wall above the fixture with a vacuum breaker. A bedpan washer also should be installed next to the clinical sink. The type of bedpan washer depends on the hospital's method of washing and sterilizing bedpans.

Birthing Rooms

Each birthing room should include a vitreous china lavatory provided with a gooseneck spout and wrist-blade handles or hands-free controls. Each labor room should have access to a water closet and lavatory. A shower should be provided for labor room patients. The shower controls, including pressure and thermostatic mixing valves, should be located outside the wet area for use by the hospital's nursing staff. A water closet should be accessible to the shower facility.

Anesthesia Workrooms

These areas are designed for the cleaning, testing, and storing of anesthesia equipment and should contain a counter-mounted work sink, usually made of stainless steel. The faucet should be of the gooseneck spout design with wrist-blade handles and/or hands-free controls.

Fracture Rooms

A large-size, vitreous china plaster work sink equipped with a combination water supply fitting and wrist-blade handles, gooseneck spout, and plaster trap on the waste line (located for convenient access) should be provided.

Dialysis Treatment Rooms

These areas are designated for administering patient dialysis. They should include sinks with wrist-blade handles, water supply and drainage connection points for dialysis machines, and pure water equipment with circulated supply piping to points designated by the department staff.

Fixtures for Kitchens and Laundries

The plumbing designer should consult with the architect and the food service consultant for kitchen equipment utility requirements. Typically, one of these people should provide locations and rough-in drawings for all kitchen equipment. Normally required are toilet fixtures for kitchen staff, food preparation sinks, handwash sinks, pot- and pan-wash sinks, dishwashers, glassware washers, floor drains, hose bibbs, mixing stations, and grease interceptors. Kitchen grease traps shall be located and arranged to permit easy access without entering food preparation or storage areas. Grease traps shall be of the capacity required and shall be accessible from outside the building without interrupting any services. In dietary areas, floor drains and/or floor sinks shall be of a type that can be easily cleaned by the removal of a cover. Provide floor drains or floor sinks at all wet equipment (such as ice machines) and as required for the wet cleaning of floors. The location of floor drains and floor sinks shall be coordinated to avoid situations where the equipment makes the removal of covers for cleaning difficult. Also, the kitchen equipment may require other utility services, such as fuel gas, steam, and condensate.

When considering laundry facilities, the plumbing designer should consult with the architect and the laundry consultant for equipment utility requirements. These facilities require large-capacity washers/extractors and dryers, presses, and folding machines. Wastewater drainage may require lint intercepters. These facilities are prime candidates for heat- and water-recovery systems. Also, the laundry equipment may require other utility services, such as fuel gas, steam, and condensate.

The hot water temperatures required for these areas (100, 140, and 180°F [38, 60, and 82°C]) are discussed in *Plumbing Engineering Design Handbook*, Volume 2, Chapter 6: "Domestic Water Heating Systems."

Decontamination Area Fixtures

The fixtures usually provided in these areas include a shower compartment with a floor drain and sediment bucket and a large showerhead with an integral flexible hose and vacuum breaker, allowing water to be sprayed onto any part of a patient on a stretcher. A utility sink and a lavatory are usually required, both having a gooseneck spout and wrist-blade handles. A toilet is usually provided. The shower and all fixtures shall drain to a hazardous materials tank completely separate from the facility system. This tank and its

Table 2-2 Hospital Plumbing Fixtures

	Fixture Units			gpm (L/sec)		gph (L/h)
	Total Water	Cold Water	Hot Water	Total Water	Cold Water	Hot Water
Aspirator, fluid suction	2	2	—	3 (.19)	—	—
Aspirator, laboratory	2	2	—	3 (.19)	—	—
Autopsy table, complete	4	3	2	8 (.50)	4½ (.28)	20 (75.7)
Autopsy table, aspirator	2	2	—	3 (.19)	—	—
Autopsy table, flushing hose	2	2	—	3 (.19)	—	—
Autopsy table, flushing rim	3	3	—	4½ (.28)	—	—
Autopsy table, sink and faucet	3	2½	2½	4½ (.28)	4½ (.28)	20 (75.7)
Autopsy table, waste disposal	1½	1½	—	4 (.25)	—	—
Bath, arm	4	2	3	3 (.19)	7 (.44)	35 (132.5)
Bath, emergency	4	2	3	3 (.19)	7 (.44)	15 (56.8)
Bath, immersion	20	7	15	15 (.95)	35 (2.21)	450 (1,703.3)
Bath, leg	10	4	7	8 (.50)	16 (1.01)	100 (378.5)
Bath, sitz	4	2	3	3 (.19)	7 (.44)	30 (113.6)
Bed pan, washer, steam	10	10	—	25 (1.58)	—	—
Cleaner, sonic	3	2½	2½	4½ (.28)	4½ (.28)	20 (75.7)
Cuspidor, dental and surgical	1	1	—	2 (.13)	—	—
Cuspidor, dental chair	1	1	—	2 (.13)	—	—
Drinking fountain	1	1	—	2 (.13)	—	—
Floor drain, flushing type	10	10	—	25 (1.58)	—	—
Hose, bed pan general	2	1½	1½	3 (.19)	3 (.19)	5 (18.9)
Hose, bed pan private	1	1	1	3 (.19)	3 (.19)	8 (30.3)
Laundry tub	3	2½	2½	4½ (.28)	4½ (.28)	30 (113.6)
Lavatory, barber	2	1½	1½	3 (.19)	3 (.19)	15 (56.8)
Lavatory, dental	1	1	1	3 (.19)	3 (.19)	8 (30.3)
Lavatory, general	2	1½	1½	3 (.19)	3 (.19)	8 (30.3)
Lavatory, private	1	1	1	3 (.19)	3 (.19)	4 (15.1)
Lavatory, nursery	2	1½	1½	3 (.19)	3 (.19)	8 (30.3)
Lavatory, scrub-up	2	1½	1½	3 (.19)	3 (.19)	10 (37.9)
Lavatory, treatment	1	1	1	3 (.19)	3 (.19)	4 (15.1)
Microscope, electron	1	1	—	0.2 (.01)	—	—
Sanistan	10	10	—	25 (1.58)	—	—
Sanitizer, boiling, instrument	2	—	2	—	3 (.19)	10 (37.9)
Sanitizer, boiling, utensil	2	—	2	—	3 (.19)	10 (37.9)
Shower, general	4	2	3	1½ (.09)	3½ (.22)	50 (189.3)
Shower, private	2	1	2	1½ (.09)	3½ (.22)	20 (75.7)
Shower, obstetrical	4	2	3	1½ (.09)	3½ (.22)	50 (189.3)
Shower, therapeutic	15	6	11	15 (.95)	35 (2.21)	400 (1,514)
Sink, barium	3	2½	2½	4½ (.28)	4½ (.28)	15 (56.8)
Sink, clean-up room	3	2½	2½	4½ (.28)	4½ (.28)	15 (56.8)
Sink, central supply	3	2½	2½	4½ (.28)	4½ (.28)	15 (56.8)
Sink, clinical	10	10	3	25 (1.58)	3 (.19)	10 (37.9)
Sink, clinical, bed pan hose	10	10	4	25 (1.58)	4½ (.28)	15 (56.8)
Sink, floor kitchen	4	3	3	4½ (.28)	4½ (.28)	20 (75.7)
Sink, formula room	4	3	3	4½ (.28)	4½ (.28)	20 (75.7)
Sink, cup	1	1	—	3 (.19)	—	—
Sink, laboratory	2	1½	1½	3 (.19)	3 (.19)	5 (18.9)
Sink, laboratory and trough	3	2½	1½	5 (.32)	3 (.19)	5 (18.9)
Sink, pharmacy	2	1½	1½	3 (.19)	3 (.19)	5 (18.9)
Sink, plaster	4	3	3	4½ (.28)	4½ (.28)	15 (56.8)

contents shall be able to be tested for contamination and then emptied into a hazardous materials disposal truck. A washdown hose bibb for the area shall be provided. This area shall have a special entrance directly accessible from the outside.

Unique Fixtures

Fixture-unit values for the unique fixtures found in healthcare facilities can be found in Table 2-2.

Fixtures for Laboratory Rooms

Laboratory Sinks

Most of the time, the architect provides the countertops and sinks, usually made of epoxy or other acid-resistant materials, in their specifications. However, the plumbing designer occasionally is responsible for selecting the laboratory sinks. Laboratory sinks should be acid resistant and can be of stainless steel, stone, or plastic. Laboratory and cup sinks are currently available in epoxy resin, composition stone, natural stone, ceramic or vitreous china, polyester fiberglass, plastic, stainless steel, and lead. The lead type is not recommended where mercury, nitric, hydrochloric, or acetic acids are used.

Often, these laboratory sinks are furnished with the laboratory equipment as rectangular sinks or cup sinks mounted in, or as part of, countertops and as cup sinks in fume hoods. Rules of thumb that can be used when the sink sizes are not recommended by the laboratory staff are as follows:

- Sinks with a compartment size of 12×16×7.5 inches (304.8×406.4×190.5 mm) for general laboratory work areas
- Sinks with a compartment size of 18×24×10 inches (457.2×609.6×254 mm) for classroom work and tests
- Sinks with a compartment size of 24×36×12 inches (609×914.4×304.8 mm) for washing large equipment

The sink itself and sink outlet should be chemically resistant, a minimum of 316 stainless steel, and so designed that a stopper or an overflow can be inserted and removed easily. The outlet should be removable and have a strainer to intercept any materials that might cause a stoppage in the line. Unless an industrial water system is employed that isolates the laboratory water systems from the potable water system via a central backflow prevention device, all faucets should be provided with vacuum breakers. Supply fittings for distilled or deionized water are usually either virgin plastic or tin-lined and, where central systems are used, should be able to withstand higher pressures. Many fitting types, especially PVC, can handle pressures up to but not exceeding 50 psig (344.74 kPa). In these cases, pressure regulation is required.

Cup Sinks

These are small (3×6, 3×9, or 3×11 inches [76.2×152.4, 76.2×228.6, or 76.6×279.4 mm]) oval sinks for receiving chemicals, normally from a condensate or a supply line. They are designed to fit into the center section between tabletops, against a wall, or on raised back ledges. These sinks are also common in fume hoods.

Laboratory Glass Washers

These are usually included, either furnished by the laboratory equipment supplier or selected by the plumbing designer. Automatic washers are available. In addition to waste or indirect waste services, these units require hot water (usually 140°F [60°C] boosted to 180°F [82°C]) internal to the unit, distilled or deionized water, and compressed air. Manual-type glass bottle and tube washers also may be required in these rooms. Tube washers may have manifold-type supply fittings using cold water only. The manifolds can be fitted with a number of individually serrated tip outlets provided with separate controls and vacuum breakers.

Emergency Showers

These should be included throughout and located in adjacent corridors or at door exits. The showers must be accessible, require no more than 10 seconds to reach, and be within a travel distance of no greater than 100 feet (30.5 m) from the hazard rooms. The showerhead is a deluge type with a 1-inch (25.4-mm) nominal cold water stay-open design with a supply valve operated by a hanging pull rod, a chain and pull ring, or a pull chain secured to the wall. The latest edition of ANSI Z358.1: *Emergency Eyewash and Shower Equipment* and local codes should be consulted. A tempered water supply is required. A floor drain may be provided, if required. If floor drains are provided, trap primers should be incorporated.

Eyewash and Face Wash Fountains

Wash fountains also are required. These are wall- or counter-mounted units with a foot-pedal or wrist-blade-operated water supply fixture; double side-mounted, full-face wash outlets; or deck-mounted, handheld (with hose) face and body-spray units. ANSI Z358.1 and local codes should be consulted. A tempered water supply is required.

Laboratory Service Outlets

Outlets for air, nitrogen, vacuum, and other required gas services may be furnished as part of the related equipment under another contract or may be included in the plumbing work. In either case, the plumbing designer should be knowledgeable about the various types of service outlets currently available, the materials (or construction), and the usage (diversity). It is desirable to use bodies of cast red brass, brass forgings, or brass bar stock that are specially designed for laboratory use and, where possible, made by one manufacturer. Handles should be made of forged brass and provided with screw-in, color-coded index discs. All outlets should be properly labeled. Serrated tips should be machined from solid stock or forgings. The service fittings should be chrome plated over nickel plating or copper plating. The outlets in fume hoods should have an acid- and solvent-resistant plastic coating over the chrome-plated surface or be made of acid-resistant materials. Nonmetallic fittings are also available.

Special Equipment

The plumbing engineer should always consult with the equipment manufacturer's authorized representative and the local administrative authority to determine equipment requirements and acceptability under the jurisdiction's applicable codes during the preliminary design. Some example special equipment requirements are as follows:

- Dialysis machines require a funnel drain or floor sink and cold water hose bibb with a vacuum breaker.
- Heart-and-lung machines also require a funnel-type drain. If the apparatus is located in the operating room, an indirect waste is required.
- Electron microscopes require filtered, backflow-protected cold water or circulated chilled water.
- Stills for producing distilled water require cold water with a vacuum breaker and floor sinks or funnel drains.
- Sterilizers require an acid-resistant floor sink or funnel drains, a backflow-protected water supply, and sometimes steam and condensate connections.
- Film-processing (x-ray) areas require an acid-resistant floor sink or funnel drains for indirect waste and a hot, cold, and/or tempered water supply operating between 40 and 90°F (4.4 and 32.2°C). Drain piping for any photo-developing equipment should not be brass or copper. Polypropylene, high-silica, cast iron, corrosion-resistant piping and drains should be used. Silver recovery and neutralization may be required; consult with the local authority.
- Dental areas should include console services (water, air, medical gas, nitrous oxide, and waste). For oral surgery, a separate surgical vacuum system should be provided.

ACID WASTE DRAINAGE SYSTEMS

In addition to the conventional sanitary drainage systems (those found in most buildings), special sanitary drainage systems may be required in health-care facilities.

If possible, drainage piping shall not be installed within the ceiling or exposed in operating or delivery rooms, nurseries, food-preparation centers, food-serving facilities, food-storage areas, central services, electronic data-processing areas, electric closets, and other sensitive areas. Where exposed, overhead drain piping in these areas is unavoidable. Special provisions shall be made to protect the space below from leakage, condensation, or dust particles.

Acid waste drainage systems require special design criteria because the corrosive solutions demand special handling from the actual work area to an approved point at which such acid waste (and fumes) can be safely neutralized and discharged. The plumbing engineer must exercise extreme care in this regard.

Acid-resistant waste and vent systems are necessary where acids with a pH lower than 6.5 or alkalis with a pH greater than 8.5 are present. These special conditions are commonly encountered in hospitals, research facilities, and laboratories. Since acid fumes are often more corrosive than the liquid acids themselves, proper drainage and venting are imperative.

Nationally recognized standards for sanitary systems that handle acid wastes and other reagents are set forth in the model plumbing codes, and such systems often are further regulated by local building and safety or health department requirements. For these reasons, the plumbing engineer should check for all special design conditions that may affect the project.

Strong acids and caustics may enter the sanitary waste system in large quantities and at elevated temperatures. These substances can mix to form highly corrosive and even dangerous compounds. Common laboratory procedures encourage neutralization or flushing with copious amounts of water to dilute and cool these chemicals to more acceptable levels. However, the plumbing engineer must protect the acid waste system by designing for the maximum hazard conditions that might be brought about by any human error, poor housekeeping, or accidental spillage.

Corrosive Waste System Materials

Borosilicate Glass Pipe

Sizes range from 1½ to 6 inches (40 to 150 mm). Beneficial properties include a mechanical joint, flame resistance, easy visual inspection, and high corrosion resistance.

High-silicon Cast Iron

Sizes range from 1½ to 4 inches (40 to 100 mm). Beneficial properties include a mechanical joint, flame resistance, and high corrosion resistance. It acts as a fire stop at floor penetrations equal to cast iron, but it is more fragile and heavier than standard-weight cast iron and easier to break in the field. It is an excellent choice for moderate- to high-budget projects.

Polypropylene

Sizes range from 1½ to 6 inches (40 to 150 mm). It comes with mechanical or heat-fusion joints. Mechanical joints are not recommended for straight runs or sizes more than 2 inches (50 mm), but they should be used to access p-traps or other maintenance areas. Polypropylene is flame resistant and acceptable within most jurisdictions (meets 25/50 flame/smoke criteria). Newer Underwriters Laboratories (UL)-listed options are similar to glass in cost. Consult the local authority for approval. Polypropylene is lightweight and easy to install and is a good choice for moderate acids at low temperatures; however, it must be installed by qualified technicians. It is inexpensive compared to borosilicate glass and high-silicone cast iron.

Double-containment Waste Piping

With ever-increasing pressure to protect our environment, double-containment (pipe within a pipe) systems have become a strong consideration. Such piping is usually made of polypropylene inside and PVC or fiberglass outside. Systems should be pitched toward a containment vault for the collection of leaking fluid.

Alarm Systems

These can be employed to detect leaks at the collection basin, or if the budget and the nature of the liquid allow, sensors can be installed between the pipe walls that can pinpoint the original leak location. The latter could reduce the amount of excavation or exploration required to find a leak.

Discharge to Sewers

Many local jurisdictions require the building's sanitary sewer discharge to be at an acceptable pH level before it can be admitted into a sanitary sewage system. In such cases, it is recommended that a clarifying (or neutralizing) tank be added to the sanitary system. Small ceramic or polypropylene clarifiers with limestone can be located under casework for low flow rates; however, sufficient space must be allowed above the unit for servicing. Unless properly maintained and monitored, this type of system can be rendered ineffective. Large clarifiers and neutralizers may be

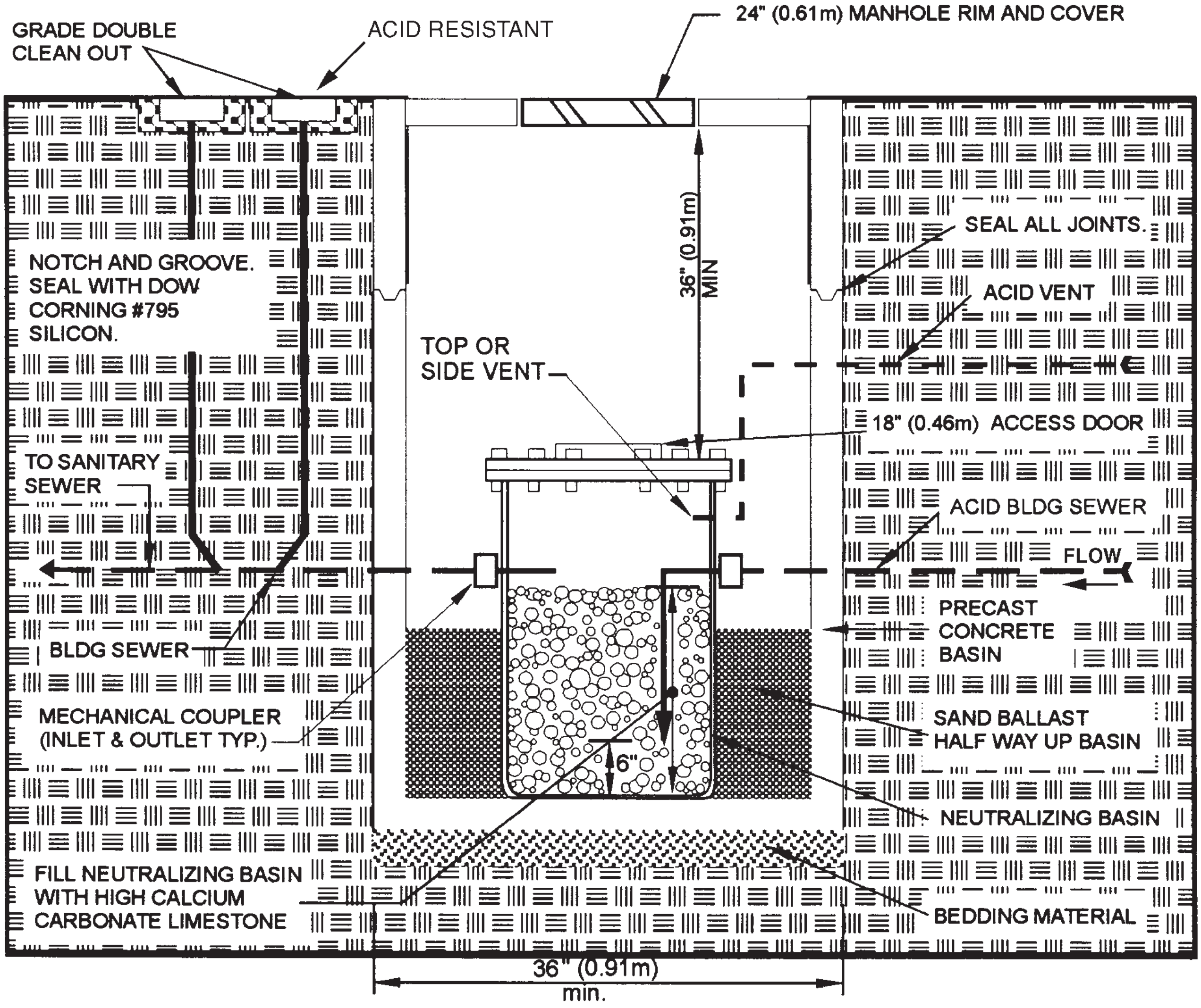


Figure 2-1 Acid-neutralizing Tank Detail

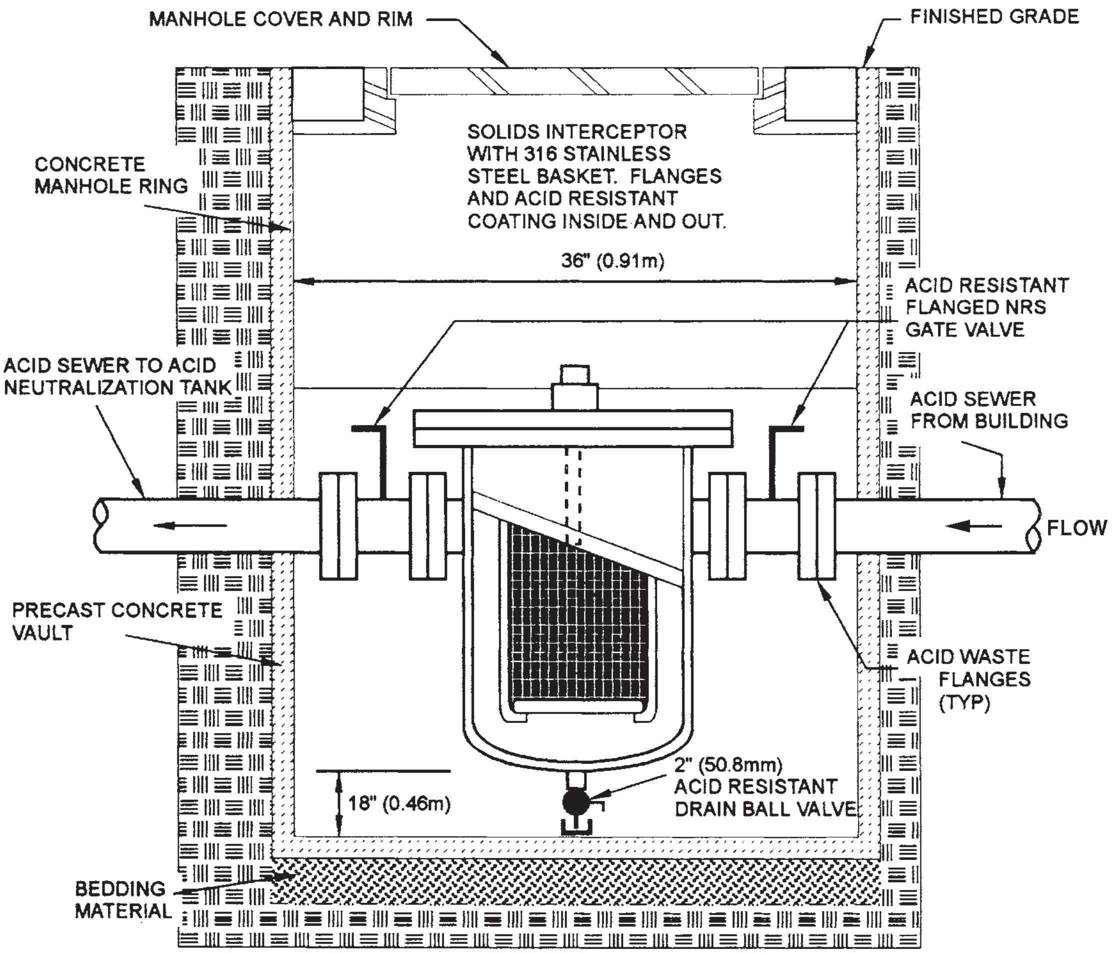


Figure 2-2 Acid Waste Solids Interceptor Detail

regulated by the requirements of a local industrial waste department.

Acidic Waste Neutralization

Lower pH values mean higher concentrations of acid, and discharging high concentrations of acid into a public sewer may cause considerable corrosion of piping systems and eventual failure. Most local authorities do not allow acid wastes to be discharged to a public sewer without some form of treatment.

The neutralization of acidic wastes is generally and most economically dealt with through an acid-neutralization tank, which may be constructed of polyethylene, molded stone, stainless steel, or another acid-resistant material. Tanks are sized to provide a dwell time of two to three hours (refer to Table 2-3). Limestone or marble chips fill the interior of the tank, helping neutralize incoming acid wastes. Chips may be 1 to 3 inches (25.4 to 76.2 mm) in diameter and should have a calcium carbonate content in excess of 90 percent. A discharge pH sensor and routine maintenance schedule must be provided to ensure that the system operates properly. An example of a neutralization tank is depicted in Figure 2-1.

Table 2-3 Acidic Waste Neutralization Tank Sizing Table

Number of Lab Sinks	Tank Size, gal (L)
2	5 (18.9)
4	15 (56.8)
8	30 (113.6)
16	55 (208.2)
22	75 (283.9)
27	90 (340.7)
30	108 (408.8)
40	150 (567.8)
50	175 (662.4)
60	200 (757.0)
75	275 (1,040.9)
110	360 (1,362.6)
150	500 (1,898.5)
175	550 (2,081.8)
200	650 (2,460.3)
300	1200 (4,542)
500	2000 (7,570)
600	3000 (11,355)

Note: For commercial and industrial laboratories, the number of lab sinks should be multiplied by a 0.5 use factor.

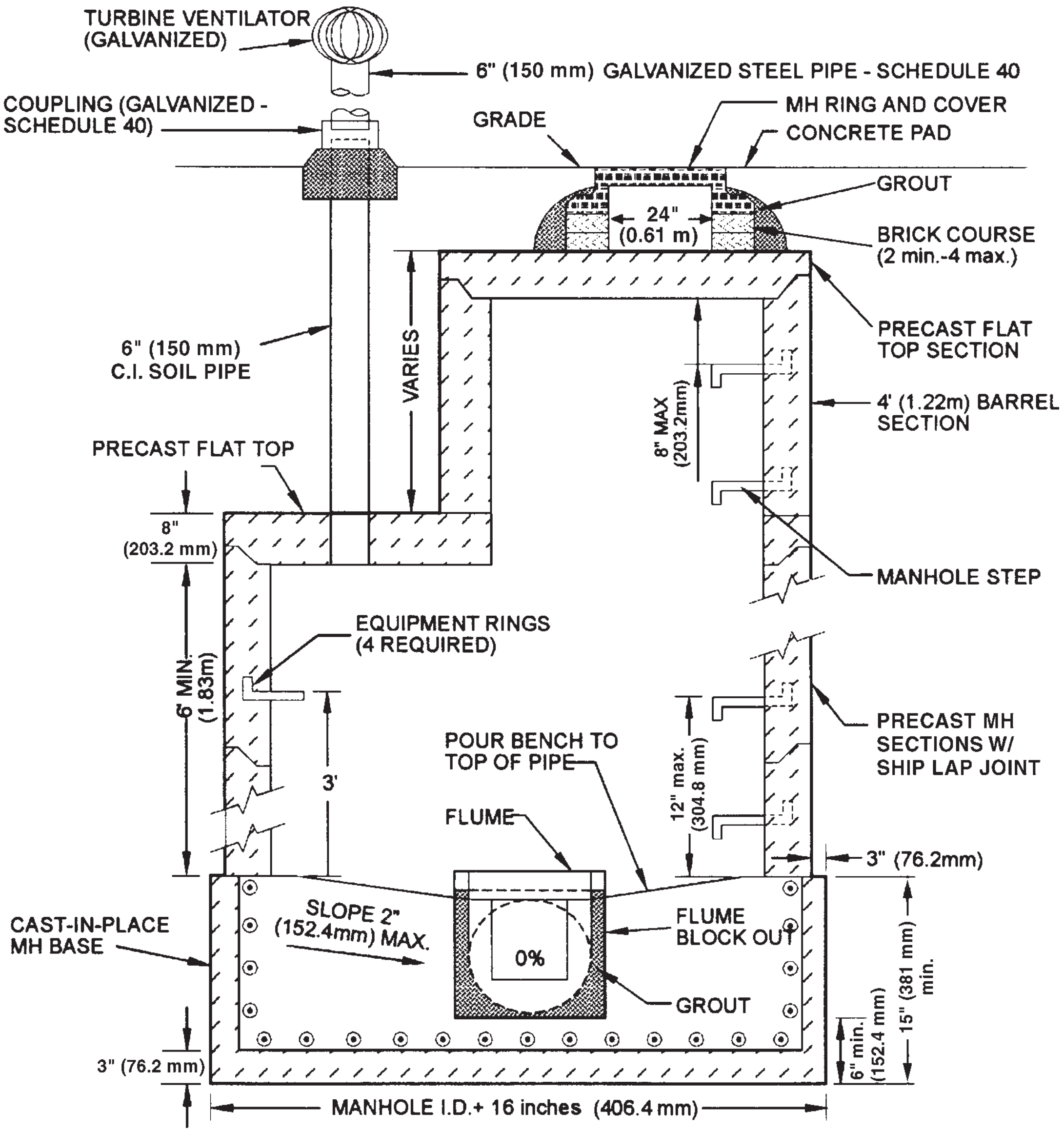


Figure 2-3 Sampling Manhole

Acid Waste Solids Interceptor

As with many sewer systems, it is impossible to control all materials discarded to the drain system. Unless building effluent is controlled, many unwanted items, such as glass fragments and needles, will find their way into the neutralization tank, thereby clogging the limestone or marble chips.

When this happens, replacement of the chips is required. One way to prolong chip life is to install an acid waste solids interceptor immediately upstream of the neutralization tank, as shown in Figure 2-2, although maintenance of the interceptor may have to be done quite frequently.

Acid Waste Metering Detail

Many local authorities require some means of sampling effluent from industrial, institutional, and laboratory buildings. An example of a device used for this purpose is a sampling manhole, depicted in Figure 2-3. This unit is installed as the last component before neutralized acidic wastes or treated industrial wastes are discharged to a public sewer. There are as many types of sampling point requirements as there are municipal sewer authorities. Consult local code authorities for individual requirements.

Traps for Laboratory Sinks

The trap is recognized by most plumbing engineers as the weakest link in the acid waste system. The trap must be acid resistant. If strong acids and solvents collect in an ordinary trap, failure of the system will occur. Three types of acid waste traps are currently in common use: p-traps, drum traps, and centrifugal drum traps. (Running and s-traps are not allowed by many local plumbing codes because of the potential for trap siphoning.) P-traps maintain a water seal to keep the acid fumes from reentering the work area. Drum traps provide a greater water seal and are frequently used to separate either precious metals or other matter before they enter the drainage system to become lost or cause a stoppage in the sink. Drum traps with removable bottoms should be installed high enough above the floor for servicing. P-traps, including some of the simple drum traps, can easily be back-siphoned if the head pressures are extreme. Centrifugal drum traps are designed to prevent back-siphonage conditions.

Laboratory Waste and Vent Piping

The sizing of under-table waste and vent piping, as determined by the local plumbing codes, should be suitable for the installation and allow for future expansion. Approved corrosion-resistant piping should be used for vent piping, since acid fumes are highly corrosive. Space is often limited under tables and in vent areas, and the space-saving features of mechanical joint piping have proven to be useful in many installations. (Note: When fusion-joint, plastic piping systems are used, mechanical joints should be installed at traps and trap arms for maintenance reasons.)

Special island (or loop) venting is frequently used when cabinets or work tables are located in the center of the laboratory area.

The transporting of acid waste, above and below the ground, must be done in approved, corrosion-resistant piping (acceptable to the local administrative authority) and continued to a suitable point where neutralization can occur or where sufficient water or chemicals can be introduced to bring the pH level of the solution to an acceptable level. Acids below a pH of 6.5 normally are not permitted into the sanitary sewage system or into surrounding soil, which would pollute (or degenerate) the local ground water. High-silicon cast iron with hub-and-spigot joints may be caulked with Teflon, or neoprene gaskets may be used for sealing. This type of joint allows flexibility and, when properly supported, is particularly recommended on the horizontal runs where the expansion and contraction of pipe from heated chemicals can cause leaking. Plumbing codes require proper bed preparation and careful backfilling on all belowground piping, particularly plastic piping.

The plumbing engineer should check the manufacturer's recommendations to evaluate the severity of the chemicals to be used. A listing of the common chemicals and how these substances react with the various materials must be considered by the designer.

WATER SUPPLY SYSTEMS

A domestic water supply of adequate flow volume and pressure must be provided for all plumbing fixtures and related equipment. Systems typically encountered in healthcare facilities are as follows:

- Potable water systems
  a. Cold water
  b. Hot water (at various temperatures)
  c. Chilled water
  d. Controlled-temperature (tempered) water
  e. Hot water recirculation
- Nonpotable water systems
- Pure water systems
  f. Distilled water
  g. Deionized (or demineralized) water
  h. Reverse osmosis

Healthcare facilities should have dual domestic water services installed to ensure the provision of an uninterrupted supply of water. The design should consider water-conservation provisions. Many local jurisdictions have strict water-conservation laws in effect. Water recycling may be a consideration for use in landscaping, etc., depending on local code and health department regulations. (For more information, see *Plumbing Engineering Design Handbook*, Volume 2, Chapter 2: "On-site Wastewater Reuse and Storm Water Harvesting.")

Water supply through a tank (suction or gravity type) should be considered by the plumbing engineer when the water supply source may be subjected to unusual demands, pressure fluctuations, and/or interruptions that will cause a sudden excessive draw and pressure loss on the main system. The tank will act as a buffer. Inadequate flow and pressure require the design of a water storage tank and/or a booster pump for the water supply system. Excessive pressure fluctuations are highly undesirable in medical research laboratories. When such facilities are supplied from street pressure systems, the engineer may provide pressure-reducing valves on the branch lines or a gravity tank system.

The use of diversity factors for sizing the water systems must be carefully analyzed by the designer. Medical school laboratory classrooms have higher rates of simultaneous use than most research laboratories. Emergency rooms, outpatient treatment rooms, and operating room wash-up areas also have high rates of simultaneous use.

Extreme care must be taken to protect the potable water supply from contamination (cross-connection). When an industrial (nonpotable) system is not present, the engineer should specify the appropriate type of vacuum breakers (necessary for each fixture below the rim connection), hose-end outlet, and an aspirator or other serrated-tip laboratory outlet, whether they are required by local plumbing regulations or not. The vacuum breakers provided for fume hood outlets should be located outside the hood. Built-in (or integral) vacuum breakers are preferred to the hose-end units.

Potable Water Systems

Cold water should be provided at all required locations. Hot water should be generated with the most economical heating medium available.

With today's technology, several reliable methods can be applied to produce and store domestic hot water. Refer to ASPE's *Domestic Water Heating Design Manual* and *Plumbing Engineering Design Handbook*, Volume 2, Chapter 6: "Domestic Water Heating Systems" for in-depth explanations of design methods for hot water systems and a discussion of the various hot water systems available. When large dump loads are anticipated (for kitchens and laundries), storage of hot water is recommended. Hot water usage in patient care areas requires consideration of water temperature and bacterial growth. The most common waterborne bacterium of concern is Legionella pneumophila.

Recommended water temperatures for specific applications are as follows:

- Patient care and hospital general usage requires water temperatures between 105 and 120°F (40.5 and 49°C), except where the local plumbing codes or other regulations require other maximum temperatures. Hot water distribution systems serving patient care areas shall be under constant recirculation to provide continuous hot water at each hot water outlet. The temperature of hot water for bathing fixtures and handwash lavatories shall be appropriate for comfortable use, but shall not exceed 120°F (49°C).
- Kitchen general usage requires 140°F (60°C) to fixtures, except the dishwasher's sanitizing cycle. The sanitizing cycle requires 180 to 190°F (82 to 88°C) to the dishwasher, with 180°F (82°C) minimum required at the dish rack. (Consult local health department regulations.) Also, some health departments set a maximum temperature of 105 to 120°F (40.5 to 49°C) for handwashing lavatories.
- Laundry facilities should be supplied with two water temperatures: 140°F (60°C) for general usage and 160°F (71°C) minimum to washers/extractors for laundry sterilization.

Providing a point-of-use booster heater for high-temperature applications instead of a central water heater system is often more economical.

A closed system of chilled water may be required for the cooling of electron microscopes and x-ray tubes and should be of a recirculating design.

Film processors operate at a normal range of 40 to 30°F (4.4 to -1.1°C). Some models require controlled water temperature for film processing. Depending on the quality of the water supply, a 5- to 75-micron filter may be required.

A thermometer should also be provided on the outlets of water heaters and thermostatically controlled valves. A pressure regulator, gauge, and flow meter may also be desired on the inlet side of pressure-sensitive equipment.

Nonpotable Water Systems

Nonpotable water systems are usually employed in areas having multiple water requirements that could contaminate the potable water supply. Areas in this category include flushing-rim floor drains in animal rooms, all outlets in autopsy rooms, outlets in isolation rooms, and all outlets in infectious disease and tissue culture rooms. These systems normally use reduced-pressure backflow preventers as the means to protect the potable water system. Hot water, when required, may be provided by a separate generator supplied from the nonpotable water system.

Pure Water Systems

"Pure water" is the term generally used to describe water that is free from particulate matters, minerals (soluble ions), bacteria, pyrogens, organic matters, and dissolved gases, which frequently exist in the potable water supply. Pure water systems are usually required in the hospital's pharmacy, central supply room, laboratories, and laboratory glassware-washing facilities.

Two basic types of pure water are available in hospital facilities: biopure water (water containing no bugs or other life forms) and high-purity water (pure water that is free from minerals, dissolved gases, and most particulate matters). Refer to *Plumbing Engineering Design Handbook,* Volume 2, Chapter 11: "Water Treatment, Conditioning, and Purification" for additional information on water purity.

Water purity is most easily measured as specific resistance (in ohm-centimeter [Ω-cm] units) or expressed as parts per million (ppm) of an ionized salt (NaCl). The theoretical maximum specific resistance of pure water is given as 18.3 MΩ-cm at 77°F (25°C). This water purity is difficult to produce, store, and distribute, as it is starved for impurities and constantly attempts to absorb contaminants. It is important to note that the specific resistance of pure water is indicative only of its mineral contents and in no way shows the level of bacterial, pyrogenic, or organic contamination. An independent laboratory analysis should be made whenever possible.

Purification Methods

The five basic methods of producing pure water are as follows: distillation, demineralization, reverse osmosis, filtration, and recirculation. Depending on the type of pure water required in the facility, one (or more) of these methods will be needed. Under certain conditions, a combination of several methods may be necessary.

Distillation This method produces biopure water, which is completely free of particulate matters, minerals, organics, bacteria, pyrogens, and most of the dissolved gases and has a minimum specific resistance of 300,000 Ω. An important consideration in this case is that the water is free from bacteria and pyrogen contamination, which is dangerous to patients, particularly where intravenous solutions are concerned. Biopure water is needed in the hospital's pharmacy, central supply room, and other areas where patient contact may occur. Biopure water may also be desired in certain specific laboratories at the owner's request and as a final rinse in the laboratory's glassware washer.

The typical water distillation apparatus consists of an evaporator section, an internal baffle system, a water-cooled condenser, and a storage tank. The best material for its construction is a pure block-tin coating for both the still and the tank. The heat sources, in order of preference based on economy and maintenance, are as follows: steam, gas, and electricity. The still may be operated manually or automatically. The distilled water may be distributed from the storage tank by gravity or by a pump. A drain is required for system drainage and flushing. On stills larger than 50 gallons per hour (gph) (189.3 L/h), a cooling tower should be considered for the condenser water.

Demineralization Sometimes called deionization, demineralization produces high-purity water that is completely free of minerals, most particulate matters, and dissolved gases. Depending on the equipment used, it can have a specific resistance ranging from 50,000 Ω to nearly 18 MΩ. However, it could be contaminated with bacteria, pyrogens, and organics. (These contaminants may be produced inside the demineralizer itself.) Demineralized water can be employed in most laboratories, the laboratory's glass-washing facilities (as a final rinse), and as the pretreatment for still feedwater.

The typical demineralizer apparatus consists of either a two-bed deionizing unit (with a resistivity range of 50,000 Ω to 1 MΩ) or a mixed-bed deionizing unit (with a resistivity range of 1 to 18 MΩ). The columns are of an inert material filled with a synthetic resin, which removes the minerals by an ionization process. Since the unit operates on pressure, a storage tank is not required or recommended (as bacteria will grow in it). A demineralizer must be chemically regenerated periodically, and during that regeneration time no pure water is produced. If a continuous supply of pure water is needed, a backup unit should be considered by the engineer, as the regeneration process takes several hours. The regeneration process can be done manually or automatically. An atmospheric, chemical-resistant drain is required. High-flow water is required for backwash during the regeneration.

Reverse Osmosis (RO) Reverse osmosis produces a high-purity water that does not have the high resistivity of demineralized water and is not biopure. Under certain conditions, an RO process can offer economic advantages over demineralized water. In areas that have high mineral contents, an RO process can be used as a pretreatment for a demineralizer or a still.

Several types of reverse osmosis units are currently available. Units consist of a semipermeable membrane, in either a roll form or a tube containing numerous hollow fibers. The water is then forced through the semipermeable membrane under high pressure. A drain is required with these systems.

Note: Chlorine must be removed from the water, or it will destroy the RO membrane.

Filtration Various types of filters are currently available to remove particulate matters from the water as a pretreatment. Depending on the type of filter, a drain may be required. Bacteria may be eliminated through ultraviolet sterilization.

Recirculation High-purity systems should be provided with a circulation loop. Dead-end legs should be avoided whenever possible or limited to 50 inches (1.52 m). System design velocity should be between 4 and 7 feet per second (fps) (1.22 and 2.13 m/s) to discourage bacteria accumulation and to provide transport back to an ultraviolet sterilizer and filtration for removal.

Pure Water Piping Systems

Water treatment system components are selected to remove various impurities from the influent water. Connecting various system components involves the use of interconnecting piping. The use of this piping should not add any such impurity back into the treated water.

Selection of piping system materials is determined by the application intended, availability of the material, and cost of the material. Pure water applications, such as exist in the healthcare industry, can be very sensitive to the piping methods selected.

General pure water piping requirements include the following:

- Use inert materials to avoid leaching contaminants into the water.
- Use clean joining methods; avoid solvents, lubricants, and crevices.
- Materials must not erode or flake off particles.
- Materials should not enhance microorganism growth.
- Materials should be smooth, free of cracks and crevices, and nonporous.
- Avoid dead legs—system should have continuous flow through the piping.
- Provide chemical cleaning connections.
- Install (slope) with future cleaning and disinfection in mind.

A wide variety of piping materials are available on the market today. Their properties and cost cover a wide range. Common pure water materials include the following:

- Stainless steel, various grades (304L and 316L)
- Aluminum
- Tin-lined copper
- Glass or glass-lined pipe
- PVC or CPVC (polyvinyl chloride or chlorinated polyvinyl chloride)
- Polypropylene
- Polyethylene
- ABS (acrylonitrile butadiene styrene)
- PVDF (polyvinylidene fluoride)

Metal Pipe Aluminum, tin-lined copper, and stainless steel pipe all have been used in pure water treatment systems. Tin-lined pipe was once the material of choice in ultra-pure water systems. However, it leaches tin and eventually copper into the process fluid. Methods of joining tin-lined pipe can also create non-smooth joints with crevices.

Aluminum pipe has also been used in pure water systems. Pure water creates an oxide layer inside the pipe that continually erodes, producing particles and aluminum in the water.

Stainless steel has been used extensively in high-purity water systems. It can be joined with threads, butt welded, flanged, or manufactured with sanitary-type connection ends. Because it can use sanitary joints and can handle steam sterilizing, the sanitary-type connection method has been used in many pharmaceutical applications. However, experience has shown that even the best grades of stainless steel with the best joints still leach material from the metal that can cause problems in critical water systems.

Glass or Glass-lined Pipe Glass piping has been used in some special laboratory applications, but because it is fragile and leaches material into the water, it is not generally considered applicable for high-purity water systems.

PVC PVC pipe has been used on equipment and in piping systems successfully for many years. However, advances in technology, especially in electronics, have now raised questions about the true purity or inertness of PVC.

PVC pipe contains color pigments, plasticizers, stabilizers, and antioxidants that all can leach out of the plastic and into ultra-pure water. Remember that 18,000,000-Ω quality water is highly aggressive. When PVC pipe is made (extruded), bubbles of air exist, some of which are covered over with a thin film of PVC on the interior walls of the pipe. As the pipe ages, these thin coverings wear away, exposing small holes that then serve as debris-collecting or microorganism-breeding sites, not to mention the contribution of PVC particles and the potential release of organic dispersants, stabilizers, etc., originally trapped in these bubbles (holes).

Joints, either solvent welded or threaded, can leave crevices for the accumulation of particles and bacteria. Solvents from the weld can leach into the water. Premium grades of PVC, which reportedly have fewer leachables than standard PVC, are now being marketed.

CPVC is a special high-temperature PVC that has similar erosion and leachable characteristics.

Polypropylene Polypropylene is a very inert, strong piping material. However, in the manufacture of the pipe, antioxidants and other additives are used to control embrittlement. These additives are potential sources of contaminants that can leach into the water. However, a virgin material with no leachable products is now available.

Polypropylene pipe shows good ability to withstand both corrosive chemicals and high temperatures, up to 220°F (104°C). The natural toughness of the material minimizes damage to the pipe during installation and service.

Polypropylene is generally joined by the butt-fusion method, resulting in smooth joints.

ABS Acrylonitrile butadiene styrene (ABS) plastic pipe has been used in the primary stages of water treatment systems because of its relatively low cost and ease of installation.

ABS has some of the same contamination leach problems as PVC. In its manufacture, pigment dispersants, surfactants, styrene, and other additives are used that can leach into water over time. Hydrogen peroxide (used for system cleaning) will attack ABS plastic.

PVDF Numerous types of high-molecular-weight fluorocarbon pipes are on the market—SYGEF, Kynar, and Halar, to name a few. PVDF plastic can be extruded without the use of additives that can leach out. The different polymerization techniques used by each manufacturer can produce slightly different properties.

PVDF pipe is currently considered to be the state of the art in pure water piping systems. It has exceptional chemical resistance, temperature range (-40 to 320°F [-40 to 160°C]), impact strength, resistance to UV degradation, and abrasion resistance and smooth, clean, inside surfaces that discourage the collection of bacteria and particles. Most laboratory test reports show virtually zero leachables from PVDF piping systems.

PVDF pipe is joined by the butt-fusion method, resulting in clean, smooth joints.

When system pressures exceed 70 psig (482.6 kPa) or temperatures exceed 75°F (24°C), plastic piping system manufacturers should be consulted for compatibility. Polypropylene or PVDF-lined metal piping systems may be incorporated to meet pressures up to 150 psig (1034.2 kPa).

MEDICAL GAS AND VACUUM SYSTEMS

Healthcare is in a constant state of change, which forces the plumbing engineer to keep up with new technologies to provide innovative approaches to the design of medical gas systems. In designing medical gas and vacuum systems, the goal is to provide a safe and sufficient flow at the required pressure to the medical gas outlet or inlet terminals served. System design and layout should allow convenient access by the medical staff to outlet and inlet terminals, valves, and equipment during patient care or emergencies.

This section focuses on the design parameters and current standards required for the design of nonflammable medical gas and vacuum systems used in therapeutic and anesthetic care. The plumbing engineer must determine the needs of the healthcare staff. Try to work closely with the medical staff to seek answers to the following fundamental design questions at the start of a project:

- How many outlets and inlets are requested?
- How many outlets and inlets are required?
- Based on current conditions, how often is each outlet or inlet used?
- Based on current conditions, what is the average duration of use for each outlet or inlet?
- What is the proper usage (diversity) factor to be used?

Medical Gas System Design Checklist

As any hospital facility must be specially designed to meet the applicable local code requirements and the healthcare needs of the community it serves, the medical gas and vacuum piping systems also must be designed to meet the specific requirements of each hospital.

Following are the essential steps to a well-designed and functional medical gas piped system, which are recommended to the plumbing engineer.

1. Analyze each specific area of the healthcare facility to determine the following items:
   - Which piped medical gas systems are required?
   - How many of each different type of medical gas outlet and inlet terminal are required?
   - Where should the outlet and inlet terminals be located for maximum efficiency and convenience?
   - Which type and style of outlet and inlet terminal best meet the needs of the medical staff?
2. Anticipate any building expansion and in which direction the expansion will take place (vertically or horizontally). Determine how the medical gas system should be sized and valved to accommodate the future expansion.
3. Determine locations for the various medical gas supply sources:
   - Bulk oxygen (O_2)
   - High-pressure cylinder manifolds (O_2, N_2O, or N_2)
   - Vacuum pumps (VAC)
   - Medical air compressors (MA)
4. Prepare the schematic piping layout locating the following:
   - Zone valves
   - Isolation valves
   - Master alarms
   - Area alarms
5. Calculate the anticipated peak demand for each medical gas system. Appropriately size each particular section to avoid exceeding the maximum pressure drops allowed.
6. Size and select the various medical gas and vacuum supply equipment that will handle the peak demand for each system, including future expansions. If this project is an addition to an existing facility, determine the following:
   - What medical gases are currently provided and what are the locations and number of the stations?
   - Can the current gas supplier (or the hospital's purchasing department) furnish the consumption records?
   - Are the capacities of the existing medical gas supply systems adequate to handle the additional demand?
   - Are any existing systems valved that could be used for an extension? Are the existing pipe sizes adequate to handle the anticipated additional loads?
   - What type of equipment is in use and who is the manufacturer? Is this equipment state of the art?
   - Is it feasible to manifold the new and existing equipment?
   - What is the physical condition of the existing equipment?
   - Is adequate space available for the new medical gas supply systems and related equipment at the existing location?
   - Is existing equipment scheduled to be replaced? (A maintenance history of the existing equipment may help in this determination.)

Number of Stations

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

No code specifically mandates the exact number of stations that must be provided in various areas or rooms for all healthcare facilities. In fact, there is no clear consensus of opinion among medical authorities or design professionals as to how many stations are actually required in the facility areas. Guidelines are published by the American Institute of Architects (AIA), National Fire Protection Association (NFPA), and American Society of Plumbing Engineers (ASPE) that recommend the minimum number of stations for various services in specific areas.

The most often used recommendations for determining the number of stations for hospitals are those necessary to be accredited by The Joint Commission. Accreditation is required for Medicare and Medicaid compensation. The Joint Commission publishes a manual that refers to the AIA guidelines for the minimum number of stations for oxygen, medical air, and vacuum that must be installed to obtain accreditation. If this is a factor for the facility, these requirements are mandatory. Other jurisdictions, such as state or local authorities, may require plans to be approved by local health or building officials. These approvals may require adhering to the state or local requirements and/or NFPA 99: *Standard for Healthcare Facilities*.

If accreditation or the approval of authorities is not a factor, the number and area of locations of stations are not mandated. The actual count will depend on requirements determined by each individual facility or another member of the design team using both past experience and anticipated future use, often using the guideline recommendations as a starting point. Table 2-4 provides these recommendations.

Medical Gas Flow Rates

Each station must provide a minimum flow rate for the proper functioning of connected equipment under design and emergency conditions. The flow rates and diversity factors vary for individual stations in each system depending on the total number of outlets and the type of care provided.

The flow rate from the total number of outlets, without regard for any diversity, is called the total connected load. If the total connected load were used for sizing purposes, the result would be a vastly oversized system, since not all of the stations in the facility will be used at the same time. A diversity, or simultaneous-use factor, is used to allow for the fact that not all of the stations will be used at once. It is used to reduce the system flow rate in conjunction with the total connected load for sizing mains and branch piping to all parts of the distribution system. This factor varies for different areas throughout any facility. The estimated flow rate and diversity factors for various systems, area stations, and pieces of equipment are found in Tables 2-5, 2-6, and 2-7.

Total demand for medical gas systems varies as a function of time of day, month, patient care requirements, and facility type. The number of stations needed for patient care is subjective and cannot be qualified based on physical measurements. Knowing the types of patient care and/or authority requirements will allow placement of stations in usage groups. These groups can establish demand and simultaneous-use factors (diversities), which are used in the calculation for sizing a particular system. All medical gas piping systems must be clearly identified using an approved color-coding system similar to that shown in Table 2-8.

Medical Gas System Dispensing Equipment

Medical Gas Outlet and Inlet Terminals

Most manufacturers of medical gas system equipment offer various types of medical gas outlets. These medical gas outlets are available in various gas orders (e.g., O_2-N_2O-air), center-line spacing, and for exposed and concealed mountings. Outlet types and configurations must meet the requirements of the local jurisdictional authority and NFPA 99. All outlets must be properly identified and confirmed. Care should also be taken to accurately coordinate the various pieces of medical gas-dispensing equipment with the architect and medical staff involved in the project. If the project is a renovation, the outlet types should match existing equipment. With prefabricated patient headwall units, the medical gas outlets are generally furnished by the equipment manufacturer, and it is very important to maintain coordination to avoid unnecessary duplication of work. Over-the-bed medical gas service consoles are often specified in the electrical or equipment section of the specification, and medical gas service outlets are specified, furnished, and installed under the mechanical contract.

Gas outlet sequence, center-line spacing, and multiple gang-service outlets are some of the considerations to be taken into account when requesting information from the various equipment manufacturers. It is more practical, in terms of both the cost of the equipment and the installation, to specify and select the manufacturer's standard outlets. Details and specifications regarding the individual standard outlets are usually available from all manufacturers upon request.

The existing outlets are compatible with the adapters found on the hospital's anesthesia machines, flow meters, vacuum regulators, etc. Care should be taken to make sure all future expansions in the same facility have compatible equipment.

Patient Headwall Systems

A recent and growing trend in hospital construction is the requirement for patient headwall systems,

Table 2-4 Inlet/Outlet Station Data

Room	O_2	VAC	N_2O	Air	N_2	EVAC	Typical Uses
Anesthesia workroom	1	1	[a]	1			Equipment repair testing
Animal oper. (research surgery)	1	1	[a]				Animal anesthesia and surgery
Animal research lab	1	1		1			Routine animal care
Autopsy	1	1					Suction waste materials from body
Bed holding	1	1					Cardiac arrest, O_2 therapy
Biochemistry	[b]	1		1			Standard lab use[a]
Biochem. lab	[b]	1		1			Standard lab use[a]
Biophysics/biochemical	[b]	1		1			Standard lab use[a]
Blood processing		1		1			Standard lab use[a]
Blood receiving (blood donors)	1	1		1			Emergency use
Cardiac catheterization room	1	2					Cardiac arrest and other emergencies
Chem analysis lab (sm. lab in hosp.)		1		1			Standard lab use[a]
Chemical lab		1		1			Standard lab use[a]
Cystoscopy	1	3				1	Emergency use
Decontamination room (attached to inhalation therapy dept.)	1	1		1			Equipment testilng
Deep therapy	1	2					Cardiac arrest and other emergencies
Demonstration room (in-service training)	1	1					Demo. equip. to new empl. & students
Dental repair	1	1		1	[b]		Power drills (dental)
Dispensary (minor surgery, first aid, student health & exams)	[a]			[a]			Emergency use
Ear-nose-throat exam	1	1		1			Aspiration; topical spray
ECG (electrocardiogram)	1	1					Cardiac arrest and other emergencies
EEG (electro-encephalograms)	1	1					Cardiac arrest and other emergencies
Electron microscopy	1	1		1			Standard lab use[a]
Emergency room	1	2		1			Cardiac arrest and other emergencies
EMG (electromyogram)	1	1					Cardiac arrest and other emergencies
Examination room	1	1		1			Drive air tools and vacuum cleaning
Exam room and proctoscopic	1	1		1			Cardiac arrest and other emergencies
Experimental lab	[b]	1		1			Standard lab use[a]
Eye examination	1	1					Stock and cardiac arrest
Fluoroscopy (x-ray)	1	2					Cardiac arrest and other emergencies
Heart catheterization lab	1	1		1			Cardiac arrest and other emerg. respir.
Hematology	1	1		1			Standard lab use[a]
Intensive-care areas	2	3		1			For critically ill
Isolation (infectious & contagious diseases)	1	1		1			Patient care
Isolation room (patient room for contagious diseases)	1	2		1			Oral, gastric or thoracic
Lab annex		1		1			Pull waste evac. tubing drying apparatus
Lab cleanup area		1		1			Drying glassware
Lab—workroom		1		1			Standard lab use[a]
Labor rooms—O.B.	1	1	[a]				Analgesia, patient care
Linear accelerator vault	1	1		1			
Microbiology		1		1			Standard lab use[a]
Microbiology lab—constant temp room		1		1	[b]		Standard lab use[a]
Multi-service room	1	1					Cardiac arrest and other emergencies
Neurological pharmacy teaching lab	1		1				Standard lab use[a]
Neurological physiology teaching lab	1	1		1			Standard lab use[a]
Nursery (full-term)	1	2		1			Incubators, respirators
Nursing floor	1	2		1			Therapy, oral, gastric; IPPB, aerosols
Nursing, security (psychiatric violent patients use lock box)	1	1		1			Patient care
Observation	1	1					Cardiac arrest and other emergencies
Obstetrics (delivery room)	1	3	[a]				Analgesia, anesthesia, patient care
Operating room (surgery—major and minor	2	3	1	1	[a]	1	Patient care
Oral lab (dental)	[a]	1	[a]	1	[a]		Standard lab use[a]
Orthopedic exam room	1	1					Cardiac arrest and other emergencies
Pathology (Drs. office special lab tests)		1		1			Standard lab use[a]

Table 2-4 Inlet/Outlet Station Data (continued)

Room	O_2	VAC	N_2O	Air	N_2	EVAC	Typical Uses
Patient room	1	1		1			Patient care
Pharma. room (drug prep.)		1		1			Standard lab use[a]
Physiology lab—general	1	1		1			Standard lab use[a] plus teaching
Premature nursery and obs.	2	1		1			Incubators—respirators
Radiation, low-level (x-ray dept.)	1	2		1			Cardiac arrest and other emergencies
Radio-chemical lab		1		1			Standard lab use[a]
Radioisotope, high level (x-ray dept.)	1	2		1			Cardiac arrest and other emergencies
Radioisotope room (research room for animal lab)		1		1			Standard lab use[a]
Recovery beds	2	3		1			2 thoracic, 1 oral, 1 gastric or wound
Recovery room—private (same as regular recovery)	1	3		1			Note: Need 1 more VAC for thoracic
Respiratory therapy	1	1		1			For out-patient treatments IPPB
Scanning room (part x-ray)	1	2					Cardiac arrest and other emergencies
Serology		1		1			Standard lab use[a]
Sterilization (CS or OR)	1	1		1			Equipment testing
Surgical preparation room	1	1		1			Pre-medication for anesthesia
Teaching lab	1	1		1			Standard lab use[a]
Treatment room	1	1		1			Special therapy
Urinalysis		1		1			Standard lab use[a]
Standard x-ray rooms	1	2		1			Cardiac arrest and other emergencies

Source: Information furnished courtesy of Puritan-Bennett, modified by ASPE.

a One outlet per area.

b Consult owner for number and location.

Table 2-5 Medical Air Peak Demand Chart

Area	Free Air Design Flow, scfm (L/min)			Simultaneous Use Factor (%)
	per Room	per Bed	per Outlet	
Anesthetizing locations[a]				
Special surgery	0.5 (15)	—	—	100
Major surgery	0.5 (15)	—	—	100
Minor surgery	0.5 (15)	—	—	75
Emergency surgery	0.5 (15)	—	—	50
Radiology	0.5 (15)	—	—	25
Cardiac catheterization	0.5 (15)	—	—	50
Acute Care locations				
Recovery room	—	2 (60)	—	50
ICU/CCU	—	2 (60)	—	50
Emergency room	—	2 (60)	—	50
Neonatal ICU	—	1.5 (40)	—	75
Dialysis unit	—	—	0.5 (15)	10
Sub-acute Care locations				
Nursery	—	—	0.5 (15)	25
Patient rooms	—	0.5 (15)	—	10
Exam & treatment	1 (30)	—	—	10
Pre-op holding	—	—	1.5 (40)	10
Respiratory care	—	1 (30)	—	50
Pulmonary function lab	—	—	1 (30)	50
Other				
Anesthesia workroom	1.5 (40)	—	—	10
Respirator-care workroom	1.5 (40)	—	—	10
Nursery workroom	1.5 (40)	—	—	10
Equipment repair	—	—	1.5 (40)	10

[a] These design flows are based on the use of air in the patient breathing circuit only. If air is to be used to power equipment such as an anesthesia ventilator, the design flow should be increased accordingly.

Table 2-6 Outlet Rating Chart for Medical Vacuum Piping Systems

Location of Medical/Surgical Vacuum Outlets	Free Air Allowance, cfm (L/min) at 1 atmosphere		Zone Allowances—Corridors, Risers, Main Supply Line, Valves	
	Per Room	Per Outlet	Simultaneous Usage Factor (%)	Air to Be Transported cfm (L/min)[a]
Operating rooms:				
Major “A” (Radical, open heart; organ transplant; radical thoracic)	3.5 (100)	—	100	3.5 (100)
Major “B” (All other major ORs)	2.0 (60)	—	100	2.0 (60)
Minor	1.0 (30)	—	100	1.0 (30)
Delivery rooms	1.0 (30)	—	100	1.0 (30)
Recovery room (post anesthesia) and intensive-care units (a minimum of 2 outlets per bed in each such department):				
1st outlet at each bed	—	3 (85)	50	1.5 (40)
2nd outlet at each bed	—	1.0 (30)	50	0.5 (15)
3rd outlet at each bed	—	1.0 (30)	10	0.1 (3)
All others at each bed	—	1.0 (30)	10	0.1 (3)
Emergency rooms	—	1.0 (30)	100	1.0 (30)
Patient rooms:				
Surgical	—	1.0 (30)	50	0.5 (15)
Medical	—	1.0 (30)	10	0.1 (3)
Nurseries	—	1.0 (30)	10	0.1 (3)
Treatment & examining rooms	—	0.5 (15)	10	0.05 (1)
Autopsy	—	2.0 (60)	20	0.04 (1)
Inhalation therapy, central supply & instructional areas	—	1.0 (30)	10	0.1 (3)

[a] Free air at 1 atmosphere.

Table 2-7 Medical Vacuum Peak Demand Chart (Medical/Surgical Vacuum System)

Area	Free Air Design Flow, scfm (L/min)			Simultaneous Usage Factor (%)
	per Room	per Bed	per Outlet	
Anesthetizing locations:				
Specialized surgeries (open heart, organ transplant, etc.)	4 (115)	—	1.5 (40)	100
Major operating rooms	3.5 (100)	—	—	100
Cystoscopy	2 (60)	—	—	100
Delivery room	1 (30)	—	—	100
Emergency operating room	3 (85)	—	—	100
Other anesthetizing areas (minor O.R., orthopedic O.R., cardiac catheterization, radiology, induction rooms, etc.)	1 (30)	—	—	50
Waste anesthetic gas evacuation	2 (60)	—	—	100
Acute care (non-anesthetizing locations):				
Post-operative recovery room	—	3 (85)	—	50
O.B. recovery room	—	2 (60)	—	50
Intensive care units (except cardiac)	—	2 (60)	—	75
Emergency room	—	1 (30)	—	100
Cardiac intensive care	—	2 (60)	—	50
Neonatal I.C.U.	—	1 (30)	—	50
Sub-acute patient care areas:				
Normal nursery	—	—	1 (30)	10
Premature nursery	—	1 (30)	—	20
Labor/birthing	—	1 (30)	—	10
Patient room (surgical)	—	1.5 (40)	—	50
Patient room (medical)	—	1 (30)	—	10
Exam & treatment rooms	—	—	1 (30)	10
Other areas:				
Autopsy			2 (60)	20
Central supply			1.5 (40)	10
Respiratory care department			1.5 (40)	5
Equipment repair, calibration, and teaching			1.5 (40)	10
Medical lab			1 (30)	10

Table 2-8 Color Coding for Piped Medical Gases

Gas Intended for Medical Use	United States Color	Canada Color
Oxygen	Green	Green on white[a]
Carbon dioxide	Gray	Black on gray
Nitrous oxide	Blue	Silver on blue
Cyclopropane	Orange	Silver on orange
Helium	Brown	Silver on brown
Nitrogen	Black	Silver on black
Air	Yellow*	White and black on black and white
Vacuum	White	Silver on yellow[a]
Gas mixtures (other than mixtures of oxygen and nitrogen)	Color marking of mixtures shall be a combination of colors corresponding to each component gas.	
Gas mixtures of oxygen and nitrogen		
19.5 to 23.5% oxygen	Yellow[a]	Black and white
All other oxygen concentrations	Black and green	Pink

Source: Compressed Gas Association, Inc.

[a] Historically, white has been used in the United States and yellow has been used in Canada to identify vacuum systems. Therefore, it is recommended that white not be used in the United States and yellow not be used in Canada as a marking to identify containers for use with any medical gas. Other countries may have differing specific requirements.

which incorporate many services for the patient's care. These units may include the following:

- Medical gas outlets
- Electrical service outlets (including emergency power)
- Direct and indirect lighting
- Nurse call system
- Isolation transformers
- Grounding outlets
- Patient-monitoring receptacles
- Vacuum slide and IV brackets
- Nightlights
- Electrical switches

Bed locator units are also available, which serve to provide power for the more advanced patient beds, telephone, nightlight, and standard power. These units also function to protect the walls from damage as beds are moved and adjusted.

Headwalls currently vary in shape, size, type, and cost from a simple over-the-patient-bed standard configuration to elaborate total-wall units. Most manufacturers of medical gas equipment offer medical gas outlets for all types of patient consoles available in today's market. When specifying headwall outlets, the plumbing engineer should consider the following:

- Is the service outlet selected compatible with the existing outlet component?
- Does the patient headwall manufacturer include the type of medical gas outlets required as part of the product?

Special Types of Ceiling-mounted Medical Gas Outlets

In critical care areas, which are generally considered by most individuals to be those locations of the hospital providing a special treatment or service for the patient (such as surgery, recovery, coronary, or intensive care units), the designer's selection and placement of the medical gas service equipment must be done very carefully to provide efficient work centers around the patient for the medical staff.

Manufacturers of medical gas service equipment usually provide a wide range of equipment that is available for use in these areas. Depending on the customer's preference and the available budget, the equipment is selected to provide the necessary individual gas services and accessories.

Table 2-9 provides a quick reference guide for the engineer to use as a basis for selecting the commonly used types of outlet-dispensing equipment.

Example 2-1

The following example presents some of the most important critical care area equipment and options for the selection of the equipment.

Surgery medical gas services to be piped include:

- Oxygen
- Nitrous oxide
- Nitrogen
- Medical compressed air
- Vacuum
- Waste anesthetic gas disposal
- Carbon dioxide

Providing medical gas service outlets in the surgery room may be accomplished in several ways, such as the following:

- Ceiling outlets: Individual medical gas outlets are mounted in the ceiling with hose assemblies providing the medical staff with connections from the outlets to the administering apparatus. This method is considered to be the most economical means of providing an adequate gas service to surgery areas. The ceiling gas service outlets are generally located at both the head and the foot of the operating table to provide alternate positioning of the table.

- Surgical ceiling columns: Surgical ceiling columns are usually available in two designs: rigid (a predetermined length from the ceiling height above the floor) and retractable. Both types of surgical ceiling column provide medical gas services within an enclosure that projects down from the ceiling. The ceiling columns are usually located at opposite ends of the operating table to provide convenient access to the medical gas outlets by the anesthesiologist. In addition to the medical gas outlets, these ceiling columns can be equipped with electrical outlets, grounding receptacles, physiological monitor receptacles, and hooks for hanging intravenous solution bottles. Most manufacturers offering surgical ceiling columns allow for many variations in room arrangements of medical gas services and related accessories, depending on the specific customer's needs and the engineer's specifications. When specifying this type of equipment, it is necessary to carefully specify all medical gas service requirements and their desired arrangements. Also, the engineer must coordinate all other required services with the electrical engineer and medical staff.
- Surgical gas tracks: Surgical gas tracks are forms of ceiling outlet and hose-drop arrangements that allow the movement of the hose drops from one end of the operating table to the other on sliding tracks mounted on the ceiling. These products are currently available from various manufacturers, and all provide the same basic services. The proper selection and specification of specific types are based on individual customer preference. Many variations in products and particular product applications are available in critical (intensive) care areas. Consultation with the appropriate manufacturers for recommendations is always advisable.
- Articulating ceiling-service centers: Articulated ceiling-service centers are moved by pneumatic drive systems and are designed for the convenient dispensing of medical gas and electrical services in operating rooms. The medical gas and electrical systems are complete for single-point connection to each outlet at the mounting support platform.

High-pressure Nitrogen-dispensing Equipment

Special consideration must be given by the plumbing engineer to the placement of the nitrogen outlets. The primary use of nitrogen gas in hospitals is for driving turbo-surgical instruments. Variations of these turbo-surgical instruments, in both their manufacture and intended use, will require several different nitrogen gas pressure levels to be available. For this reason, it is necessary for the engineer to provide an adjustable pressure-regulating device near the nitrogen gas outlet. A nitrogen control panel is usually located on the wall (in the surgery room) opposite the operating

Table 2-9 Types of Dispensing Equipment for Specific Areas

	Medical Gas Outlet Dispensing Equipment						
Hospital Areas	**Wall-mounted Outlets**	**Patient Care Head Wall**	**Ceiling-mounted Outlets with Hose Stops**	**Rigid Ceiling Columns**	**Retractable Ceiling Columns**	**Ceiling with Gas Stacks**	**Nitrogen Control Cabinets**
Autopsy rooms	●		●				
Delivery rooms	●		●				
Emergency examination and treatment rooms	●		●				
Emergency operating rooms	●						●
Induction rooms	●						
Labor rooms	●	●					
Major surgery rooms	●		●	●	●	●	●
Minor surgery, cystoscopy	●		●				●
Neonatal intensive care units	●	●					
Normal nursery rooms	●	●					
Nursery workrooms	●						
O.B. recovery rooms	●	●					
Patient rooms	●	●					
Pediatric and youth intensive care unit	●	●	●				
Post-operative recovery rooms	●	●	●				
Premature and pediatric nursery rooms	●	●	●				
Pre-op holding rooms	●	●					
Radiology rooms	●						
Respiratory care unit	●						
Specialized surgeries (cardiac and neuro)	●		●				

area sterile field. The installation should allow for the access and adjustment of pressure settings by a surgical nurse.

Piping from the nitrogen control panel to a surgical ceiling outlet will provide a convenient source of nitrogen for surgical tools. This will prevent hoses from being located on the floor or between the wall outlet and the operating table. Excess hose can be obstructive to the surgical team.

Medical Gas Storage

After deciding the medical gas services to be provided at the facility, the engineer should determine the storage capacity and the pipe sizing required and possible locations for the source. Local codes and references as well as the administrative authority having jurisdiction should be consulted for each medical gas system.

Because of the unique characteristics of each medical gas source, the gases are described separately in this section. Also, an explanation of the techniques currently employed to exhaust anesthetic gases is provided.

Figure 2-4 illustrates a typical layout of liquid oxygen, oxygen emergency reserve supply (equal to one day's supply), cylinder nitrous oxide supply, and cylinder nitrogen supply.

Oxygen

Several factors must be known when estimating the monthly consumption of oxygen in new or existing healthcare facilities:

- Type of medical care provided
- Number of oxygen outlets or number of patient beds
- Future expansion of facility
- Approximate consumption (in existing facilities)

Two methods can be used by the plumbing engineer to estimate the consumption of oxygen. The more accurate method is to obtain a detailed consumption record from the healthcare facility or monthly oxygen shipment invoices from the supplier. If inventory records are not available from the healthcare facility or the supplier, use consumption records from a comparably sized facility, with good judgment.

The second method is to apply the following rules of thumb to estimate the monthly supply of oxygen. This estimating method should be used with good judgment. Always coordinate estimated demand with the oxygen supplier during the design process.

- In non-acute care areas, allow 500 cubic feet (14 m^3) per bed per month for supply and reserve oxygen storage.
- In acute care areas, allow 1,000 cubic feet (28 m^3) per bed per month for supply and reserve oxygen storage.

Oxygen supply sources are divided into two categories: bulk oxygen systems and cylinder manifold supply systems. Bulk oxygen systems should be considered for healthcare facilities with an estimated monthly demand more than 35,000 cubic feet (991 m^3) or equal to 70 oxygen outlets. Manifold systems are used in small general hospitals or clinics.

Bulk Oxygen Systems When selecting and placing bulk oxygen systems, several factors must be considered: oxygen transport truck size, truck access to bulk storage tanks, and NFPA 50: *Standard for Bulk Oxygen Systems at Consumer Sites*. Bulk oxygen equipment, construction, installation, and location must comply with NFPA 50 recommendations. If liquid oxygen is spilled or leaked, an extreme fire or explosive hazard could occur. NFPA has design standards to minimize fire exposure to and from surrounding structures. The location of bulk oxygen storage tanks and equipment must be certain distances from specified structures and materials, as shown in Table 2-10.

Bulk storage systems consist of cryogenic tanks that store liquid oxygen at low pressures (225 psi [1,551.3 kPa] or less). Cryogenic tanks are ASME unfired, double-walled, vacuum-insulated pressure vessels. Liquid oxygen has a boiling point of -297.3°F (-182.9°C) and a liquid density of 71.27 pounds per cubic foot (1,141.8 kg/cm^3). When vaporized into gas, it produces 900 times its liquid volume. Furthermore, since the tank is changed less often, process stability is maximized, and the introduction of atmospheric impurities is reduced. Tank systems are furnished with an integral pressure-relief valve vented to the atmosphere should the liquid oxygen convert to a gas. Table 2-11 depicts currently available cryogenic tank capacities, and Figure 2-5 illustrates a typical bulk oxygen system schematic.

Most bulk oxygen storage systems are furnished with vaporizers. Vaporizers are banks of finned-tube heat exchangers that convert the liquid to its gaseous state. The vaporizers come in several sizes and styles, including atmospheric, powered (forced air, steam, and electric), waste heat, and hybrid. The selection of a vaporizer should be based on demand, intermittent or continuous usage, energy costs, and temperature zones. Poorly ventilated sites or undersized heat exchangers can cause ice to form on vaporizers during the conversion process, and excessive ice formations can clog and damage the vaporizer. Also, ice could allow extremely cold gas or the cryogenic liquid to enter the piped system; damage the valves, alarms, and medical components; and even injure patients. Automatic controls furnished with the tanks regulate the flow of liquid through the vaporizers. When there is a demand for oxygen, the supply system draws liquid from the bottom of the cryogenic storage tank through

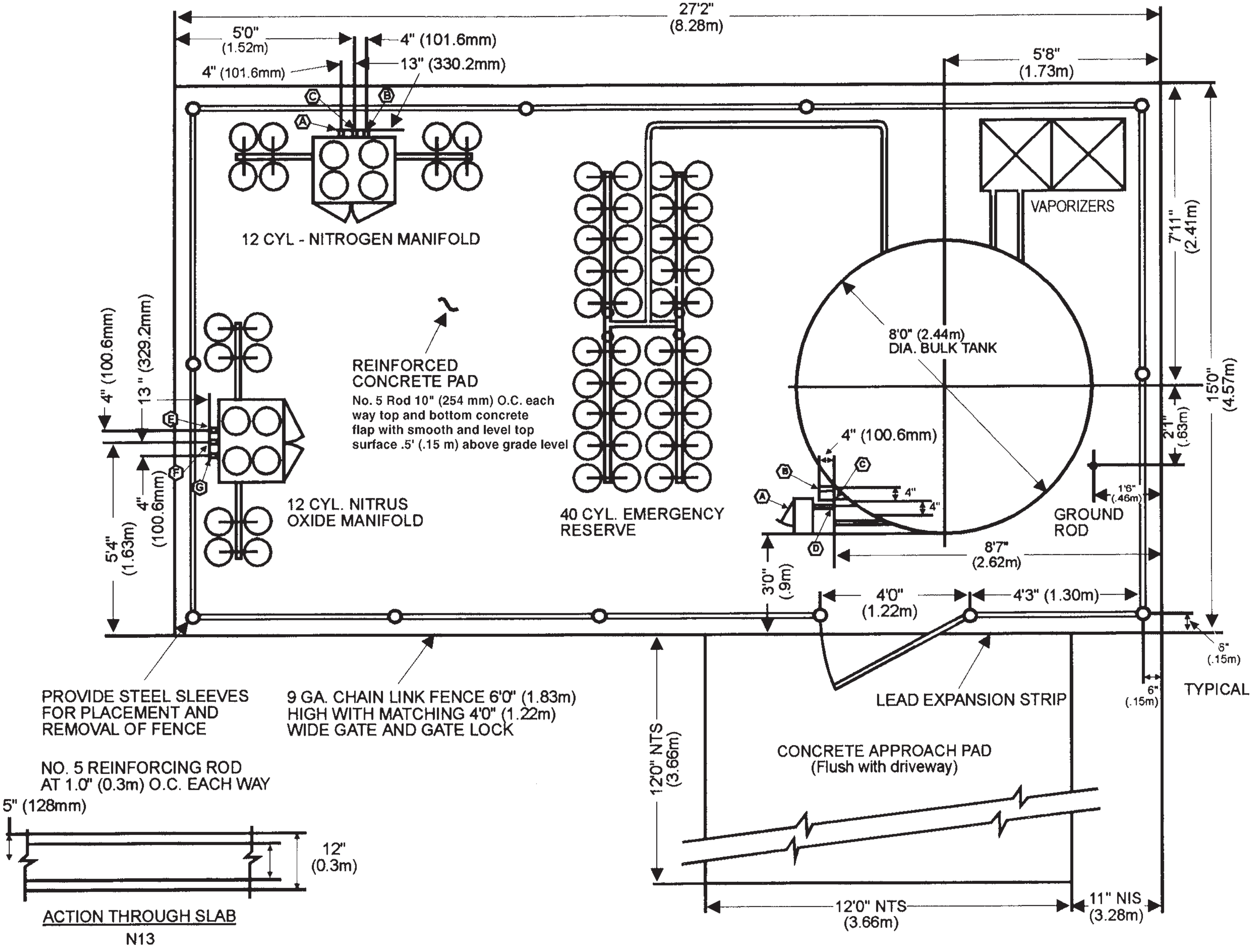


Figure 2-4 Typical Layout of Liquid Oxygen, Oxygen Reserve Supply, Cylinder Nitrous Oxide Supply, and Cylinder Nitrogen Supply

Table 2-10 Exterior Bulk Oxygen Storage Installation Criteria

Bulk Tank Separation Distances, ft (m)	Item
1 (0.30)	Building structure (except wood frame)
5 (1.52)	Property line
10 (3.05)	Parked vehicles, sidewalk, structure openings
15 (4.57)	All classes of flammable and combustible liquids stored below ground. Class III B liquid, 1000 gal (3785 L) or less, above-ground storage.
25 (7.62)	Solid slow-burning material, coal, lumber, etc., underground tank vent or fill openings. Above-ground flammable and combustible liquids, 1000 gal (3785 L) or less, except Class III B liquids.
35 (10.67)	Clearance for ventilation one side.
50 (15.24)	Public assembly area, open or enclosed. Wood-frame structure. Non-ambulatory patient area.
75 (22.86)	Liquefied hydrogen storage above ground. Clearance for ventilation one side.
25 (7.62)	1000 gal (3785 L) liquefied gas or 25,000 ft^3 (700 m^3) non-liquefied gas.
50 (15.24)	Over 1000 gal (3785 L) of liquefied gas or over 25,000 ft^3 (700 m^3) of non-liquefied gas.

Source: NFPA 50

the vaporizers, and then the gas moves through a final line regulator. Thus, a constant supply of oxygen at a regulated pressure is provided.

In case of mechanical difficulty or the depletion of the liquid oxygen supply, the reserve supply will begin to feed into the distribution system automatically. An alarm signal should alert appropriate hospital personnel when the liquid in the oxygen storage tank reaches a predetermined level. The alarm signals should indicate low liquid levels, reserve in use, and reserve low.

Cylinder Manifold Supply Systems Compressed-oxygen systems are comprised of cylinder manifolds that allow a primary supply source of oxygen cylinders to be in use and an equal number of oxygen cylinders to be connected as a reserve supply. The controls of the cylinder manifold will automatically shift the flow of the oxygen gas from the service side to the reserve side when the service side is depleted. Refer to Figure 2-6 for a typical oxygen manifold system schematic.

Manifold systems can be located indoors or outdoors. When manifolds are located indoors, the engineer should observe the following:

- Location: Preferably, the manifold should be in a dedicated room on an outside wall near a loading dock and have adequate ventilation and service convenience. Air compressors and vacuum pumps shall be located separately from medical gas (i.e., oxygen and nitrous oxide cylinder storage enclosures).
- Adjacent areas: There should be no doors, vents, or other direct connections between the anesthetizing location or the storage location and any combustible agents. If locating near or adjacent to an elevated-temperature area is unavoidable, the engineer should specify sufficient insulation to prevent cylinder overheating.
- Fire rating: The fire-resistance rating of the room should be at least one hour.
- Ventilation: Outside ventilation is required. If the total amount of gas in a room exceeds 3,000 cubic feet, mechanical ventilation is required. Relief vents from manifolds shall be piped to the outside.
- Security: The room (or area) must be provided with a door or a gate that can be locked and labeled.

Oxygen manifolds are sized taking into consideration the following:

- Size of the cylinders (see Table 2-12 for a sizing chart)
- Hospital's usage of oxygen, in cubic feet (L) per month

Nitrous Oxide

The common source of nitrous oxide is a cylinder manifold system. High-pressure manifold systems

Table 2-11 Cryogenic Storage Tank Capacities

Gross Volume, gal (L)	Net Liquid Capacity, gal (L)	Capacity Oxygen, ft^3 (10^6 L)	Approximate Weight Empty Vessel, lb (kg)	Approximate Weight Vessel Loaded with Oxygen, lb (kg)
330 (1249.1)	314 (1188.5)	36,200 (1.02)	4,000 (1816)	7,000 (3178)
575 (2176.4)	535 (2025)	61,500 (1.74)	5,800 (2633.2)	10,900 (4948.6)
975 (3690.4)	920 (3482.2)	105,700 (2.99)	9,300 (4222.2)	18,100 (8217.4)
1,625 (6150.6)	1,533 (5802.4)	176,100 (4.99)	10,400 (4721.6)	25,000 (11 350)
3,400 (1286.9)	3,250 (12 301.3)	374,000 (10.59)	18,500 (8399)	49,400 (22 427.6)
6,075 (22 993.9)	5,935 (22 463.9)	684,999 (19.40)	27,999 (12 711.5)	83,500 (37 909)
9,200 (34 822)	8,766 (33 179.3)	1,009,000 (28.57)	34,000 (15 436)	117,500 (53 345)
11,000 (41 635)	10,500 (39 742.5)	1,215,000 (34.41)	40,000 (18 160)	139,750 (63 446.5)

Note: Consult local supplier for available tank capacities.

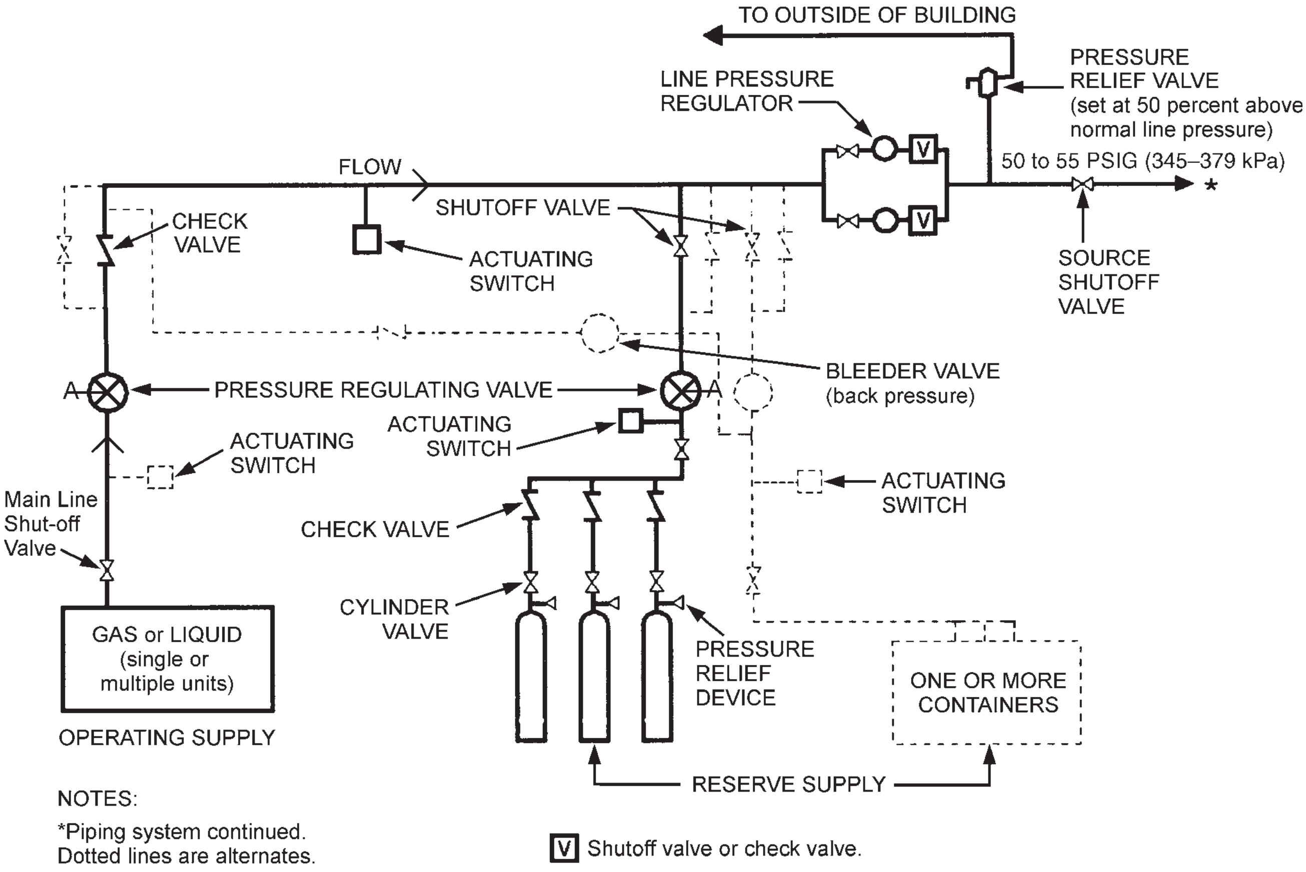


Figure 2-5 Typical Bulk Supply System Schematic

consist of two banks of cylinders, primary and reserve. (See the discussion under "Oxygen" above.)

System demands for nitrous oxide can be more difficult to determine than they are for other medical gases. The number of surgeries scheduled, types and lengths of surgeries, and administering techniques used by the anesthesiologists cause extreme variations in the amount of nitrous oxide used. Because of this variation, consideration must be given to the size and selection of the nitrous oxide manifold system.

Avoid locating the nitrous oxide manifold system outdoors in areas with extremely cold climates. Nitrous oxide is supplied liquefied at its vapor pressure of 745 psi at 70°F (5,136.6 kPa at 21.1°C). At extremely cold temperatures, the cylinder pressure will drop dramatically to a point where it is impossible to maintain an adequate line pressure. This is due to a lack of heat for vaporization. For nitrous oxide manifolds located indoors, the same precautions previously listed for oxygen systems must be observed. Central supply systems for nitrous oxide and carbon dioxide using cylinders or portable containers shall be prevented from reaching temperatures lower than 20°F (-6.7°C) and higher than 130°F (54.4°C).

The following should be considered when selecting and sizing nitrous oxide manifolds and determining the number of cylinders required:

- Size of the cylinders (see Table 2-13)
- Number of anesthetizing locations or operating rooms

Provide one-half of one cylinder per operating room for in-service and reserve supplies.

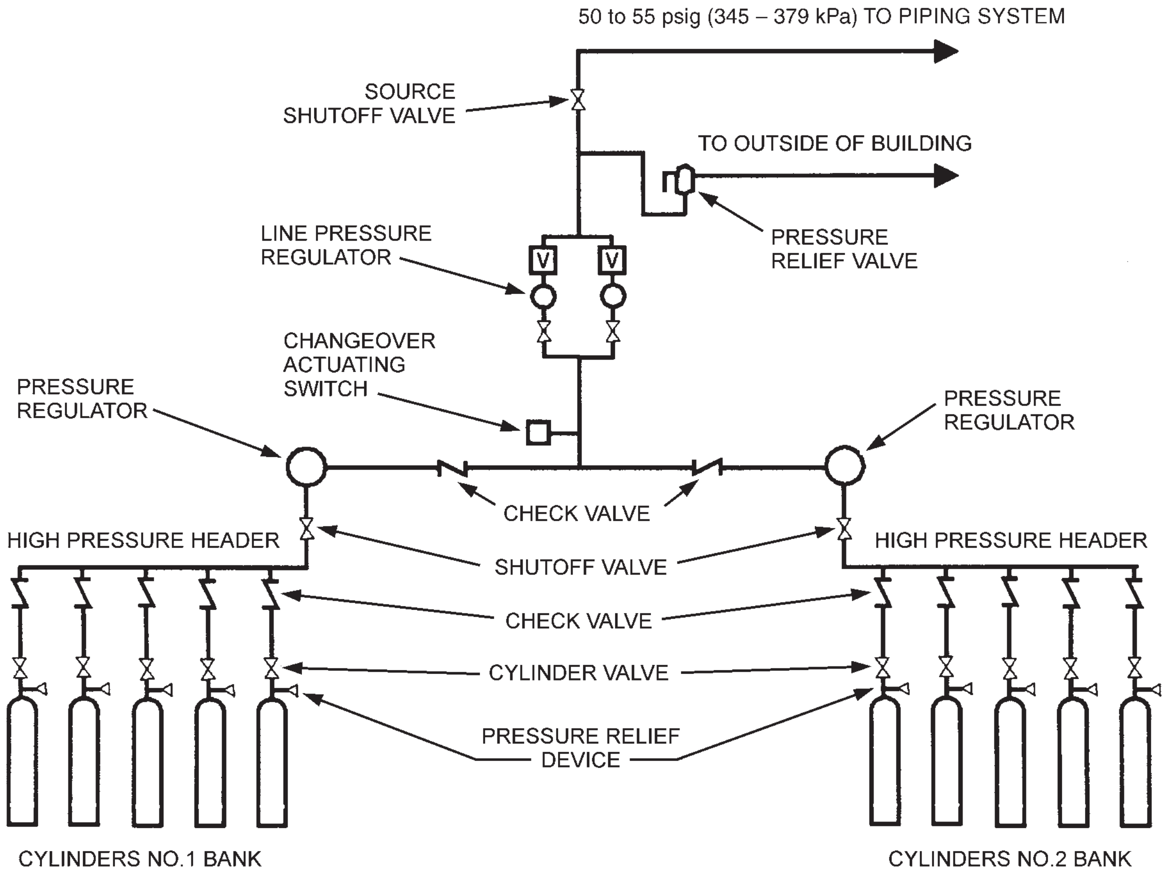
Carbon Dioxide

Carbon dioxide is now a common gas used in the operating room, and the same requirements for nitrous oxide manifolds and piping apply. System demand also is typically the same as nitrous oxide.

Table 2-12 Selection Chart for Oxygen Manifolds

Hospital Usage		Duplex Manifold Size	
Cu. Ft. (10^3 L) per month		Total Cylinders	Cylinders per Side
5,856	(165.8)	6	3
9,760	(276.4)	10	5
13,664	(386.9)	14	7
17,568	(497.5)	18	9
21,472	(608.0)	22	11
25,376	(718.6)	26	13
29,280	(829.1)	30	15
33,154	(938.8)	34	17

Note: Based on use of 244 ft^3 (6909.35 L) H-cylinders.



NOTES:

For SI Units: 1 psig = 6.895 kPa guage.

V Shutoff valve or check valve.

Figure 2-6 Typical Cylinder Supply System without Reserve Supply Schematic

Note: Supply systems with different arrangements of valves and regulators are permissible if they provide equivalent safeguards (Level 1 gas system).

Medical Compressed Air

Medical/surgical low-pressure compressed air (at about 55 psig [379.2 kPa]) and high-pressure instrument air (at 200 psig [1,379 kPa]) are usually supplied from air compressors. In facilities that require less volume, a manifold system may be provided. The manifold systems for compressed air are similar in configuration to those for oxygen and nitrous oxide (see the discussion under "Oxygen" above). Air supplied from cylinders or that has been reconstituted from oxygen USP and nitrogen NF must comply, at a minimum, with Grade D in ANSI/CGA G-7.1: *Commodity Specification for Air*.

Medical compressed air produced by compressors may be defined as outside atmospheric air to which no contaminants (in the form of particulate matter, odors, oil vapors, or other gases) have been added by the compressor system. It must comply with NFPA 99 and/or the Canadian Standards Association's air-quality standards. Air compressed for medical-breathing purposes is to be used for this purpose only and should not be used for other applications or cross-connected with other compressed air systems.

Table 2-13 Sizing Chart for Nitrous Oxide Cylinder Manifolds

Number of Operating Rooms	Duplex Manifold Size			
	Indoor		Outdoor	
	Total Cylinders	Cylinders per Side	Total Cylinders	Cylinders per Side
4	4	2	4	2
8	8	4	10	5
10	10	5	12	5
12	12	6	14	7
16	16	8	20	10

Note: Based on use of 489 ft^3 (13.85×10^3 L) K-cylinders.

Not every compressor is suitable for use as a source for medical compressed air in healthcare facilities. Only those compressor units specifically designed and manufactured for medical purposes should be considered as a reliable source of oil-free, moisture-free, and low-temperature compressed air. Three major types of medical air compressors are in the marketplace today: centrifugal, reciprocating, and rotary screw. The reciprocating and rotary screw are positive-displacement units, while the centrifugal compressor is a dynamic compressor. The medical air compressor shall be designed to prevent the introduction of contaminants or liquid into the pipeline by one of two methods: Type 1 air compressors eliminate oil anywhere in the compressor, while Type 2 air compressors separate the oil-containing section from the compression chamber. Examples of a Type 1 compressor are the liquid ring, rotary screw, and permanently sealed bearing compressor. Type 2 compressors have extended heads.

A positive-displacement compressor is rated in actual cubic feet per minute (acfm). This is the amount of air taken from atmospheric conditions that the unit will deliver at its discharge. Within a broad range, changes in inlet air temperature, pressure, and humidity do not change the acfm rating of either the reciprocating or the rotary screw compressor. The centrifugal compressor's capacity, however, is affected slightly by the inlet air conditions due to the nature of the compression process. For example, as the air temperature decreases, the capacity of the dynamic compressor will increase. The capacity of a centrifugal compressor is defined in inlet cubic feet per minute (icfm). In an effort to obtain an "apples to apples" comparison of various compressors, many manufacturers specify their capacity requirements in standard cubic feet per minute (scfm). This sometimes causes much confusion because many people do not fully understand how to convert acfm or icfm to scfm (see Figure 2-7). The design engineer specifying scfm must define a typical inlet air condition at the building site and a set of standard conditions—typically 14.7 pounds per square inch absolute (psia) at 60°F (101.4 kPa at 15.6°C) and 0 percent relative humidity. The warmest normal condition often is specified because scfm decreases as the temperature increases.

In the case of a dynamic compressor, the icfm airflow at the given inlet conditions is inserted in place of the acfm in the formula. Another design issue that the engineer should be aware of is how altitude affects the output of the compressor. At altitudes above sea level, all medical air systems have reduced flow. In these cases, the required sizing will need to be adjusted to compensate. To do this, multiply the scfm requirements by the correction factor in Table 2-14. In other words, to correctly size the medical air system, apply the correction factor listed in Table 2-14 to the peak-calculated load (scfm) at sea level.

Example 2-2

A facility is located at 5,000 feet (1,524 m) above sea level, and the system demand is 29.4 scfm. What is the adjusted scfm?

Multiply 29.4 scfm by 1.08 (the correction factor from Table 2-14) to get the adjusted scfm requirement of 31.8 scfm at 5,000 feet above sea level.

As this example shows, a medical air system of greater capacity is needed at higher altitudes.

Another handy formula for compressed air systems is the following: to convert scfm to L/min, multiply the scfm by 28.31685.

Each compressor must be capable of maintaining 100 percent of the medical air peak demand regardless of the standby compressor's operating status. Where more than two units are provided for a facility, any two units must be capable of supplying the peak calculated demands (refer back to Table 2-5). Provide automatic alternators (duty-cycling controls) to ensure even wear in normal usage. Alternator controls incorporate a positive means of automatically activating the additional unit (or units) should the in-service pump fail to maintain the minimum required pressure.

The basic compressor package consists of filter intakes, duplex compressors, aftercoolers, receiving

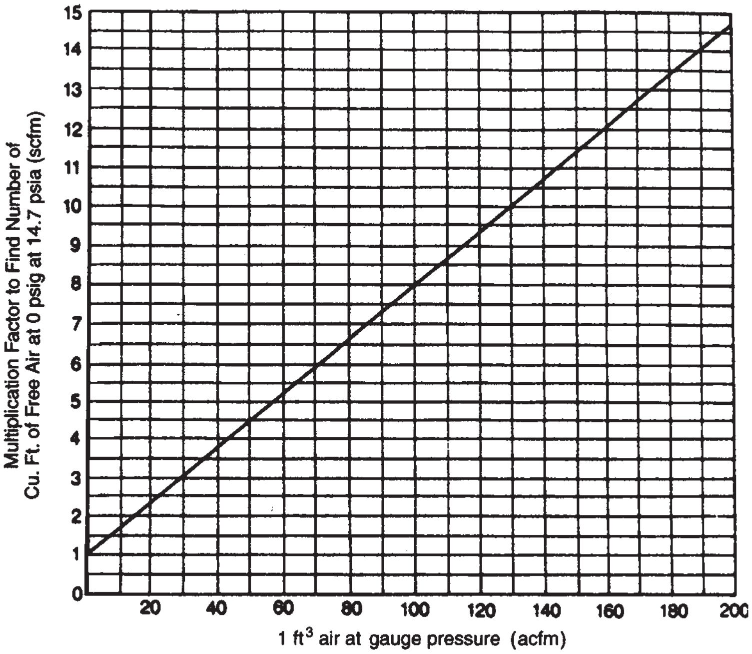


Figure 2-7 Conversion from acfm to scfm

Ratio of free air to compressed air. To find the free air equivalent for 1 acfm at 130 psig pressure, find 130 at the bottom, go up to the diagonal, then horizontal to the left, to find the multiplier of 9.8. Then 1 acfm will equal 9.8 scfm.

1 psig × 7 = kPa.

1 cfm × 0.03 = m³/min.

Source: Facility Piping Systems Handbook

Table 2-14 Altitude Correction Factors for Medical Air Systems

Altitude, ft (m)	Normal Barometric Pressure, in. Hg (mm Hg)	Correction Factor for scfm (L/min)
Sea level	29.92 (759.97)	1.0 (28.31)
1,000 (304.8)	28.86 (733.04)	1.01 (28.6)
2,000 (609.6)	27.82 (706.63)	1.03 (29.16)
3,000 (914.4)	26.82 (681.23)	1.05 (29.73)
4,000 (1219.2)	25.84 (656.33)	1.06 (30.01)
5,000 (1524)	24.90 (632.46)	1.08 (30.58)
6,000 (1828.8)	23.98 (609.09)	1.10 (31.14)
7,000 (2133.6)	23.09 (586.48)	1.12 (31.71)
8,000 (2438.4)	22.23 (564.64)	1.15 (32.56)
9,000 (2743.2)	21.39 (543.3)	1.17 (33.13)
10,000 (3048)	20.58 (522.7)	1.19 (33.69)

tanks, air dryers, inline filters, regulators, dewpoint monitors, and valves. The compressor components are connected by piping that allows equipment isolation, provides pressure relief, and removes condensate from receivers. See Figure 2-8 for a typical arrangement of a medical air compressor system.

The compressor air intake shall be located outside above the roof level, at a minimum distance of 10 feet (3.05 m) from any door, window, exhaust, other intake, or opening in the building, and a minimum distance of 20 feet (6.1 m) above the ground. (Refer to NFPA 99 for the proper location of medical air intakes.) The compressor shall draw air from a source of clean air located where no contamination is anticipated from engine exhausts, fuel storage vents, medical/surgical vacuum system discharges, particulate matter, or odor of any type. Beware of gases from boilers and gas-fired water heaters, as they are a common source of problems with medical air intakes. Where the outside atmospheric air is polluted, special filters can be attached to the compressor's intake to remove carbon monoxide and other contaminants.

Table 2-15 provides the minimum pipe sizes for medical air compressor intake risers. Consult with the compressor manufacturer on intake recommendations and allowable friction loss for the intake riser before finalizing the pipe size equipment selection.

High-pressure Gas (Nitrogen) or Compressed Air Systems

The supply source for nitrogen is generally in the form of high-pressure cylinder manifolds (see the discussion under "Oxygen" above). The primary use of nitrogen is to power surgical pneumatic instruments.

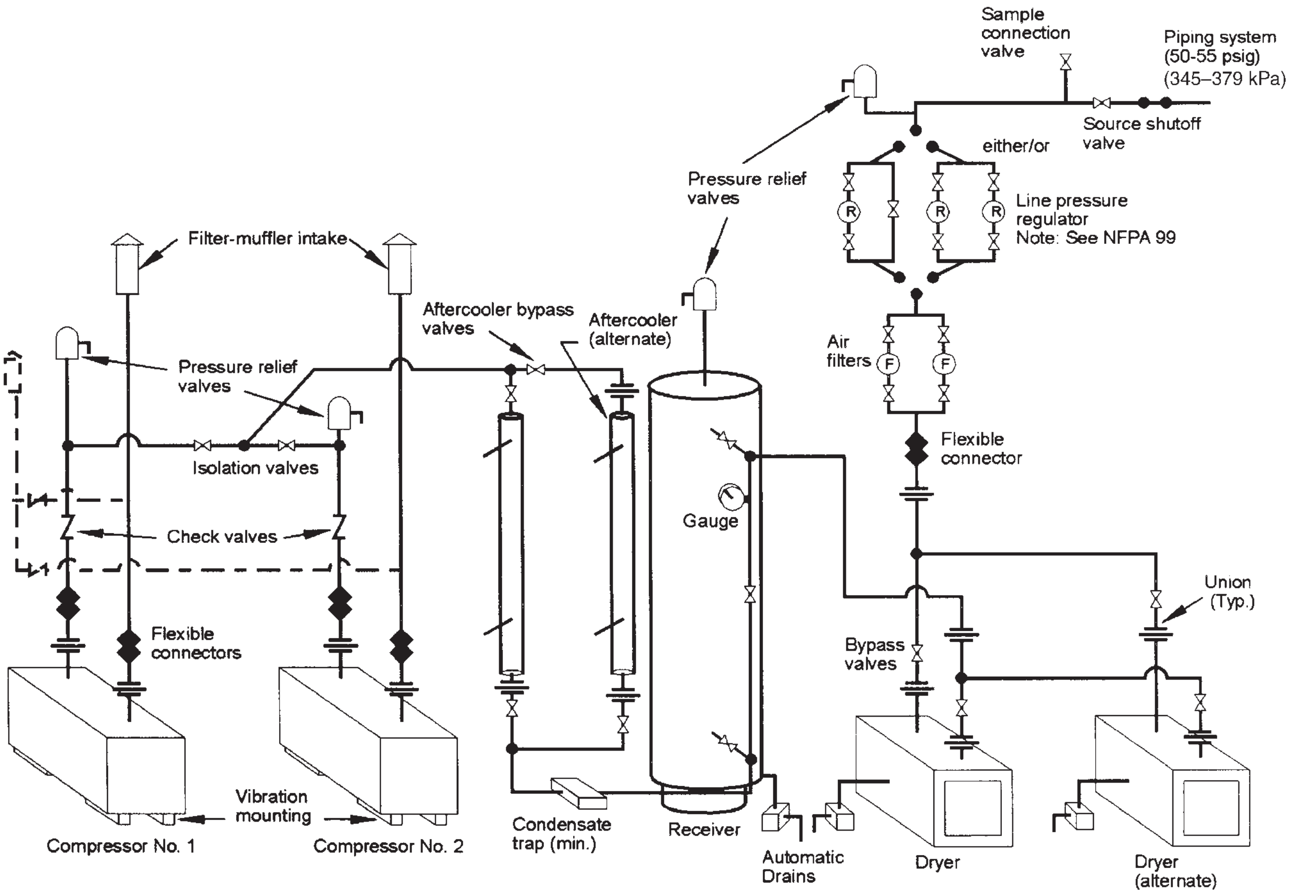


Figure 2-8 Typical Duplex Medical Air Compressor System (Type 1 Gas System)

The selection and size of nitrogen manifolds should be based on the instruments with the highest pressure requirements at the greatest gas consumption rate.

Surgical instruments are used to drill or cut bones and metals. Surgical applications include neurology, where instruments are used to cut the cranium; orthopedic service for bone work and joint replacement; facial reconstruction; and open-heart surgery. The tools are operated by a foot pedal. The gas supply to the tool and discharge from the tool are both brought to the floor where the foot pedal is located.

A series of instruments is currently available with the highest pressure requirements and the greatest flow rates of all instruments: 200 psig (1,379 kPa) at the instrument and a maximum flow rate of 15 scfm (7.08 L/s) to operate effectively. Recent developments have resulted in a new series of tools that requires only 120 psig (827.4 kPa) with a maximum flow rate of 12 scfm (5.66 L/s) to achieve the same effectiveness as the older, higher-pressure line of tools. Other manufacturers of pneumatically operated instruments commonly use a pressure of 160 psig (1,103.2 kPa) and a maximum flow rate of 15 scfm (7.08 L/s). For the foreseeable future, various facilities will use a mixture of instruments.

Revisions in NFPA 99 made provisions for pressures up to 300 psig (2,068.4 kPa), up from a maximum of 200 psig (1,379 kPa) previously allowed. Care must be taken to ensure that all components of a proposed distribution system, including connectors, hose, etc., are rated and approved for the higher pressures.

Table 2-15 Minimum Pipe Sizes for Medical Air Compressor Intake Risers

Pipe size, in. (mm)	Flow rate, cfm (L/min)
2.5 (63.5)	50 (1416)
3 (76.2)	70 (1985)
4 (101.6)	210 (5950)
5 (127.0)	400 (11,330)

The following should be considered when selecting and sizing nitrogen manifolds and determining the number of cylinders required:

- Size of the cylinder (see Table 2-16)
- Number of operating rooms served by the nitrogen or compressed gas
- Flow rate and pressure requirements of utilized instruments

One cylinder should be provided per operating room for in-service and reserve supplies.

Vacuum Systems

Vacuum is a negative pressure created by the vacuum pumps within the piping system. The evacuation of the air from the piping system allows ambient air to be pulled from station inlets and exhausted to the outside. The volume of air, in cubic feet per minute (cfm) (L/min), in the piping is greater than the volume of the ambient air at atmospheric pressure entering the system, due to expansion under vacuum. In a vacuum system, acfm is the air that has been expanded in a vacuum volumetric flow. Values of acfm are much greater than values of scfm. To convert acfm to scfm at 19 inches of mercury (Hg) (482.6 mm Hg), divide acfm by 2.73. For the ratio of scfm to acfm at other pressures, refer back to Table 2-17.

At altitudes above sea level, all vacuum systems have reduced flow. In these cases, the required sizing will need to be adjusted to compensate. To do this, multiply the total demand in scfm by the appropriate multiplier shown in Table 2-18. In other words, to size the medical vacuum system correctly in accordance with NFPA 99 recommendations of scfm at 19 inches Hg (482.6 mm Hg), apply the correction factor listed in Table 2-18 to the peak calculated demand in scfm at 19 inches Hg (482.6 mm Hg).

Example 2-3

A facility's total demand is 27.5 scfm to produce 19 inches Hg (482.6 mm Hg) of vacuum at sea level. If this facility is located at 5,000 feet (1,524 m) above sea level, what is the adjusted scfm?

Multiply 27.5 scfm by 1.20 (the correction factor from Table 2-18) to get the adjusted total requirement of 33.3 scfm at 5,000 feet (1,524 m) above sea level.

Be sure to use acfm to size vacuum pumps. The patient vacuum system is intended to be a dry vacuum system. However, occasionally fluids enter the piping system accidentally. This should not affect the operation of the vacuum pump, but it will eventually restrict flow as the pipes' inner walls become coated with dry body fluids, dust, and debris. Some facilities use the vacuum system to remove airborne smoke particles from electrosurgical or laser-surgery areas. This is not a recommended application for the vacuum system. The smoke contains particulates, hydrocarbons, and water, which, if captured, will condense on the pipes' inner walls, producing a tar-like substance that eventually will restrict flow.

The vacuum pump system includes duplex (or more) vacuum pumps, a receiver tank and automatic drain, controls, exhaust piping, muffler, and valves. System components are connected by piping that allows equipment isolation and drainage of the receiver tank. The receiver serves as a reservoir and an interceptor for fluids that may enter the vacuum system. Fluids must be periodically drained to the sanitary sewer from the receiver. Figure 2-9 illustrates the schematic of a typical duplex medical/surgical vacuum pump system.

The vacuum pump system must be selected, sized, and specified to provide the estimated peak flow demand and a dependable source of medical vacuum at all required times. Each vacuum pump of a duplex system must be sized for 100 percent of the estimated

Table 2-16 Selection Chart for Nitrogen Cylinder Manifolds

Number of Operating Rooms Piped with Nitrogen	Duplex Manifold Size	
	Total Cylinders	Cylinders per Side
1	2	1
2–4	4	2
5–8	8	4
9–12	12	6
13–16	16	8
17–20	20	10
21–24	24	12
25–28	28	14

Note: Based on use of 224 ft^3 (6343.35 L) H-cylinders.

Table 2-17 acfm to scfm Vacuum Conversion Table

Vacuum Level, in. Hg	Ratio at Sea Level (scfm:acfm)
0	1:1
15	1:2
18	1:2.5
19	1:2.73
20	1:3
21	1:3.33
22	1:3.75
23	1:4.28
24	1:5
25	1:6
26	1:7.5
27	1:10
28	1:15
29	1:30
29.5	1:60

Table 2-18 Altitude Correction Factors for Vacuum Systems

Altitude, ft (m)	Normal Barometric Pressure	Multiplier used for required scfm
0 (0)	29.92″ Hg	1.0
500 (152.4)	29.39″ Hg	1.02
1,000 (304.8)	28.86″ Hg	1.04
1,500 (457.2)	28.33″ Hg	1.06
2,000 (609.6)	27.82″ Hg	1.08
2,500 (762)	27.32″ Hg	1.10
3,000 (914.4)	26.82″ Hg	1.12
3,500 (1066.8)	26.33″ Hg	1.14
4,000 (1219.2)	25.84″ Hg	1.16
5,000 (1524)	24.90″ Hg	1.20
6,000 (1828.8)	23.98″ Hg	1.25
7,000 (2133.6)	23.09″ Hg	1.30
8,000 (2438.4)	22.23″ Hg	1.35
9,000 (2743.2)	21.39″ Hg	1.40
10,000 (3048)	20.58″ Hg	1.45

peak demand. When a triplex or quadruplex system is specified, each pump shall be sized so if one pump fails, the remaining pumps are capable of maintaining the required vacuum at 100 percent of the peak calculated demand. Provide automatic alternators (duty-cycling controls) to ensure even wear in normal usage. Alternator controls incorporate a positive means of automatically activating the additional unit (or units) should the in-service pump fail to maintain the minimum required vacuum.

Individual exhaust stacks should be straight and as short as possible. The exhaust shall be free of dips and loops that might trap condensate or oil. Where such low points are unavoidable, a drip leg and valved drain shall be installed. The collection of the duplex stacks to a single stack is permissible if it is ensured that back-pressure will not be a potential problem for the system in the future. The exhaust system should be piped to the outside environment, have a gooseneck termination, and be properly screened to prevent insects, leaves, and debris from entering. The exhaust vents should be a minimum distance of 25 feet (7.6 m) from any door, window, outside air intakes, or other opening and a minimum distance of 20 feet (6.1 m) above the ground. The prevailing wind currents and the proximity of the power vents and intake louvers are very important factors to be considered when locating the outdoor vacuum pump exhaust.

Table 2-19 provides minimum pipe sizes for vacuum exhaust risers. Consult with the vacuum pump manufacturer on back-pressure (friction loss) before finalizing pipe size and equipment selection.

Laboratories should be served by a dedicated vacuum line that is separate from the medical vacuum system, be equipped with drainable fluid traps, and be connected by separate laterals, risers, and mains to the receiver.

Because the vacuum requirements vary considerably in the different sections of a hospital, in both peak demand and frequency of use, the total demand for the entire vacuum system should be calculated by the following:

Equation 2-1

$$FR \times UF \times NI = EPF$$

where

FR= Room or station inlet flow rates, scfm
UF= Simultaneous usage factors
NI= Number of rooms or station inlets
EPF = Estimated peak flow, scfm

Waste Anesthetic Gas Management

Anesthesia is as common to medical care as the antiseptic care of wounds. For too long, however, exposure to and control of waste anesthetic gases (WAGD) and vapors during surgical procedures have put healthcare workers in jeopardy. At any given time, more than

250,000 people who work in hospitals, operating rooms, dental offices, and veterinary clinics might be exposed unnecessarily to harmful levels of WAGD.

Table 2-19 Minimum Pipe Sizes for Vacuum Exhaust Risers

Pipe Size, in. (mm)	Flow Rate, cfm (L/min)
1¼ (31.75)	12 (340)
1½ (38.1)	23 (655)
2 (50.8)	40 (1 140)
2½ (63.5)	70 (1 990)
3 (76.2)	130 (3 685)
4 (101.6)	160 (4 535)
5 (127.0)	350 (9 915)
6 (152.4)	525 (14,875)

The waste anesthetic gases and vapors of concern are nitrous oxide and halogenated agents (vapors) such as halothane, enflurane, methoxyflurane, trichloroethylene, and chloroform. Those workers with the potential for exposure to WAGD include nurses, physicians, surgeons, obstetricians, gynecologists, operating room technicians, recovery room personnel, dentists, veterinarians and their assistants, and other auxiliaries. Hospital emergency room personnel may also be exposed, but not on a regular basis.

The WAGD system should consist of a dedicated and labeled wall/column inlet piped through the zone valve box and either piped separately back to the medical vacuum pump or piped 10 feet (3.05 m) downstream of the valve box to connect to the medical vacuum branch main.

A complete WAGD management program includes the application of a well-designed WAGD scavenging system. Such a system consists of a collecting device (scavenging adapter) to collect WAGD and vapors from breathing systems at the site of overflow, a ventilation system to carry WAGD from the operating room, and a method or device for limiting both positive and negative pressure variations in the breathing circuit that may be used by the scavenging system. Most anesthesia equipment being manufactured today includes a scavenging system.

The remainder of the WAGD management program should include work practices minimizing gas leakage, the application of a routine equipment maintenance program also to minimize gas leaks, periodic exposure monitoring, and the provision of adequate general ventilation.

System Control Valves

After the proper selection of the medical gas system source has been made by the plumbing engineer, the next step in the design of such a system is the specification and installation of the piping and controls. These typically include source shutoff valves, main shutoff valves, inline shutoff valves, and zone valve box assemblies. The purpose of including these intermediate valves in the medical gas system is to provide the capability of isolating various portions of the system, in total or by area. This is useful in case of an emergency and to allow for maintenance without interrupting the entire medical gas system. Often, future remodeling connections should be considered in the determination of valve placement.

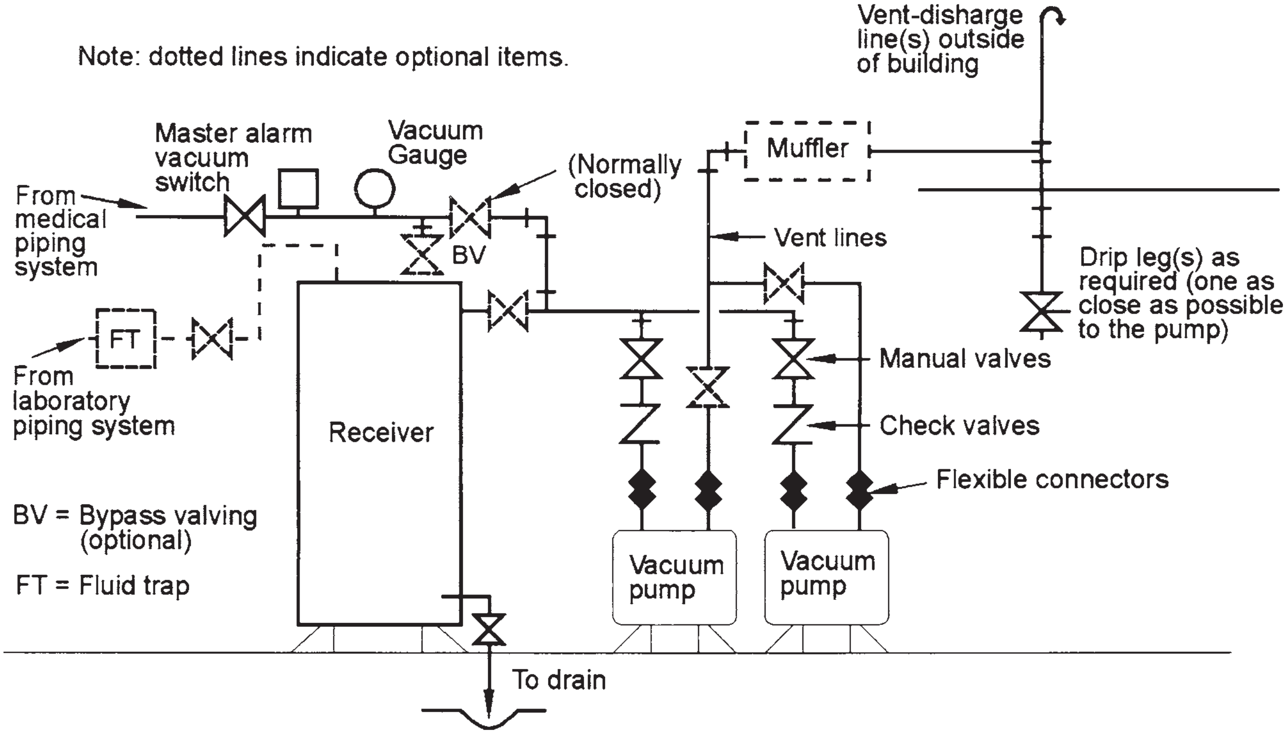


Figure 2-9 Schematic of a Typical Duplex Medical/Surgical Vacuum Pump System

All valves in medical gas systems must be totally accessible, labeled, and, if concealed, identified. This allows area shutdown, purge, and certification to be done while the remainder of the system stays in service. Based on the latest NFPA recommendations, zone valves that are accessible to those other than authorized personnel should be installed inside valve boxes that are provided with breakable or removable windows. This valve is to be readily operable from a standing position in the corridor on the same floor it serves. A gauge, installed downstream of the zone valve, is required in patient rooms.

The valves and box assemblies should be full-port ball valves with 90 degrees from the open to the closed position. The size of the valves should be based on the size of the pipe they serve to avoid reducing (or restricting) the flow of the pipeline system.

Inline shutoff valves (other than those in zone valve boxes) shall have locking handles to allow them to be locked open or closed. Shutoff valves should be located in medical gas systems at the following locations:

- Source equipment outlets
- Main supply line entering the building
- Base of each medical gas riser adjacent to the riser connection
- Each floor distribution zone serving patient areas
- Each anesthetizing location
- Each critical (intensive) care area, emergency room, and recovery room

The locations cited above are the minimum recommendations; local plumbing codes, NFPA standards, and site conditions should prevail in the final determination of the valve placement. All piping, except control-line tubing, shall be identified. All service main, branch main, and riser valves shall be tagged, and a valve schedule shall be provided to the facility owner for permanent record and reference.

Valves, fittings, and other components shall be cleaned for oxygen service.

Warning Systems

The facility's gas-dispensing equipment is adjusted to deliver a particular gas at a given flow and pressure. Fluctuations in the given pressure may cause the dispensing equipment to stop functioning or to function inaccurately. For this reason, line-pressure sensing switches should be installed in all medical gas lines immediately downstream of the source's main shutoff valve. Monitoring of the design conditions is extremely important because any alarms require a certain response from maintenance engineers, nursing personnel, and supply personnel.

Warning systems are classified into two basic groups: master alarms and area alarms. Additionally, interface controls (relays) are now being provided in computerized signal equipment.

Master Alarms

NFPA requires two master alarm panels to be provided, located in the engineer's office and in an area where 24-hour surveillance is maintained. The master alarm provides its signals by a pressure switch (vacuum switch) located immediately downstream of the source's main shutoff valve or at the site of the source. For example, with a liquid oxygen system, various pressure switches are located at the bulk site, which provide signals of reserve changeover, reserve in use, reserve failure, and low reserve. Additional oxygen signals needed for the master alarm are line pressure high and line pressure low.

Typical manifold gases, such as nitrous oxide, require signals to the master alarm to indicate line pressure high, line pressure low, and reserve supply in use.

Area Alarms

Area alarms are local alarms usually provided with a self-contained pressure switch and a gauge located in the panel. These area alarms monitor the line pressure in areas to indicate if the pressure increases or decreases from the normal operating pressure.

Area alarms shall be located in all critical care areas. These areas are defined in NFPA as follows: ICU, CCU, angiography labs, cardiac cath labs, delivery rooms, operation rooms, post-anesthesia recovery rooms, emergency rooms, and similar areas in which patients are intended to be subjected to invasive procedures and connected to line-operated, patient-care-related electrical appliances. Except where each operating or delivery room is valved, the area alarm signals are from the specific line supplying the area, with the individual room shutoff valve being the only one between the actuating switch and the room outlets.

Care should be taken by the engineer to locate the area alarm in convenient view of the nursing personnel who normally work in the area covered. In case of a stoppage of the medical gas or any other alarm condition, the proper personnel must take prompt and precise corrective actions.

Interface Controls

To advise total building maintenance systems of any malfunctions in the medical gas systems, most manufacturers usually provide a relay interface control so that easy and compatible signals can be provided by the total building maintenance and control system.

Medical Gas Piping Installation

The basic principles regarding medical gas piping to be considered by the plumbing engineer and kept in mind during the design phase are as follows:

- Always protect against leakage, frost, corrosion, and physical damage. Conduit or castings may be used as necessary. Medical gas piping may be installed in the same utility tunnel with fuel gas pipelines, electrical lines, or steam lines, provided that adequate natural or forced-air ventilation is available. The medical gas pipelines must not be placed in a tunnel, trench, or duct where they may be exposed to physical contact with oil or corrosive materials.
- In concealed spaces, always protect against any physical damage by installation within a pipe or conduit. Openings for pipelines installed in combustible partitions must be firestopped with a type of construction having a fire resistance equal to or greater than the original construction.
- Medical gas systems may be installed in a pipe and duct shaft if suitably protected against any possible physical damage, excessive heat, corrosion, or contact with oil. Shafts that penetrate multiple floors must meet local code requirements regarding fire rating and sealing of shaft penetrations.
- The following installation locations are prohibited by codes and must not be considered by the plumbing engineer: elevator shafts, kitchens, electrical switch-gear rooms, and storage rooms for combustible materials.
- Installation in an activity area (such as a corridor where movement of portable equipment may damage piping) should be avoided if possible. If unavoidable, use a hard-temper tubing and provide adequate identification, protective shields, and monitoring.
- Pipe should be supported from the building structure in accordance with the Manufacturers Standardization Society (MSS) or the schedule given in Table 2-20.
- The installation of an emergency oxygen supply connection (EOSC) is required when the oxygen supply is remote from the building being served. The EOSC shall be attached to the building being served and be accessible by emergency supply vehicles at all times

Medical Gas Pipe Sizing Criteria

Pipe sizing is one of the most important aspects of designing medical gas systems. Oversized piping may be required for future expansions, and undersized pipes will never provide adequate flow or pressure during peak demand conditions. The friction loss or pressure drop between the supply source and the outlets must be designed within acceptable limits. Each medical gas system has a system operating pressure and a maximum pressure loss (drop), which are given later in this section.

To determine the approximate pressure loss for a system, start by measuring the longest pipe run from the source to the last station outlet and inlet. Multiply the longest pipe run by a fitting factor (30 to 50 percent is normal) to establish the equivalent length. Divide the allowable pressure drop by the equivalent length, and multiply by 100 (30.48) to obtain an allowable friction loss per 100 feet (30.48 m). Friction-loss tables provided later in this chapter give the friction loss per 100 feet (30.48 m) of various pipe sizes. The system's peak probable demand is calculated by multiplying the number of stations by the flow allowance by the simultaneous use factor. Pipe diameters are determined by reading the friction-loss tables at the proper correlating flow rate and friction loss per 100 feet (30.48 m) of pipe. Refer to the following equations:

Table 2-20 Medical Gas Pipe Support Schedule

Pipe Size, in. (mm)	Maximum Span Between Hangers, ft (m)
¼ (6)	5 (1.52)
⅜ (10)	6 (1.83)
½ (12.5)	6 (1.83)
¾ (20)	7 (2.13)
1 (25)	8 (2.44)
1¼ (32)	9 (2.74)
1½ (40) and larger	10 (3.05)

Equation 2-2

$$\mathrm{EL} = \mathrm{DM} \times \mathrm{ff}$$

then

Equation 2-2a

$$\mathrm{PL} = \frac{\mathrm{APD}}{\mathrm{EL}} \times 100$$

where

EL= Equivalent length, feet (meters)
DM= Longest pipe length or run, feet (meters)
ff= Fitting factor
PL= Pressure loss, feet per 100 feet (meters per 30.48 meters)
APD = Allowable pressure drop, feet (meters)

Acceptable pipeline system design criteria require the risers to be sized larger than the laterals and the laterals larger than the drops to the outlets. In general, the diameters tend to reduce from the source to the end of the distribution system.

Oxygen

The flow rate for oxygen outlets is 1 cfm (0.47 L/s). A source pressure of 55 psi (379.2 kPa) and a maximum pressure drop of 5 psi (34.47 kPa) should be used in the design. Adult and infant ventilators require oxygen volumes that exceed the 1 cfm (0.47 L/s) flow rate. The recommended flow rate for adult ventilators is 6.36 cfm (3 L/s) with no diversity factor. Infant ventilators require 1 cfm (0.47 L/s) with no diversity factor. Refer to Table 2-21 for outlet ratings and diversity factors. The friction-loss data for oxygen pipe systems is given in Table 2-22.

Nitrous Oxide

The flow rate for nitrous oxide outlets is 1 cfm (0.47 L/s). A source pressure of 55 psi (379.2 kPa) and a maximum pressure drop of 5 psi (34.47 kPa) should be used in the design. Refer to Table 2-21 for outlet ratings and diversity factors.

Oxygen and nitrous oxide pipe sizes should be selected based on the more stringent of the following requirements:

- Maximum friction loss of 1 psi (6.90 kPa) per 100 feet (30.48 m)
- Maximum friction loss of 5 psi (34.47 kPa) to the farthest outlet

The friction-loss data for nitrous oxide pipe systems is given in Table 2-22.

Nitrogen

The flow rate for nitrogen outlets is 15 cfm (7.1 L/s) per operating room. The source pressure range is 200 to 300 psi (1,378.96 to 2,068.44 kPa), and the maximum pressure drop is 10 percent of the total system pressure. Specific pressure requirements for tools may dictate the pressure required at a specific point in the system. Refer to Table 2-21 for outlet ratings and diversity factors.

Nitrogen pipe size should be selected based on the more stringent of the following requirements:

- Maximum friction loss of 2 psi (13.79 kPa) per 100 feet (30.48 m)
- Maximum friction loss not to exceed 10 percent of the total system pressure to the farthest outlet

The friction-loss data for nitrogen pipe systems is given in Table 2-23.

Medical Air

The flow rate for medical air outlets is generally 1 cfm (0.47 L/s), although this may vary. A source pressure of 50 psi (344.74 kPa) and a maximum pressure drop of 5 psi (34.47 kPa) should be considered. Specific pressure requirements for equipment may dictate the pressure required at a specific point in the system. Refer to Table 2-21 for outlet ratings and diversity factors. The friction-loss data for medical air pipe systems and high-pressure compressed air is given in Tables 2-24 and 2-25.

Vacuum

The flow rate for vacuum inlets is different than it is for other systems because areas vary in demand. Table 2-21 provides outlet rating data and diversity factors. Consider a source vacuum of 19 inches (64.2 kPa) Hg at the service inlet with a maximum pressure drop of 5 inches (16.9 kPa) Hg. The friction-loss data for vacuum pipe systems is given in Table 2-26.

Medical Gas Piping Materials

Pipe and fittings installed in medical gas systems shall be thoroughly cleaned for oxygen service, with the removal of oil, grease, and other readily oxidizable materials. Such piping systems shall be plugged or capped until final assembly to prevent contamination. Piping materials allowed by code, subject to local requirements, shall be hard-drawn, seamless medical gas tube, type K or L (ASTM B819), cleaned and capped, and shall bear one of the following markings: “oxy, med,” “oxy/med,” “acr/oxy,” or “acr/med.” Mains and branches in piping systems shall not be less than 0.5 inch (12.5 mm) in nominal size. For systems operated at pressures between 200 and 300 psig (1,379 and 2,068.4 kPa), ASTM B819, type K copper shall be used. Joints in medical gas tube shall be brazed; however, memory metal couplings with temperature and pressure ratings not less than those of a brazed joint are also acceptable. Unions are not permitted in any medical gas distribution pipeline system.

Hoses and Flexible Connections

Metallic and nonmetallic hoses or flexible connections are to be no longer than required and should not be permanently concealed in walls, floors, ceilings, or partitions. Hoses are to have a flame-spread rating of 200 in accordance with NFPA 255: *Standard Method of Test of Surface Burning Characteristics of Building Materials*.

Certification of Medical Gas Systems

Testing shall be in strict accordance with state and local regulations and NFPA 99. Note: The alternative test specified in NFPA 99 Section 4-3.4.1.3(a)2 is not recommended. Because of the possibility of line pressure drops, malfunction of test gauges, and/or human error, it should not be allowed in cross-connection testing of vital life-support gases.

Medical Gas Certification Checklist

It is recommended that a step-by-step checklist be followed to ensure that every aspect of the medical gas and vacuum system is tested properly. Prior to having the system certified, the plumbing contractor should perform steps 1 through 6 below. Typically, these are inspected by local inspectors.

1. Clean the piping system by clearing it with pressurized, oil-free dry air or nitrogen. This cleaning shall be performed just after the installation of the piping system but before installation of the alarm switches, manifolds, pressure gauge, and other peripheral components.
2. Visually inspect each brazed joint. This inspection shall be done to make sure that the brazing alloy has been properly applied to the joint and

Table 2-21 Medical Gas Diversity (Simultaneous Use) Factors

System	Abbreviation	Quantity of Outlets	Diversity (%)	Minimum Flow, cfm (L/min)
Oxygen & nitrous oxide	O_2 and N_2O	1–3	100	— —
		4–12	75	2 (56.64)
		13–20	50	4 (113.28)
		21–40	33	5 (141.60)
		41 & over	25	6 (169.92)
High-pressure nitrogen	N_2	1 & 10	100	— —
		11–20	75	2.5 (70.8)
		21 & over	66	3.75 (106.2)
Medical laboratory compressed air	MA	1–2	100	— —
		3–12	80	3 (84.96)
		13–38	60	10 (283.2)
		39–115	40	25 (708.0)
		116–316	30	50 (1,416.0)
		317–700	20	95 (2,690.4)
		701–1880	15	145 (4,106.4)
		1881–4400	10	285 (8,071.2)
		4401–16,000	5	445 (12,602.4)
		16,001–80,000	2	800 (22,656.0)
		80,000 & over	2	800 (22,656.0)
Laboratory vacuum	VAC	1–4	100	— —
		5–12	80	5 (141.60)
		13–33	60	10 (283.20)
		34–80	50	21 (594.72)
		81–150	40	40 (1,132.80)
		151–315	35	61 (1,727.52)
		316–565	30	111 (3,143.52)
		566–1000	25	171 (4,842.72)
		1001–2175	20	251 (7,108.32)
		2176–4670	15	436 (12,347.52)
		4671 & over	10	701 (19,852.32)

Minimum recommended pipe sizes, in. (mm)

Service	O_2	N_2O	N_2	MA	MV
Minimum system pipe/tube size	½ (12.5)	½ (12.7)	½ (12.7)	½ (12.7)	¾ (19.1)
Minimum riser size	¾ (19.1)	¾ (19.1)	1 (25.4)	¾ (19.1)	1 (25.4)
Minimum branch size	½ (12.7)	½ (12.7)	½ (12.7)	½ (12.7)	¾ (19.1)
Minimum single outlet supply size	⅜ (9.5)	⅜ (9.5)	⅜ (9.5)	⅜ (9.5)	⅜ (9.5)

Table 2-22 Data for Sizing Oxygen and Nitrous Oxide Supply Piping

O_2 and N_2O, cfm (L/min)	Nominal Pipe Size, in. (mm)								
	½ (12.7)	¾ (19.1)	1 (25.4)	1¼ (31.8)	1½ (38.1)	2 (50.8)	2½ (63.5)	3 (76.2)	4 (101.6)
	Pressure Drop per 100 ft (30.48 m) of Pipe, psi (kPa)								
1.76 (50)	0.04 (0.28)								
3.53 (100)	0.16 (1.1)								
4.41 (125)	0.25 (1.72)								
5.3 (150)	0.33 (2.27)	0.04 (0.28)							
6.18 (175)	0.48 (3.31)	0.06 (0.41)							
7.06 (200)	0.63 (4.34)	0.07 (0.48)							
8.83 (250)	0.99 (6.83)	0.11 (0.76)							
10.89 (300)	1.41 (9.72)	0.16 (1.1)	0.04 (0.28)						
14.12 (400)	2.51 (17.31)	0.29 (2.0)	0.07 (0.48)						
17.66 (500)	3.92 (27.03)	0.45 (3.1)	0.11 (0.76)						
26.48 (750)		1.02 (7.03)	0.24 (1.65)						
35.31 (1 000)		1.80 (12.41)	0.42 (2.9)	0.13 (0.9)	0.05 (0.34)				
44.14 (1 250)		2.81 (19.37)	0.66 (4.55)	0.21 (1.45)	0.09 (0.62)				
52.97 (1 500)			0.95 (6.55)	0.30 (2.07)	0.12 (0.83)				
70.62 (2 000)			1.05 (7.24)	0.67 (4.62)	0.22 (1.52)	0.05 (0.34)			
88.28 (2 500)				0.83 (5.72)	0.34 (2.34)	0.08 (0.55)			
105.93 (3 000)				1.19 (8.2)	0.49 (3.38)	0.11 (0.76)			
141.24 (4 000)				2.11 (14.55)	0.88 (6.07)	0.20 (1.38)	0.06 (0.41)		
176.55 (5 000)				3.30 (22.75)	1.36 (9.38)	0.32 (2.2)	0.10 (0.69)		
264.83 (7 500)					3.10 (21.37)	0.71 (4.9)	0.22 (1.52)	0.09 (0.62)	
353.11 (10 000)						1.27 (8.76)	0.40 (2.76)	0.16 (1.1)	
529.66 (15 000)						2.82 (19.44)	0.89 (6.14)	0.35 (2.41)	0.08 (0.55)
706.21 (20 000)						5.00 (34.47)	1.58 (10.9)	0.63 (4.34)	0.15 (1.03)
882.77 (25 000)							2.47 (17.03)	0.98 (6.76)	0.23 (1.59)
1059.32 (30 000)							3.55 (24.48)	1.40 (9.65)	0.31 (2.14)
1412.43 (40 000)								2.48 (17.1)	0.59 (4.07)
1765.54 (50 000)								3.90 (26.9)	0.92 (6.34)

Table 2-23 Data for Sizing Nitrogen Supply Piping

cfm (L/min)	Nominal Pipe Size, in. (mm)					
	½ (12.7)	¾ (19.1)	1 (25.4)	1¼ (31.8)	1½ (38.1)	2 (50.8)
	Pressure Loss, psi per 100 ft (kPa per 3.48 m) of 160 psi (1103.2 kPa) Piping					
5 (145)	0.11 (0.76)	0.01 (0.07)				
10 (284)	0.43 (2.96)	0.07 (0.48)	0.02 (0.14)	0.01 (0.07)		
15 (425)	0.96 (6.62)	0.12 (0.83)	0.04 (0.28)	0.01 (0.07)		
20 (567)	1.70 (11.72)	0.26 (1.79)	0.07 (0.48)	0.02 (0.14)	0.01 (0.07)	
25 (708)	2.66 (18.34)	0.42 (2.90)	0.11 (0.76)	0.03 (0.21)	0.01 (0.07)	
30 (850)		0.59 (4.07)	0.17 (1.17)	0.04 (0.28)	0.02 (0.14)	
35 (992)		0.81 (5.58)	0.22 (1.52)	0.05 (0.34)	0.02 (0.14)	
40 (1133)		1.06 (7.31)	0.29 (2.00)	0.07 (0.48)	0.03 (0.21)	
45 (1275)		1.34 (9.24)	0.37 (2.55)	0.09 (0.62)	0.04 (0.28)	0.01 (0.07)
50 (1416)		1.65 (11.38)	0.46 (3.17)	0.11 (0.76)	0.05 (0.34)	0.01 (0.07)
60 (1700)		2.37 (16.34)	0.66 (4.55)	0.15 (1.03)	0.07 (0.48)	0.02 (0.14)
70 (1984)			0.90 (6.21)	0.21 (1.45)	0.09 (0.62)	0.02 (0.14)
80 (2266)			1.17 (8.07)	0.27 (1.86)	0.12 (0.83)	0.03 (0.21)
90 (2550)			1.48 (10.20)	0.34 (2.34)	0.15 (1.03)	0.04 (0.28)
100 (2833)			1.83 (12.62)	0.43 (2.96)	0.19 (1.31)	0.05 (0.34)
110 (3116)			2.21 (15.24)	0.51 (3.52)	0.23 (1.54)	0.06 (0.41)
120 (3400)				0.62 (4.27)	0.27 (1.86)	0.07 (0.48)
130 (3683)				0.72 (4.96)	0.32 (2.21)	0.09 (0.62)
140 (3966)				0.83 (5.72)	0.37 (2.55)	0.10 (0.69)
150 (4250)				0.96 (6.62)	0.42 (2.90)	0.11 (0.76)

Table 2-24 Pressure Loss, psi per 100 ft (kPa per 30.48 m) in 50 psi (344.74 kPa) Compressed Air Piping

	Nominal Pipe Size, in. (mm)								
cfm (L/s)	½ (12.7)	¾ (19.1)	1 (25.4)	1¼ (31.8)	1½ (38.1)	2 (50.8)	2½ (63.5)	3 (76.2)	4 (101.6)
5 (2.36)	0.30 (2.07)	0.03 (0.21)	0.01 (0.07)						
10 (4.72)	1.15 (7.93)	0.18 (1.24)	0.05 (0.34)	0.01 (0.07)					
15 (7.08)		0.40 (2.76)	0.11 (0.76)	0.03 (0.21)					
20 (9.44)		0.69 (4.76)	0.20 (1.38)	0.05 (0.34)	0.02 (0.14)				
25 (11.80)		1.14 (7.86)	0.31 (2.14)	0.07 (0.48)	0.03 (0.21)				
30 (14.16)			0.44 (3.03	0.10 (0.69)	0.05 (0.34)				
35 (16.52)			0.61 (4.21)	0.14 (0.97)	0.06 (0.41)				
40 (18.88)			0.80 (5.52)	0.18 (1.24)	0.08 (0.55)				
45 (21.24)			1.00 (6.89)	0.23 (1.59)	0.10 (0.69)	0.03 (0.21)			
50 (23.60)				0.29 (2.00)	0.13 (0.90)	0.04 (0.28)			
60 (28.32)				0.42 (2.90)	0.18 (1.24)	0.05 (0.34)			
70 (33.04)				0.56 (3.86)	0.25 (1.72)	0.07 (0.48)	0.03 (0.21)		
80 (37.76)				0.74 (5.10)	0.33 (2.28)	0.09 (0.62)	0.03 (0.21)		
90 (42.48)				0.93 (6.41)	0.41 (2.83)	0.11 (0.76)	0.04 (0.28)		
100 (47.20)				1.15 (7.93)	0.51 (3.52)	0.14 (0.97)	0.05 (0.34)		
110 (51.92)					0.62 (4.27)	0.17 (1.17)	0.06 (0.41)		
120 (56.64)					0.73 (5.03)	0.20 (1.38)	0.08 (0.55)		
130 (61.36)					0.86 (5.93)	0.23 (1.59)	0.09 (0.62)	0.03 (0.21)	
140 (66.08)					1.00 (6.89)	0.27 (1.86)	0.11 (0.76)	0.03 (0.21)	
150 (70.80)						0.31 (2.14)	0.12 (0.83)	0.04 (0.28)	
175 (82.60)						0.42 (2.90)	0.16 (1.10)	0.05 (0.34)	
200 (94.40)						0.54 (3.72)	0.21 (1.45)	0.07 (0.48)	
225 (106.20)						0.69 (4.76)	0.29 (2.00)	0.08 (0.55)	
250 (118.00)						0.85 (5.86)	0.33 (2.28)	0.10 (0.69)	
275 (129.80)						1.03 (7.10)	0.40 (2.76)	0.13 (0.90)	
300 (141.60)							0.48 (3.31)	0.15 (1.03)	
325 (153.40)							0.56 (3.86)	0.18 (1.24)	
350 (165.20)							0.65 (4.48)	0.20 (1.38)	
375 (177.00)							0.74 (5.10)	0.23 (1.59)	
400 (188.80)							0.84 (5.79)	0.27 (1.86)	
450 (212.40)							1.06 (7.31)	0.32 (2.21)	
500 (236.00)								0.42 (2.90)	
550 (259.60)								0.50 (3.45)	0.12 (0.83)
600 (283.20)								0.60 (4.14)	0.14 (0.97)
650 (306.80)								0.70 (4.83)	0.17 (1.17)
700 (330.40)								0.82 (5.65)	0.19 (1.31)
750 (354.00)								0.94 (6.48)	0.22 (1.52)
800 (377.60)								1.06 (7.31)	0.25 (1.72)
850 (401.20)									0.28 (1.93)
900 (424.80)									0.32 (2.21)
950 (448.40)									0.36 (2.48)
1000 (472.00)									0.39 (2.69)
1100 (519.20)									0.48 (3.31)
1200 (566.40)									0.57 (3.93)
1300 (613.60)									0.67 (4.62)
1400 (660.80)									0.77 (5.31)
1500 (708.00)									0.89 (6.14)
1600 (755.20)									1.00 (6.89)

Table 2-25 High-pressure Compressed Air Friction Loss Table

		1/2"			3/4"			1"			1 – 1-1/4"		
	Pipe Size	at 125 psi	at 175 psi	at 250 psi	at 125 psi	at 175 psi	at 250 psi	at 125 psi	at 175 psi	at 250 psi	at 125 psi	at 175 psi	at 250 psi
SCFM	6	.102	.075	.054	.023								
	8	.181	.133	.096	.041	.030							
	10	.283	.208	.149	.064	.047	.034	.017					
	15	.636	.469	.336	.144	.106	.076	.038					
	20	1.131	.833	.597	.255	.188	.135	.067	.050	.036	.016		
	25	1.768	1.302	.933	.399	.294	.211	.105	.078	.056	.025	.019	
	30	2.546	1.875	1.344	.574	.423	.303	.152	.112	.080	.037	.027	
	35	3.465	2.552	1.829	.782	.576	.413	.206	.152	.109	.050	.037	.026
	40	4.526	3.333	2.388	1.021	.752	.539	.270	.199	.142	.065	.048	.034
	45	5.728	4.218	3.023	1.292	.952	.682	.341	.251	.180	.083	.061	.044
	50	7.071	5.208	3.732	1.596	1.175	.842	.421	.310	.222	.102	.075	.054
	60	10.183	7.499	5.374	2.296	1.692	1.213	.607	.447	.320	.147	.108	.078
	70	13.860	10.207	7.315	3.128	2.300	1.651	.826	.608	.436	.200	.147	.105
	80		13.331	9.554	4.085	3.008	2.156	1.079	.794	.569	.261	.192	.138
	90		16.872	12.092	5.170	3.807	2.729	1.365	1.005	.721	.330	.243	.174
	100		20.830	14.928	6.383	4.700	3.369	1.685	1.241	.890	.408	.300	.215
	125			23.325	9.973	7.344	5.263	2.633	1.939	1.390	.637	.469	.336
	150				14.361	10.576	7.579	3.792	2.793	2.001	.918	.676	.484
	175					14.395	10.316	5.162	3.801	2.724	1.249	.920	.659
	200					18.801	13.474	6.742	4.965	3.558	1.632	1.202	.861
	225						17.053	8.533	6.284	4.503	2.065	1.521	1.090
	250						21.054	10.534	7.757	5.559	2.550	1.878	1.346
	275						25.475	12.746	9.387	6.727	3.085	2.272	1.628
	300						30.317	15.169	11.171	8.006	3.671	2.704	1.938
	325								13.110	9.396	4.309	3.173	2.274
	350								15.205	10.867	4.997	3.680	2.637
	375								17.454	12.509	5.736	4.224	3.027
	400								19.859	14.232	6.527	4.806	3.445
	425								22.419	16.067	7.368	5.426	3.889
	450									18.013	8.260	6.083	4.360

Table 2-26 Data for Sizing Vacuum Piping Systems

Air Flow, cfm (L/s)	Nominal Pipe Size, inches (mm)							
	¾ (19.1)	1 (25.4)	1¼ (31.8)	1½ (38.1)	2 (50.8)	2½ (63.5)	3 (76.2)	4 (101.6)
	Pressure Drop per 100 Ft (30.48 m) of Pipe, in. Hg (kPa)							
1 (0.5)	0.15 (0.51)							
2 (0.9)	0.39 (1.32)	0.10 (0.34)						
3 (1.4)	0.77 (2.60)	0.19 (0.64)						
4 (1.9)	1.24 (4.19)	0.31 (1.05)	0.10 (0.34)					
5 (2.4)	1.78 (6.01)	0.44 (1.49)	0.14 (0.47)					
6 (2.8)	2.40 (8.10)	0.60 (2.03)	0.19 (0.64)					
7 (3.3)		0.77 (2.60)	0.24 (0.81)	0.12 (0.41)				
8 (3.8)		0.95 (3.21)	0.31 (1.05)	0.15 (0.51)				
9 (4.3)		1.17 (3.95)	0.38 (1.28)	0.18 (0.61)				
10 (4.7)		1.38 (4.66)	0.45 (1.52)	0.22 (0.74)				
15 (7.1)		2.80 (9.46)	0.88 (2.97)	0.44 (1.49)	0.12 (0.41)			
20 (9.4)			1.46 (4.93)	0.72 (2.43)	0.19 (0.64)			
25 (11.8)			2.20 (7.43)	1.09 (3.68)	0.29 (0.98)	0.10 (0.34)		
30 (14.2)				1.52 (5.13)	0.41 (1.38)	0.14 (0.47)		
35 (16.5)				2.00 (6.75)	0.54 (1.82)	0.18 (0.61)		
40 (18.9)				2.50 (8.44)	0.67 (2.26)	0.22 (0.74)	0.10 (0.34)	
45 (21.2)					0.81 (2.74)	0.27 (0.91)	0.12 (0.41)	
50 (23.6)					0.99 (3.34)	0.33 (1.11)	0.14 (0.47)	
60 (28.3)					1.34 (4.53)	0.45 (1.52)	0.19 (0.64)	
70 (33.0)					1.79 (6.04)	0.60 (2.03)	0.26 (0.88)	0.07 (0.24)
80 (37.8)					2.30 (7.77)	0.77 (2.60)	0.32 (1.08)	0.09 (0.30)
90 (42.5)						0.96 (3.24)	0.41 (1.38)	0.11 (0.37)
100 (47.2)						1.17 (3.95)	0.50 (1.69)	0.14 (0.47)
125 (59.0)						1.71 (5.77)	0.74 (2.50)	0.20 (0.68)
150 (70.8)						2.30 (7.77)	0.99 (3.34)	0.27 (0.91)
175 (82.6)							1.28 (4.32)	0.35 (1.18)
200 (94.4)							1.61 (5.43)	0.44 (1.49)

that there are no discernible defects. During the inspection, excess flux shall be removed.

3. Before the wallboard application, pressurize each section of the piping system to 150 psig (1,034.22 kPa) using oil-free dry air or nitrogen. After the system has been pressurized, each joint shall be checked for leakage using a soap/water solution or another nontoxic leak-detecting agent. If leaks are detected, the system shall be repaired and retested.
4. After testing each individual medical gas system, the completely assembled station outlets and all other components shall be installed and subjected to a 24-hour standing pressure test at 20 percent above normal operating line pressure. This test gas shall be oil-free dry nitrogen. The source valve shall be closed. Leaks, if any, shall be located, repaired, and retested.
5. Each dedicated gas system shall be tested with oil-free dry nitrogen to verify that there are no cross-connections to any other system. To determine the presence of cross-connections, pressurize only one system to 50 psig (344.74 kPa) at a time, and then test each outlet to verify that the gas exists only at each of the expected outlets. (See step 7.)
6. Each gas piping system shall be purged of contaminants by flushing it with the appropriate source gas while under system pressure. The piping system for each gas shall be purged by successively opening each outlet in progressive order, starting with the outlet that is nearest the pressure source and ending at the outlet that is farthest from the pressure source. The gas shall be purged through a white cloth material at a flow rate of at least 3.5 cfm (100 L/min) until there is no longer any evidence of discoloration or particulates. It is also important to purge for a sufficiently long time so that all of the test gas previously used is removed from the system. (See step 11.)

   Startup, testing, and certification of the medical gas systems shall be conducted by an independent, third-party, trained representative with a minimum of five years of experience in medical gas pipeline testing and certification. Proof of liability insurance should be requested by the owner or general contractor.

   After successful startup of all systems and components, vital information regarding the proper operation of the equipment shall be made part of the medical gas certification. This shall include, but not be limited to, the following:

   - Medical air compressors, dryers, purifiers, filters, regulators, and dewpoint and carbon monoxide monitors
   - Medical vacuum pumps
   - Bulk liquid oxygen field and oxygen, nitrous oxide, nitrogen, and carbon dioxide manifolds
   - Master and area alarms and their signal devices
   - Medical gas valves and zone valve boxes
   - Outlets, nitrogen control panels, columns, and hose drop assemblies
7. After the walls are closed and the requirements of NFPA 99 Section 4-3.4.1.2 have been completed, it shall be determined that no cross-connection of piping systems exists. All medical gas systems shall be reduced to atmospheric pressure. All sources of test gas from all of the medical gas systems, with the exception of the one system to be checked, shall be disconnected. This system shall be pressurized with oil-free nitrogen to 50 psig (344.74 kPa gauge). With appropriate adapter-matching outlet labels, each individual station outlet of all medical gas systems installed shall be checked to determine that test gas is being dispensed only from the outlets of the medical gas system being tested.

   The source of the test gas shall be disconnected, and the system tested shall be reduced to atmospheric pressure. Proceed to test each additional piping system in accordance with the above instructions. Where a medical vacuum piping system is installed, the cross-connection testing shall include the piped vacuum system with all medical gas piping systems.

   The presence and correctness of labeling required by NFPA 99 for all components (e.g., station outlets, shutoff valves, pipelines, and signal panels) shall be verified.
8. Valves installed in each medical gas piping system shall be tested to verify proper operation in rooms or areas of control. Records shall be made listing the rooms or areas controlled by each valve for each gas. The information shall be utilized to assist and verify the proper labeling of the valves.
9. All outlets shall be tested for flow. Tests shall be performed with the use of oil-free dry nitrogen as described in CGA P-9: *Inert Gases: Argon, Nitrogen, and Helium*. Oxygen, nitrous oxide, and air outlets shall deliver 3.5 scfm (1.65 L/s) with a pressure drop of no more than 5 psig (34.47 kPa) and a static pressure of 50 psig (344.74 kPa). Nitrogen outlets shall deliver 5 scfm (2.36 L/s) with a pressure drop of no more than 5 psig (34.47 kPa) and a static pressure of 160 psig (1,103 kPa).
10. All warning systems for each medical gas piping system shall be tested to ensure that all components function properly prior to placing the piping system into service. Permanent records of these tests shall be maintained. Warning systems that are part of an addition to an existing piping

system shall be tested prior to the connection of the new piping to the existing system. Tests of warning systems for new installations (initial test) shall be performed after the cross-connection testing discussed in step 7 but before the purging and verifying in step 12. Initial tests of warning systems that may be included in an addition or extension to an existing piping system shall be completed before connection of the addition to the existing system. The test gas for the initial tests shall be oil-free dry nitrogen.

The master alarm system test shall be performed for each of the nonflammable medical gas piping systems. Permanent records of these tests shall be maintained with those required under NFPA 99 Section 4-3.5.3. The audible and noncancellable visual signals of NFPA 99 Section 43.1.2.1(b)3e shall indicate when pressure in the main line increases or decreases 20 percent from the normal operating pressure.

The warning signals for all medical gas piping systems supplying anesthetizing locations and other vital life-support and critical care areas, such as post-anesthesia recovery, intensive care units, and coronary care units, shall indicate the pressure in the piping system if it increases or decreases 20 percent from the normal operating pressure.

11. To remove any traces of particulate matter deposited in the pipelines as a result of construction, a heavy, intermittent purging of the pipeline shall be done. The appropriate adapter shall be obtained from the facility or manufacturer, and high purge rates of least 8 cfm (225 L/min) shall be put on each outlet. After the purge is started, it shall be rapidly interrupted several times until the purge produces no discoloration in a white cloth loosely held over the adapter during the purge. To avoid possible damage to the outlet and its components, this test shall not be conducted using any implement other than the proper adapter.

    For each positive-pressure gas system, cleanliness of the piping system shall be verified. Filter a minimum of 35 cubic feet (991.1 L) of gas through a clean, white 0.45-micron filter at a minimum flow of 3.5 scfm (99.12 L/min). The filter shall show no discoloration and shall accrue no more than 0.1 milligrams of matter. Each zone shall be tested at the outlet most remote from the source. The test shall be performed with the use of oil-free dry nitrogen described in CGA P-9.

12. For each positive-pressure system, the purity of the piping system shall be verified. Test each zone at the most remote outlet for dewpoint, total hydrocarbons (as methane), and halogenated hydrocarbons, and compare those values with the source gas. The test shall be performed with the use of oil-free nitrogen gas as described in CGA P-9. The two tests shall not exceed the maximum allowable variations:
    - Dewpoint: 41°F at 50 psig (5°C at 375 kPa)
    - Total hydrocarbons: ±1 ppm (as methane)
    - Halogenated hydrocarbons: ±2 ppm
13. Prior to the connection of any work, extension, or addition to an existing piping system, the tests in steps 7 through 12 shall be successfully performed. After connection to the existing system and before use of the addition for patient care, the tests in steps 14 through 16 shall be completed. Permanent records of these tests shall be maintained in accordance with NFPA 99 Section 4-3.5.3.

    The final connection between the addition and the existing system shall be leak tested with the gas of system designation at the normal operating pressure. This pressure shall be maintained until each joint has been examined for leakage by means of soapy water or another equally effective means of leak detection safe for use with oxygen.
14. Operational pressure test: Piping systems, with the exception of nitrogen systems, shall maintain pressure at 50 +5/-0 psig (345 +35/-0 kPa gauge) at all station outlets at the maximum flow rate noted below. A nitrogen system shall be capable of delivering at least 160 psig (1,103 kPa gauge) to all outlets at the flow noted below. Piping systems that vary from the normal pressures shall be capable of delivering flows and pressures consistent with their intended use. Oxygen, nitrous oxide, and air outlets shall deliver 3.5 scfm (1.65 L/s) with a pressure drop of no more than 5 psig (34.47 kPa) and a static pressure of 50 psig (344.74 kPa). Nitrogen outlets shall deliver 5 scfm (2.36 L/s) with a pressure drop of no more than 5 psig (34.47 kPa) and a static pressure of 160 psig (1,103 kPa).
15. Medical gases concentration test: After purging each system with the gas of system designation, each pressure gas source and outlet shall be analyzed for concentration of gas, by volume, using instruments designed to measure the specific gas dispensed. The allowable concentrations shall be within the following ranges:
    - Oxygen: 99+% oxygen
    - Nitrous oxide: 99+% nitrous oxide
    - Nitrogen: <1% oxygen or 99+% nitrogen
    - Medical air: 19.5 to 23.5% oxygen
    - Other gases: Concentration as specified by their labeling ±1%, unless otherwise specified
16. Medical air purity test (compressor): Analyze the medical air source for concentration of contaminants, by volume. Take samples for an air system

test at a sample point. The compared tests shall not exceed the maximum allowable variations as follows:

- Dewpoint: +39°F at 50 psig (3.9°C at 375 kPa)
- Carbon monoxide: £10 ppm
- Carbon dioxide—air: ±500 ppm
- Gaseous hydrocarbons—air: £25 ppm (as methane)
- Halogenated hydrocarbons—air: £2 ppm

Codes and Standards

Care must be taken by the plumbing engineer to investigate and review the most recent local plumbing code and NFPA 99 provisions pertaining to the piping of nonflammable medical gas systems. The plumbing engineer should note that in many areas, state and/or local codes exist that may take precedence over the nationally recognized, voluntary standards.

GLOSSARY

acfm (actual cubic feet per minute) The unit used to express the measure of the volume of gas flowing at operating temperature and pressure, as distinct from the volume of a gas flowing at standard temperature and pressure (see scfm)

Air, oil-free, dry (air for testing) Air complying, at a minimum, with Grade D in ANSI/CGA G-7.1: *Commodity Specification for Air* and having a maximum dewpoint of -20°F (-28.9°C) at line pressure

Alarm system, Level III An area alarm system for a patient nonflammable medical gas system, typically oxygen, nitrous oxide, and medical air in dental care facilities and medical care facilities

Alarm system, local A warning system that provides visible and audible signals for the monitoring functions of medical gas and vacuum system source equipment at the equipment site

Alarm system, master A warning system that provides visible and audible signals for the monitoring of medical gas and vacuum sources and systems, consisting of alarm panels and associated actuating devices

Ampacity The current-carrying capacity of electric conductors, expressed in amperes

Anesthetic As used in this chapter, any inhalation agent used to produce relative analgesia or general anesthesia

Anesthetizing location Any area of a facility that has been designated to be used for the administration of nonflammable, inhalation anesthetic agents in the course of examination or treatment, including the use of such agents for relative analgesia (see anesthetic)

Authority having jurisdiction (AHJ) The organization, office, or individual responsible for approving equipment, an installation, or a procedure

Clinic A healthcare facility where patients are seen on an ambulatory basis, but where surgery involving general anesthesia is not performed

Combustible A substance that, if ignited, will react with oxygen and burn

Combustion products The gases, volatilized liquids and solids, particulate matter, and ash generated by combustion

DISS connector A threaded medical gas connector complying with CGA V-5: *Diameter Index Safety System (Non-Interchangeable Low-Pressure Connections for Medical Gas Applications)*

Emergency oxygen supply connection (EOSC) An assembly of equipment that permits a gas supplier to make a temporary connection to supply oxygen to a building that has had its normal source of oxygen disconnected

Flammable gas Any gas that will burn when mixed in any proportion with air, oxygen, or nitrous oxide

Flash point The minimum temperature at which a liquid gives off vapor in sufficient concentration to form an ignitible mixture with air near the surface of the liquid within the vessel, as specified by appropriate test procedures and apparatus

Healthcare facilities Buildings or portions of buildings in which medical, dental, psychiatric, nursing, obstetrical, or surgical care is provided, including, but not limited to, hospitals, nursing homes, limited-care facilities, clinics, medical and dental offices, and ambulatory care centers, whether permanent or movable

Hyperbaric pressures Pressure above atmospheric pressure

Hypobaric pressures Pressures below atmospheric pressure

Laboratory A building, space, room, or group of rooms intended to serve activities involving procedures for investigation, diagnosis, or treatment in which flammable, combustible, or oxidizing materials are to be used, not intended to include isolated, frozen-section laboratories; areas in which oxygen is administered; blood donor rooms in which flammable, combustible, or otherwise hazardous materials normally used in laboratory procedures are not present; and clinical service areas in which hazardous materials are not used

Limited-care facility A building or part thereof used on a 24-hour basis for the housing of four or more persons who are incapable of self-preservation because of age, physical limitation due to accident or illness, or mental limitations such as mental retardation or developmental disability, mental illness, or chemical dependency

Medical air For the purposes of this chapter, air that is supplied from cylinders, bulk containers, or medical air compressors or has been reconstituted from oxygen USP and nitrogen NF and complies with the following:

- Medical air USP
- Total hydrocarbons, liquid and nondetectable gaseous: <25 ppm
- Pressure dewpoint at 50 psig: <39°F (4°C)
- Permanent particulates: 5 mg/m^3 at normal atmospheric pressure at 1-micron size or greater

Note: Air supplied from an on-site compressor and associated air-treatment systems (as opposed to medical air USP supplied in cylinders) that complies with the above limits is considered medical air.

Hydrocarbon carryover from the compressor into the pipeline distribution system could be detrimental to the safety of the end user and to the integrity of the piping system. The mixing of air and oxygen is a common clinical practice, and the hazards of fire are increased if the air is thus contaminated.

Compliance with these limits is considered important to fire and patient safety. The quality of local ambient air should be determined prior to its selection for compressors and air-treatment equipment.

Medical compressed air has many uses in the healthcare field. It is used in respiratory therapy applications in conjunction with high-humidity treatments using nebulizers in pediatrics and nurseries. It is also used to power pneumatic surgical instruments that have a pressure range of 120 to 200 psi (827.4 to 1,379 kPa).

Medical air compressor A compressor that is designed to exclude oil from the air stream and compression chamber and that does not under normal operating conditions or by any single fault add any toxic or flammable contaminants to the compressed air

Miscellaneous gases Carbon dioxide, helium, and mixtures of each of these two gases with oxygen, used in a teaching institution or in a hospital specializing in cardiovascular surgery

Nitrogen (N_2) An element that, at atmospheric temperatures and pressures, exists as a clear, colorless, odorless, and tasteless gas. It is a nontoxic and inert gas that inhibits combustion by displacing the air. The principle use of nitrogen gas in a healthcare facility is for powering pneumatic surgical instruments.

Nitrous oxide (N_2O) A nonflammable gas commonly used as an analgesic and, in combination with one or more agents, for the production of a balanced anesthesia

Oxidizing gas A gas that supports combustion such as oxygen and nitrous oxide as well as many others, including halogens

Oxygen (O_2) The most widely used of all medical gases, oxygen is colorless, odorless, and tasteless. Of the three basic essentials for the maintenance of life—oxygen, water, and food—the deprivation of oxygen leads most rapidly to death. Tissue cells have no reserve; they must be continually supplied with oxygen by the body's circulation system. Oxygen is a nonflammable gas used for respiratory therapy and in surgery for anesthesia.

Note: Its outstanding properties are its ability to sustain life and to support combustion. Although oxygen is nonflammable, materials that burn in air will burn much more vigorously and create higher temperatures in oxygen or in oxygen-enriched atmospheres.

> ***Oxygen, gaseous*** A colorless, odorless, and tasteless gas; also, the physical state of the element at atmospheric temperature and pressure
>
> ***Oxygen, liquid*** Exists at cryogenic temperature, approximately -300°F (-184.4°C) at atmospheric pressure. It retains all of the properties of gaseous oxygen, but, in addition, when allowed to warm to room temperature at atmospheric pressure, it will evaporate and expand to fill a volume 860 times its liquid volume.
>
> Note: If spilled, the liquid can cause frostbite on contact with skin.

Oxygen-delivery equipment Any device used to transport and deliver an oxygen-enriched atmosphere to a patient. If an enclosure such as a mask, hood, incubator, canopy, or tent is used to contain the oxygen-enriched atmosphere, then that enclosure is considered to be oxygen-delivery equipment.

Oxygen-enriched atmosphere For the purpose of this chapter, and only for the purpose of this chapter, an atmosphere in which the concentration of oxygen exceeds 23.5 percent by volume

Oxygen index The minimum concentration of oxygen, expressed as a percent by volume, in a mixture of oxygen and nitrogen that just supports combustion of a material under the conditions of ASTM D2863: *Standard Test Method for Measuring the Minimum Oxygen Concentration to Support Candle-Like Combustion of Plastics (Oxygen Index)*

Oxygen toxicity (hyperbaric) Physical impairment resulting from breathing gaseous mixtures containing oxygen-enriched atmospheres at elevated partial pressures for extended periods. Under the pressures and times of exposure normally encountered in hyperbaric treatments, toxicity is a direct function of concentration and time of exposure.

Patient vacuum (VAC) Typically used to provide a source for patient drainage, aspiration, and suction to remove body fluids (such as saliva or blood) from an affected patient area. The body fluid is normally trapped in a container near the patient. The vacuum source only provides a source of subatmospheric pressure.

Piping The tubing or conduit of the system. The three general classes of piping are:

> ***Main lines*** Those parts of the system that connect the source (pumps, receivers, etc.) to the risers, branches, or both
>
> ***Risers*** The vertical pipes connecting the system main lines with the branch lines on the various levels of the facility
>
> ***Branch (lateral) lines*** Those sections or portions of the piping system that serve a room or group of rooms on the same story of the facility

psia (pounds per square inch absolute) A unit of pressure measurement with zero pressure as the base or reference pressure

psig (pounds per square inch gauge) A unit of pressure measurement with atmospheric pressure as the base or reference pressure. Under standard conditions, 0 psig is equivalent to 14.7 psia.

scfm (standard cubic feet per minute) The unit used to express the measure of the volume of a gas flowing at standard conditions—a temperature of 68°F (20°C) and a pressure of 1 atmosphere (29.92 inches Hg)

Station inlet An inlet point in a Type I medical/surgical piped vacuum distribution system at which the user makes connections and disconnections

Station outlet An outlet point in a piped medical gas distribution system at which the user makes connections and disconnections

Vacuum system, Level 1 A system consisting of central vacuum-producing equipment with pressure and operating controls, shutoff valves, alarm warning systems, gauges, and a network of piping extending to and terminating at suitable station inlets at locations where patient suction might be required

Vacuum system, Level 3 A vacuum system, either a wet or dry piping system, designed to remove liquid, air, gas, and solids from the treated area

Notes: The system is not intended for Level 1 vacuum applications. A wet piping system is designed to accommodate liquid, air, gas, and solids through the service inlet. A dry piping system is designed to accommodate air and gas only through the service inlet. (Liquids and solids are trapped before entering the service inlet.)

Waste anesthetic gas disposal (WAGD) A surgical vacuum system that is used to evacuate the anesthetic gases from the operating room after the gases have been exhaled by the patient; also the process of capturing and carrying away gases vented from the patient breathing circuit during the normal operation of gas anesthetic equipment

REFERENCES

- CSA Z-305.1: *Nonflammable Medical Gas Piping Systems*
- CGA P-2: *Characteristics and Safe Handling of Medical Gases*
- ANSI/CGA G-7.1: *Commodity Specification for Air*
- CGA G-10.1: *Commodity Specification for Nitrogen*
- CGA G-7: *Compressed Air for Human Respiration*
- CGA V-5: *Diameter Index Safety System (Non-interchangeable Low Pressure Connections for Medical Gas Applications)*
- CGA P-9: *Inert Gases: Argon, Nitrogen, and Helium*
- CGA C-9: *Standard Color Marking of Compressed Gas Containers for Medical Use*
- CGA G-8.1: *Standard for the Installation of Nitrous Oxide Systems at Consumer Sites*
- NFPA 50: *Standard for Bulk Oxygen Systems at Consumer Sites*
- NFPA 99: *Standard for Healthcare Facilities*

RESOURCES

- Canadian Standards Association: csa.ca
- Compressed Gas Association: cganet.com
- National Fire Protection Association: nfpa.org

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3

Treatment of Industrial Waste

"Industrial wastewater" is a generic term used to describe nonsanitary (plumbing) effluent, such as that typically found in chemical, pharmaceutical, and other manufacturing facilities. It also may be applied to wastewater from commercial facilities, such as self-service laundries or large restaurants. The definition also includes storm water runoff containing anything considered harmful by the U.S. Environmental Protection Agency (EPA) discharged from sites involving any industrial activity or construction.

This chapter describes the regulatory framework governing industrial wastewater, hazardous substances, and hazardous wastes and the impact of these regulations on industrial-process plumbing design. It also contains design considerations, describes a few of the more common treatment technologies, and provides resources from which more detailed information can be obtained.

Whether discharged to municipal sewers, surface waters, deep wells, or land, industrial wastewater and some storm water runoff are subject to government permitting requirements. In most cases, these wastes must be treated before discharge to abate pollution. Permits specify the maximum allowable concentrations of pollutants in the discharge and the frequency and type of monitoring required to show compliance. Pollution abatement by dilution is no longer allowed. The segregation of incidental water streams, such as non-contact cooling water or storm water runoff, from process wastewater is almost universally required. Even clean, incidental wastewater streams require a permit.

Most nonaqueous liquids (including solvents, oils, and sludge) and some solids and gases are regulated as hazardous substances or hazardous wastes during their generation, use, collection, storage, transportation, treatment, and disposal. Some aqueous wastes that are not regulated under a wastewater permit are regulated as either hazardous substances or hazardous wastes.

As a result of these regulations, plumbing designers must either consult with an experienced environmental engineer or become familiar with the various environmental requirements to ensure an acceptable installation. New facilities must meet both environmental and plumbing code requirements. For novel manufacturing processes, the designer, environmental engineer, and owner may be required to work with regulatory authorities during the design stage to ensure compliance with the intent of the various codes and regulations. The designer is responsible for producing an installation with a low probability of failure. For plumbing design, this means minimizing the possibility of leaks and providing a means to limit the impact of spills on the public's safety and the environment.

DEFINITIONS

Hazardous substance Under Section 311 of the Clean Water Act, the EPA has compiled a list of hazardous substances (40 CFR 116). If a substance on this list is spilled or discharged, it must be reported to the EPA.

Priority pollutant The Natural Resources Defense Council and the EPA determine priority toxic pollutants. These pollutants have been incorporated into several regulatory programs, including NPDES permits, pretreatment standards (40 CFR 403), hazardous wastes (40 CFR 261), and CERCLA (42 USC 103).

Hazardous wastes The EPA has adopted regulations to control hazardous wastes under RCRA. These regulations (40 CFR 261) list hazardous wastes, including specific chemicals and mixtures defined by their characteristics. It should be noted that controls under RCRA apply to waste only and not to hazardous substances that are being stored prior to use in product manufacturing or that are to be reclaimed, recycled, or reused. RCRA regulates the generation, transportation, storage, treatment, and disposal of hazardous wastes.

Hazardous materials This term means substances or materials that have been determined by the secretary of transportation, under 49 CFR 172, to be capable of posing an unreasonable risk to health, safety, and property when transported in commerce. Chemicals included in this definition are hazardous substances, hazardous wastes, most of the priority pollutants, and many other chemicals in commerce that are too numerous to mention here. In this chapter, the term "hazardous materials" is used to describe all the previously defined materials and substances.

For detailed listings of these and other regulated chemicals and wastes, refer to the regulations cited in the above definitions.

REGULATORY FRAMEWORK

The most important pieces of environmental legislation affecting the design of plumbing systems for hazardous material and waste facilities serving industrial plants are the Clean Water Act (CWA), Resource Conservation and Recovery Act (RCRA), and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), otherwise known as Superfund. These regulations, promulgated by the EPA and enforced by either the EPA or counterpart state agencies, provide a comprehensive framework of pollution control. The National Pollutant Discharge Elimination System (NPDES) permitting program has recently been revised to include the discharge of storm water from selected industrial sites. Current EPA regulations can be found in the Code of Federal Regulations (CFR), which is an annually updated compendium of all federal regulations. Any updates or regulation changes after the last publication date of the CFR can be found in the Federal Register, a daily government newspaper in which all agencies and departments publish their notices, proposals, and final regulations. Most states with counterpart regulations have similar codifications and newspapers.

The great body of codes and regulations can easily be a labyrinth, even for those persons with a good understanding of the overall outline and purpose of the statutes. Anyone with questions should not hesitate to seek advice from trade groups, regulatory officials, environmental engineers, lawyers, and other specialists as needed. Numerous current event reporting services digest federal and state regulatory actions and publish readable evaluations as well as reprints of important regulations, policies, and case notes.

Clean Water Act

The CWA establishes a mechanism for setting uniform national standards for discharge to surface waters and sewers. The EPA has established categorical effluent standards, usually prorated to production volume, for 56 industrial classifications under the Effluent Guidelines Program Plan. The affected industries are listed in Table 3-1. The EPA has also promulgated general standards for discharge to public sewer systems. These standards restrict pollutants that

Table 3-1 Industries Affected by the Effluent Guidelines Program Plan

Number	Industry Category
1	Aluminum Forming
2	Asbestos Manufacturing
3	Battery Manufacturing
4	Canned and Preserved Fruits and Vegetable Processing
5	Canned and Preserved Seafood Processing
6	Carbon Black Manufacturing
7	Cement Manufacturing
8	Centralized Waste Treatment
9	Coal Mining
10	Coil Coating
11	Concentrated Animal Feeding Operations
12	Concentrated Aquatic Animal Production
13	Copper Forming
14	Dairy Products Processing
15	Electrical and Electronic Components
16	Electroplating
17	Explosives Manufacturing
18	Ferroalloy Manufacturing
19	Fertilizer Manufacturing
20	Glass Manufacturing
21	Grain Mills
22	Gum and Wood Chemicals
23	Hospitals
24	Ink Formulating
25	Inorganic Chemicals
26	Iron and Steel Manufacturing
27	Landfills
28	Leather Tanning and Finishing
29	Meat and Poultry Products
30	Metal Finishing
31	Metal Molding and Casting
32	Metal Products and Machinery
33	Mineral Mining and Processing
34	Nonferrous Metals Forming and Metal Powders
35	Nonferrous Metals Manufacturing
36	Oil and Gas Extraction
37	Ore Mining and Dressing
38	Organic Chemicals, Plastics, and Synthetic Fibers
39	Paint Formulating
40	Paving and Roofing Materials (Tars and Asphalt)
41	Pesticide Chemicals
42	Petroleum Refining
43	Pharmaceutical Manufacturing
44	Phosphate Manufacturing
45	Photographic
46	Plastic Molding and Forming
47	Porcelain Enameling
48	Pulp, Paper, and Paperboard
49	Rubber Manufacturing
50	Soaps and Detergents Manufacturing
51	Steam Electric Power Generating
52	Sugar Processing
53	Textile Mills
54	Timber Products Processing
55	Transportation Equipment Cleaning
56	Waste Combustors

Source: U.S. Environmental Protection Agency, 2008 interfere with sewage treatment, pass through the system untreated, damage sewer lines or treatment facilities, or overload treatment processes.

State laws and regulations follow the federal format, with a few important differences. All states are allowed to make their regulations more stringent than the federal standards. Additionally, some states regulate discharges to the land (and hence to the groundwater). States also set goals for water quality levels in streams, lakes, and coastal waters. They then determine the allowable loading of each pollutant and allocate portions of that loading based on low-flow conditions where dilution is minimal. Water quality-based discharge permit limits are almost always more stringent than industry-wide limits of the categorical effluent standards.

Two types of water discharge permits may require treatment processes. Permits for a direct discharge into a surface water (stream, lake, ocean) are called National Pollutant Discharge Elimination System permits. These permits may be issued by the EPA or a state or jointly, depending on the location. Application is required well in advance of initiating a discharge.

The other type of industrial discharge permit is obtained from a publicly owned treatment works (POTW). Industrial discharges to a POTW are called indirect discharges and are regulated by pretreatment ordinances to ensure that the POTW meets the conditions of its NPDES permit. The ordinances are usually administered by the POTW, except when the industrial discharge is large, the POTW fails to meet its permit requirements, or the discharge is from an industry regulated under the Effluent Guidelines Program Plan.

RCRA and CERCLA

These two laws, together with the federal and state regulations derived from them, have had a major impact on the industrial management of hazardous substances and hazardous wastes. Almost all nonaqueous liquids, many aqueous mixtures, and many solids and gases are regulated when they become wastes or are spilled.

The purpose of CERCLA is to limit the uncontrolled release or threat of release of hazardous substances into the environment and to provide for a coordinated and effective response to mitigate actual releases. CERCLA requires industrial risk evaluations, in the form of contingency plans, and establishes a mechanism for governmental response to environmental and health hazards. CERCLA does not require any permits and does not force changes in current hazardous substance handling methods. Nevertheless, a great deal of publicity can result when the mishandling of hazardous substances leads to an environmental incident. There also can be an enormous cost to dispose of the hazardous wastes generated during a spill. These are strong inducements to chemical manufacturers and users to install process systems that minimize risk.

RCRA's purpose is similar to CERCLA's, except that RCRA regulates hazardous wastes from ongoing manufacturing activities. The goals of RCRA are accomplished through strict licensing and operational standards for every aspect of hazardous waste management.

RCRA requires identification numbers and/or permits for every hazardous waste activity. The permit application requirements are lengthy and technical for some of the regulated activities. In some cases, the regulations give performance standards that the designer must meet to obtain a permit for the facility. In other cases, the compliance method is almost completely specified. Obtaining RCRA permits for a facility may take six months and may require public hearings and disclosure of detailed process and waste information, including chemical material safety data sheets (MSDS).

When evaluating waste streams to determine if they are regulated as hazardous wastes, it is important to check both federal and state regulations. This is because states are allowed to be more stringent than the EPA. States may define certain wastes as hazardous when the EPA doesn't consider them so. For example, waste oil is considered hazardous by many states, but not by the EPA.

The relationship between RCRA and CERCLA is shown by this example: A tank containing a hazardous substance begins to leak onto the ground. Under CERCLA, the owner must notify the EPA and the state, stop the leak, and clean up the spilled material. If the owner fails to take action, the regulatory agency may act under CERCLA and then seek reimbursement up to triple the cost of its expenses. Under RCRA, the spilled hazardous substance and any contaminated soil become hazardous waste. The hazardous waste must be removed, stored, transported, and disposed of in accordance with RCRA requirements.

DESIGN CONSIDERATIONS

For plumbing designers, the challenge is to design systems that minimize the chance of leaks, contain any spills that might occur, and segregate hazardous substances from both nonhazardous process streams and incompatible hazardous process streams. The design of a system that anticipates the potential for leaks and spills must include suitable materials, reliable joining, good fabrication, and provision for the secondary containment of liquids in areas and systems that pose a high spill risk.

Many leaks occur as a result of material incompatibility between the equipment and either the hazardous substances handled or the atmosphere in

Table 3-2 General Properties of Materials Used for Storage Tanks and Piping

Containment Materials	Advantages	Disadvantages
Carbon steel	Compatible with petroleum products and dry organics and incompatible with many aqueous solutions.	Subject to attack by corrosive soils and chemicals.
Stainless steel	Better corrosion resistance than carbon steel and higher structural strength—There are more than 70 standard types of stainless steel and many special alloys.	Corroded by chloride and exposure to reducing environments.
Fiberglass-reinforced plastic (FRP)	Compatible with a wide range of petroleum and chemical products, if proper resin is selected.	Lacks the structural strength and impact resistance of steel tanks.
Polyvinyl chloride	Excellent chemical resistance to acids, alkalis, and gasoline.	Lower structural strength than steels, generally not suited for the storage or handling of organic solvents such as benzene, carbon tetrachloride, and acetone, or use at temperatures above 140°F (60°C).
Concrete	Generally good resistance to alkaline chemicals, epoxy coatings often applied to concrete to increase chemical resistance.	Subject to cracking and spalling with changes in temperature such as during freeze/thaw cycles, uncoated concrete absorbs solvents.
Polypropylene	Resistance to all aqueous solutions except strong oxidizers.	Low structural strength, temperature limit of 248°F (120°C).
Lined steel	Chemical resistance of plastic and structural strength of steel.	Relatively high cost for material and installation.

which the equipment is utilized. The incompatibility can be physical, such as polyvinyl chloride (PVC) pipes melting at high temperatures or plastic pipes dissolving in solvents they were not designed to contain. Table 3-2 lists the general properties of the most common tank and pipe materials. Specific applications should be checked with the appropriate chemical compatibility references from the manufacturer.

Even the best designed liquid-handling systems are subject to occasional failure, particularly during liquid transfer operations. Secondary containment is an important aspect of any hazardous material system design to protect employees and the environment. Secondary containment may include a dike around a tank or tank farm or pipes within pipes for systems handling extremely hazardous liquids. Common secondary containment systems typically have the following features:

- Containment floors, pads, ponds, and dikes constructed of materials impervious to the substance stored
- Perimeter diking and storage reservoirs sized to contain 110 percent of the largest tank plus the maximum rainfall predicted to occur over 24 hours once in 10 years in exterior areas (or 20 minutes of sprinkler water flow for interior areas)
- Pumps, drain valves, or siphons to empty the secondary containment area to either a storage tank or a treatment facility
- Controls and procedures to prevent the accidental release of contained spills and an alarm system to notify operations personnel if a spill occurs

Minimal equipment and practices for preventing transfer spills should include overfill prevention including level sensors, gauges and a high-level alarm, automatic valve and pump shutdown, established transfer procedures including an operator on duty, proper curbing and containment, redundant valves and controls, vapor recovery, alarms, regular inspections, and a maintenance program. The equipment used in water treatment is operated to achieve the following: mixing and flocculation, sedimentation, clarification, filtering, turbidity removal, metals removal, and disinfection.

Historically, underground tanks up to 10,000 gallons (37,854 L) in capacity and occasionally larger have been preferred for hazardous materials, primarily to minimize fire risks. Unfortunately, many of these tanks were kept in service too long and, because of corrosion, have leaked and contaminated drinking water supplies. As a result, designers now must compare the environmental and fire risks of the aboveground tank. In either case, more attention must be given in the design to ensure that an installation is resistant to leaks and capable of containing spills. Soil conditions and groundwater levels, which affect the design, must be evaluated for each installation. Secondary containment of these tanks is the primary method of ensuring against leakage.

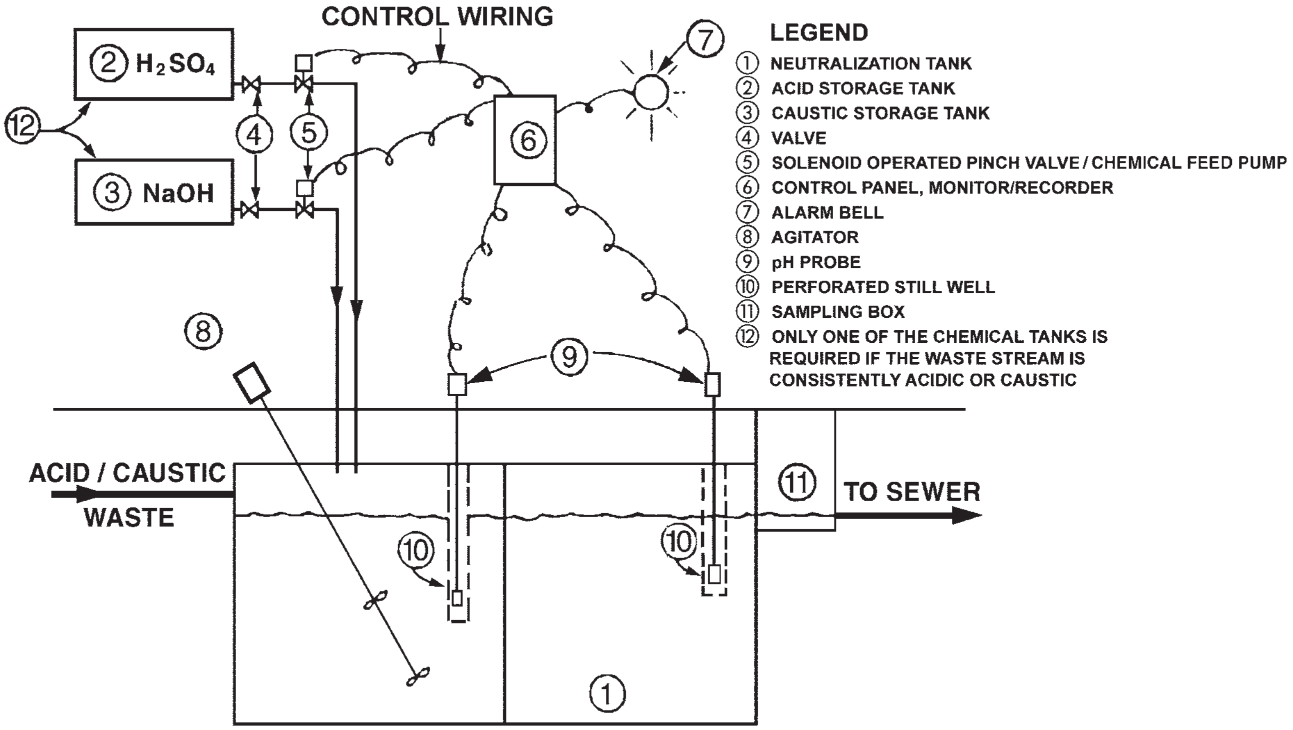


Figure 3-1 Acid/Caustic Neutralization Diagram

Note: Not to scale.

ELEMENTS OF AN INDUSTRIAL WASTEWATER HANDLING SYSTEM

pH Control

Neutralization for pH control involves the chemical reaction of an acid with an alkaline substance (a base), resulting in the formation of a salt and water. In an aqueous solution, the acid or base molecules dissociate and form ions. Sulfuric acid is presented in the solution as H^+ (hydrogen) and SO_4 (sulfate) ions and caustic soda as Na^+ (sodium) and OH^- (hydroxide) ions. The H^+ ions of the sulfuric acid and the OH^- ions of the caustic soda have a strong attraction to each other and combine to form H_2O (water). For example, in the neutralization reaction of H_2SO_4 (sulfuric acid) and NaOH (sodium hydroxide), the following process occurs:

$$H^+{}_2SO_4 + 2Na^+OH^-$$
$$Na^+{}_2SO_4 + 2H_2O$$

If excess hydrogen ions remain, the liquid will be acidic, and with a surplus of hydroxide ions, the liquid will be alkaline.

The acidity or alkalinity of a solution is expressed on the pH scale, with neutral water at a pH of 7, in the middle of the range between extremely acid (pH = 0) and extremely alkaline (pH = 14). The scale is logarithmic, so a pH of 3 is 10 times more acidic than a pH of 4. Buffers, such as bicarbonate/carbonate, undergo a chemical change when strong acids or bases are added to a solution and thereby act as capacitors that must be filled before the pH will change.

A typical two-stage, continuous-flow pH neutralization process is shown in Figure 3-1. For flows less than 10 gallons per minute (gpm) (37.85 L/min), neutralizing in a batch basis, with two tanks alternating between collection and treatment, is sometimes preferred.

The most critical feature of the pH adjustment system is the controller that activates the chemical feed pumps. The controller must have the ability to prevent overfeeding of either acid or base, which would cause wide pH swings and subsequent repetitive chemical additions. Overfeeding is most probable in wastewater with no buffering capacity near the pH setpoint (e.g., deionized and soft water). Controllers with multi-rate response adjustment should be specified for each application.

Sulfuric acid is the most costly method for pH adjustment purposes, although in some cases the commercial 93 percent acid must be diluted prior to use. The manufacturer's recommendations for materials of construction, control of the heat of dilution, and safety precautions should be carefully followed. Carbon steel pipe and tanks are commonly used for 93 percent sulfuric acid, with stainless alloy 20 (a high nickel alloy) valves, as well as PVC and chlorinated polyvinyl chloride (CPVC) plastics. For sulfuric acid at concentrations below 93 percent, polypropylene (PP), fiberglass-reinforced plastic (FRP), PVC, CPVC, and lined steel are preferred.

Sodium hydroxide (caustic or caustic soda) in 50 percent solution is the most convenient commercial

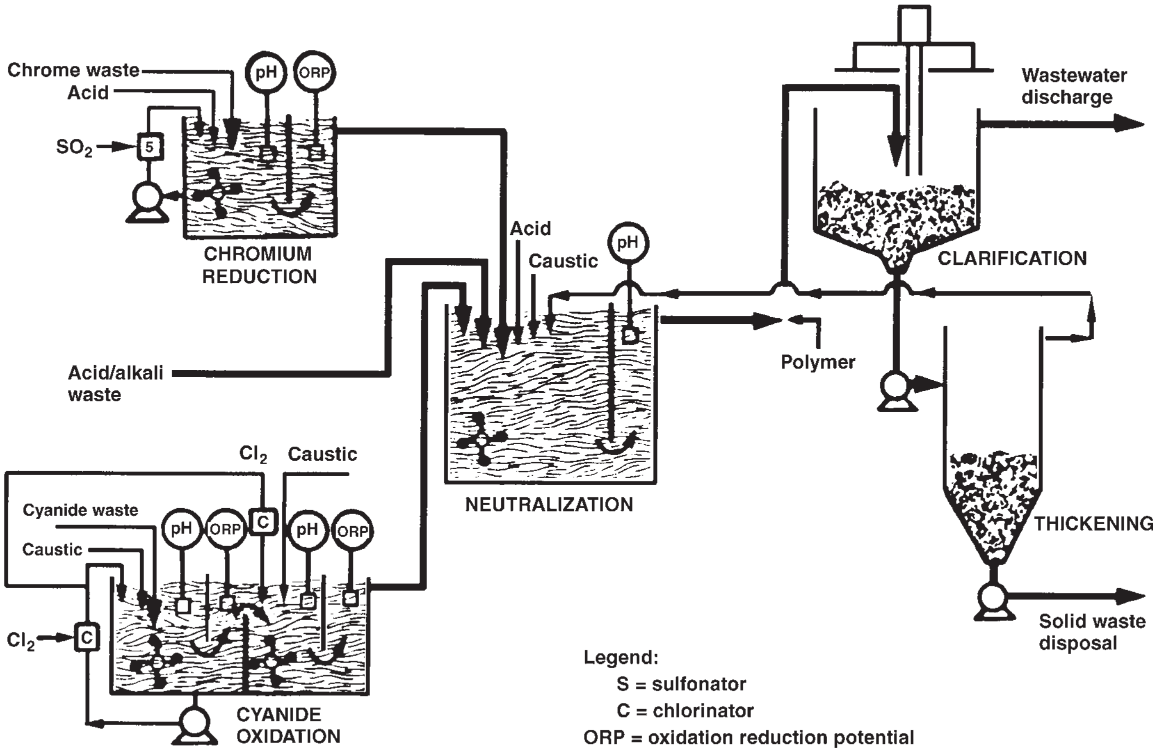


Figure 3-2 Conventional Electroplating Industry Wastewater Treatment

Note: Not to scale.

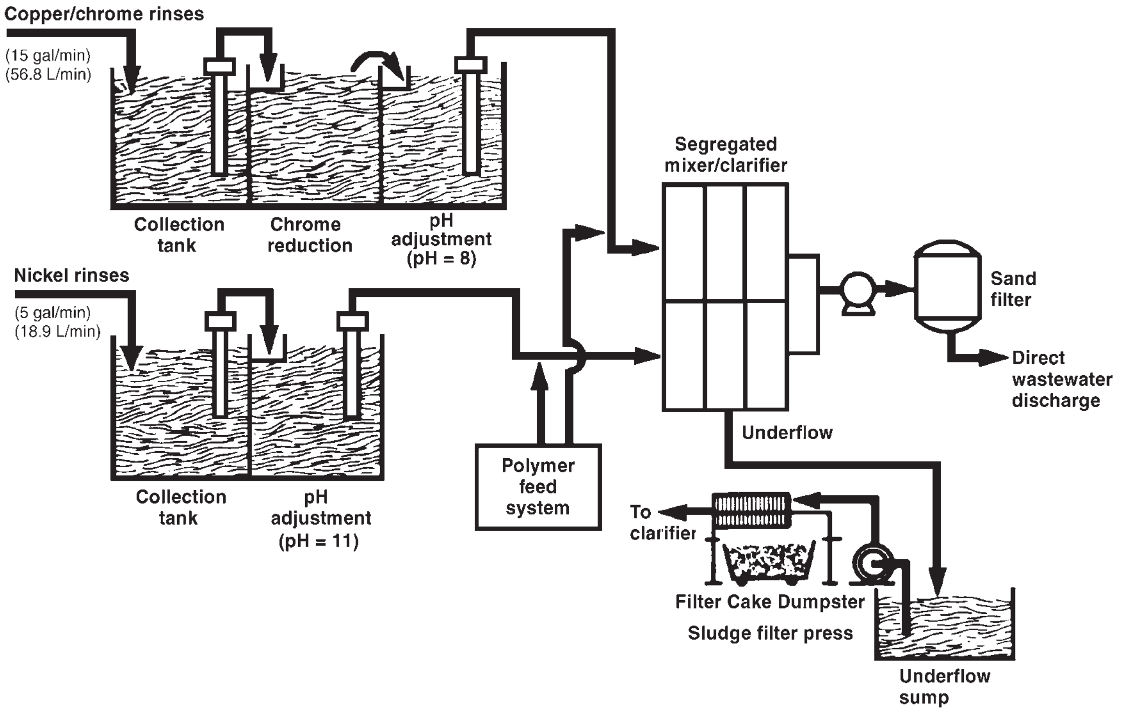


Figure 3-3 Treatment System with Wastewater Stream Segregation

Note: Not to scale.

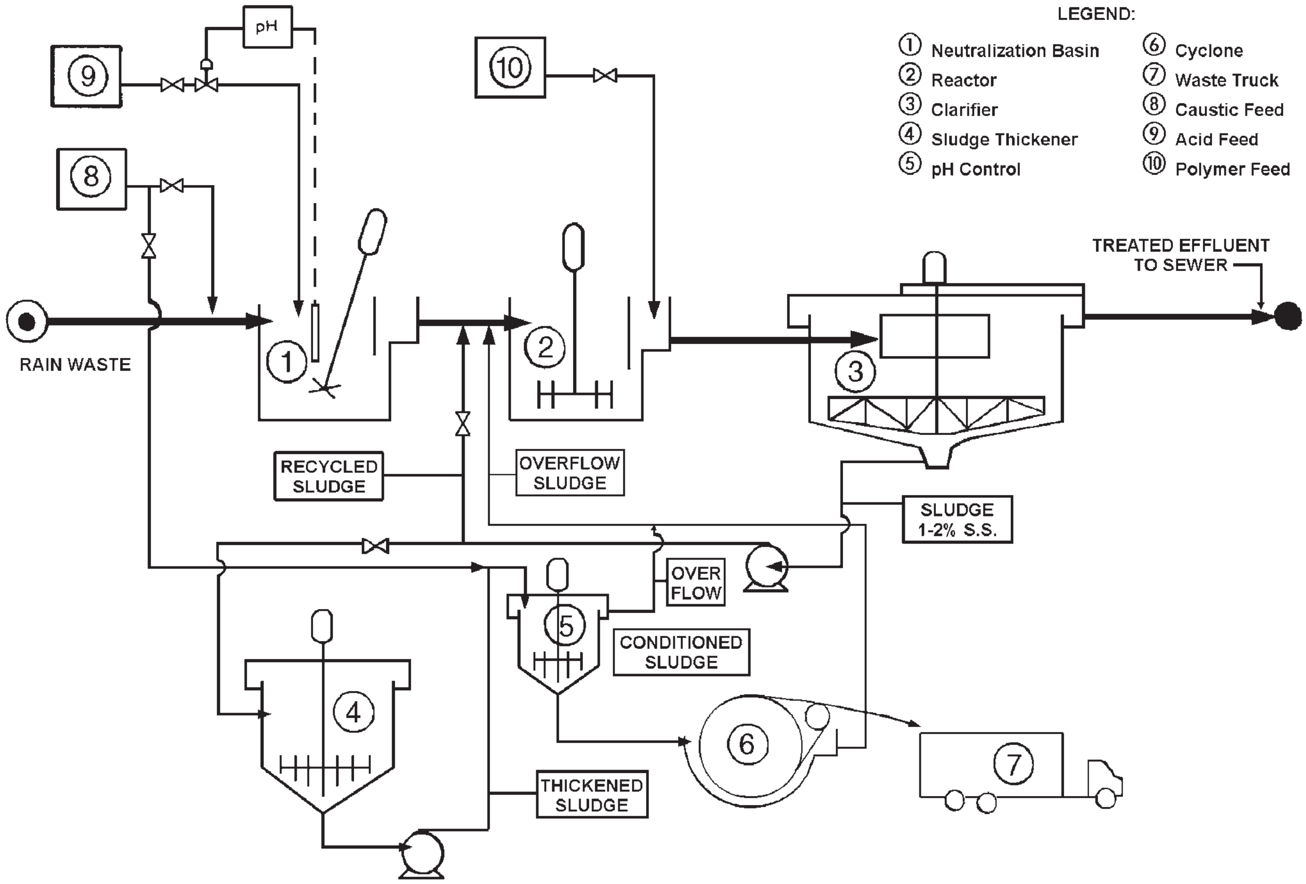


Figure 3-4 Typical Continuous Treatment of Wastewater and Solids-handling System for Heavy Metals

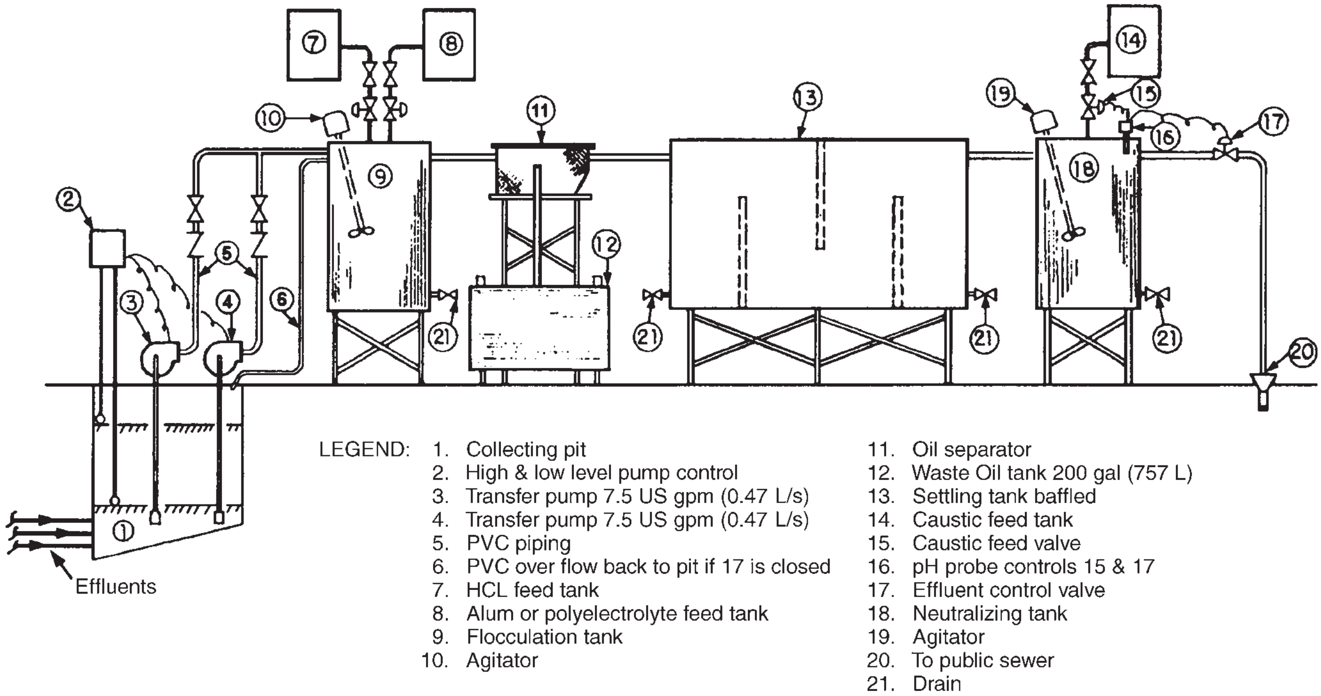
Note: Not to scale.

alkaline material for pH adjustment. Unfortunately, 50 percent caustic freezes at 54°F (12.2°C), so indoor storage or heated tanks are necessary. (Note that 20 percent caustic freezes at -18°F [-27.7°C].) Caustic solutions may be handled in carbon steel, stainless steel, and PVC tanks and pipe. Lime and hydrated lime are considerably less expensive than caustic but must be fed with dry feeders and/or slurry tanks, which require considerable maintenance. Consequently, lime is favored in applications where the cost outweighs the convenience of caustic.

Removal of Dissolved and Suspended Metals

Another common industrial wastewater treatment requirement is the removal of dissolved and suspended metals. The most popular method is to separate cyanide and chromium VI wastewater sources from each other and all other metal-bearing wastewaters. The cyanide is destroyed by oxidation with chlorine (or a sodium hypochlorite solution) at a pH of 9 to 11, and the chromium VI is reduced to chromium III with sulfur dioxide or sodium bisulfate at a pH of 2. Various treatment methods are shown in Figures 3-2, 3-3, and 3-4.

For trace metals up to 1,000 parts per million (ppm), the use of ion-exchange vessels containing resin beads tailored to the application may be considered. Ion exchange is a reversible chemical reaction wherein an ion (an atom or molecule that has lost or gained an electron and thus acquired an electrical charge) from a wastewater solution is exchanged for a similarly charged ion attached to an immobile solid particle. These solid ion particles are either naturally occurring inorganic zeolites or synthetically produced organic resins, which are the predominant type used today because their characteristics can be tailored to specific applications. This process is similar to the process for purifying water for laboratory or process applications. The exact ion combinations are based on the metals to be removed. The exchange vessels can be sized for the wastewater flow, or multiple vessels can be manifolded together to handle higher wastewater flows or to allow standby capacity. Automated controls and accessories can be furnished to back-flush or regenerate the vessels. The removed metals can then be reclaimed or safely disposed. This technology should be evaluated against other technologies for overall operating cost based on size and the type of application.



LEGEND:
1. Collecting pit
2. High & low level pump control
3. Transfer pump 7.5 US gpm (0.47 L/s)
4. Transfer pump 7.5 US gpm (0.47 L/s)
5. PVC piping
6. PVC over flow back to pit if 17 is closed
7. HCL feed tank
8. Alum or polyelectrolyte feed tank
9. Flocculation tank
10. Agitator
11. Oil separator
12. Waste Oil tank 200 gal (757 L)
13. Settling tank baffled
14. Caustic feed tank
15. Caustic feed valve
16. pH probe controls 15 & 17
17. Effluent control valve
18. Neutralizing tank
19. Agitator
20. To public sewer
21. Drain

Figure 3-5 Emulsified Oil Removal Flow Sheet

Note: Not to scale.

Oil/Water Separation

Oil/water separation may involve free-floating oils, mechanical emulsions or diversions, and chemical emulsions. The size of the oil droplets in emulsions may range from less than 20 microns (μ) to more than 150 μ. In selecting the separation equipment, the designer must consider the oil quantities, droplet size, presence of emulsifiers, temperature of the water and oil, difference in the specific gravity of the fluids, fluid viscosity, pH, and other wastewater constituents.

Separators are on the market to suit every situation, including simple settling tanks (e.g., American Petroleum Institute separators), tanks with coalescing media to promote the agglomeration of dispersed oils, and tanks with chemical pretreatment to promote the separation of chemically emulsified oils. Equipment options include sludge removal and automatic oil skimming. In special conditions, such as where oil is mixed with and adheres to suspended solids, dissolved-air flotation separators may be necessary. Figure 3-5 shows a unit designed to remove free and mechanically emulsified oil.

Biological Treatment

Wastewater discharging directly to surface or groundwater must be treated to remove organic compounds, which would deplete the dissolved oxygen in the receiving water. Typically, permits allow an average of 30 milligrams per liter of five-day biological oxygen demand (BOD5). Treatment is accomplished by processes that convert soluble organic compounds to biological cell mass, which can be separated from the effluent by gravity in a clarifier. Colloidal material and some nondegradable compounds are normally absorbed in the settled solids.

Biological wastewater treatment plants are expensive to build and operate, and specialized experience is necessary to produce a successful design. Consequently, a company faced with biological treatment requirements should first compare the feasibility and economics of discharging to a municipal treatment system to building its own facility. If the build alternative is indicated, a choice must be made among the available application methods, including activated sludge, aerated lagoons, trickling filters and rotating filters, and the anaerobic process. Expert advice is warranted.

REFERENCES

Codes and Standards

- ANSI/ASME B31.3: *Process Piping*
- API Spec 12D: *Specification for Field Welded Tanks for Storage of Production Liquids*
- API Spec 12F: *Specification for Shop Welded Tanks for Storage of Production Liquids*
- API Std 650: *Welded Tanks for Oil Storage*
- *International Boiler and Pressure Vessel Code*
- FM Global Data Sheet 7-83: *Drainage Systems for Flammable Liquids*
- NFPA 30: *Flammable and Combustible Liquids Code*
- UL 142: *Steel Aboveground Tanks for Flammable and Combustible Liquids*.

Government Publications

- *Activated Carbon Process for the Treatment of Wastewater Containing Hexavalent Chromium*, U.S. Environmental Protection Agency
- *Effluent Limitation Guidelines,* U.S. Environmental Protection Agency
- *Treatment of Organic Chemical Manufacturing Wastewater for Reuse*, U.S. Environmental Protection Agency
- *Technology for the Storage of Hazardous Liquids: A State-of-the-Art Review*, New York State Department of Environmental Conservation
- CFR 40: *Protection of Environment*, U.S. Environmental Protection Agency

Technology and Industry Handbooks

- DeRenzo, D.J., *Corrosion Resistant Materials Handbook*, 4th edition, William Andrew Publishing/Noyes, 1985.
- *Kirk-Othmer Encyclopedia of Chemical Technology,* John Wiley and Sons Inc., 2004.
- *Perry's Chemical Engineers' Handbook*, 8th edition, McGraw-Hill, 2008.
- Schweitzer, Philip A., *Handbook of Corrosion Resistant Piping*, 2nd edition, Krieger Publishing, 1985.
- *Ion Exchange for Heavy Metal Removal*, Wastech Controls and Engineering.

RESOURCES

- American National Standards Institute: ansi.org
- American Petroleum Institute: api.org
- American Society of Mechanical Engineers: asme.org
- National Fire Protection Association: nfpa.org
- National Technical Information Service: ntis.gov
- New York State Department of Environmental Conservation: www.dec.ny.gov
- U.S. Government Printing Office: gpoaccess.gov
- Underwriters Laboratories: ul.com

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4

Irrigation Systems

The function of an automatic irrigation system is to provide and distribute a predetermined amount of water to economically produce and maintain ornamental shrubs, cultivated lawns, and other large turf areas. Other benefits of an automatic irrigation system include convenience, full landscape coverage, easy control for overnight and early morning watering, and minimized plant loss during drought.

This chapter discusses the basic design criteria and components of irrigation systems for ornamental lawns and turf. Among the factors considered are water quality and requirements, soil type, system concepts, and system components. A design information sheet is also provided in Appendix A to assist the plumbing engineer in the orderly collection of the required field information and other pertinent data.

WATER QUALITY AND REQUIREMENTS

In urban areas where the source of the water supply is often the municipal water system, the plumbing engineer does not need to be concerned with the quality of the water. In cases where private or reclaimed water sources are used and the water quality is unknown, the water should be analyzed by the appropriate local health authority prior to use. The three main areas of concern are:

- Any silt content that, if high, may result in the baking and sealing of soil
- Any industrial waste that may be harmful to good growth
- Any soluble salts that may build up in the root area

The most common solution currently available for handling excessive amounts of silt is the construction of a settling basin, usually in the form of a decorative lake or pond. In those areas where the salt content is excessive, 1,000 parts per million (ppm) or more, the inability of the soil to cope with the problem may require the use of special highly salt-tolerant grasses.

The quantity of water required for an effective irrigation system is a function of the type of grass, the soil, and local weather conditions. The quantity of water is usually expressed as the depth of the water applied during a given period over the area to be covered. The amount of water applied to a given area can be controlled easily by adjusting the irrigation system's length and frequency of operation. An efficient irrigation system takes into consideration the rate of the application of the water, usually expressed in inches per hour, and the attempt to match the application rate with the absorption rate of the soil. Often, this condition is achieved through frequent short watering cycles.

SOIL CONSIDERATIONS

Sandy, porous soils have relatively high absorption rates and can handle the high output of the sprinklers. Steep slopes and very tight, nonporous soils require low precipitation rates to avoid erosion damage and wasteful runoff.

A sufficient amount of water must be applied during each irrigation period to ensure penetration to the root zone. Table 4-1 suggests guidelines for several soil profiles (net amount of water to apply per irrigation cycle). In the absence of any specific information on the soil and local weather conditions, the irrigation system may be designed for 1½ inches (38.1 mm) of water per week. The plumbing engineer should consult with the local administrative authority to determine compliance with the applicable codes in the jurisdiction. The engineer can obtain specific information on the soil and local weather conditions by contacting a local weather bureau, university, or state engineer.

Table 4-1 Net Amount of Water to Apply per Irrigation Cycle

Soil Profile	Amount, in. (mm)
Coarse, sandy soils	0.45 (11.43)
Fine, sandy loams	0.85 (21.59)
Silt loams	1.10 (27.94)
Heavy clay or clay loams	0.90 (22.86)

Note: Net amount of moisture required based on 12 in. (304.8 mm) root depth.

SYSTEM CONCEPTS

The three basic system concepts that can be used by the engineer in the design of an irrigation network are the block method, the quick-coupling method, and the valve-per-sprinkler method.

The block system is an approach in which a single valve controls the flow of water to several sprinklers. It is ideal for residential and other small turf areas. Either manual or automatic valves may be used in the block system. As the irrigation area increases or where high-volume sprinklers are employed, the block system becomes less attractive to the engineer because of the large valves and pipelines required. Examples of the block system are shown in Figure 4-1.

The quick-coupling irrigation system is an alternative to the high cost incurred on large block system projects because the quick-coupling valve provides a more flexible irrigation system. The valve is located underground but can be activated from the surface. Where manpower is not critical and security is reasonable, the quick-coupling irrigation system may be considered by the engineer. An example of a quick-coupling valve is shown in Figure 4-2.

The last concept in sprinkler system design is the valve-per-sprinkler method. Small actuator valves, operated at low voltage, provide great flexibility and control. Sprinklers in diverse areas having the same (or similar) water requirements may be operated concurrently. In other applications, such as quarter applications covering quarter circles or half circles, the irrigation sprinklers may be piped, wired, and operated together through system programmers. The valve-per-sprinkler system provides the opportunity to standardize the pipe sizes by selecting the appropriate sprinklers to be operated at any given time. Figure 4-3 illustrates this design.

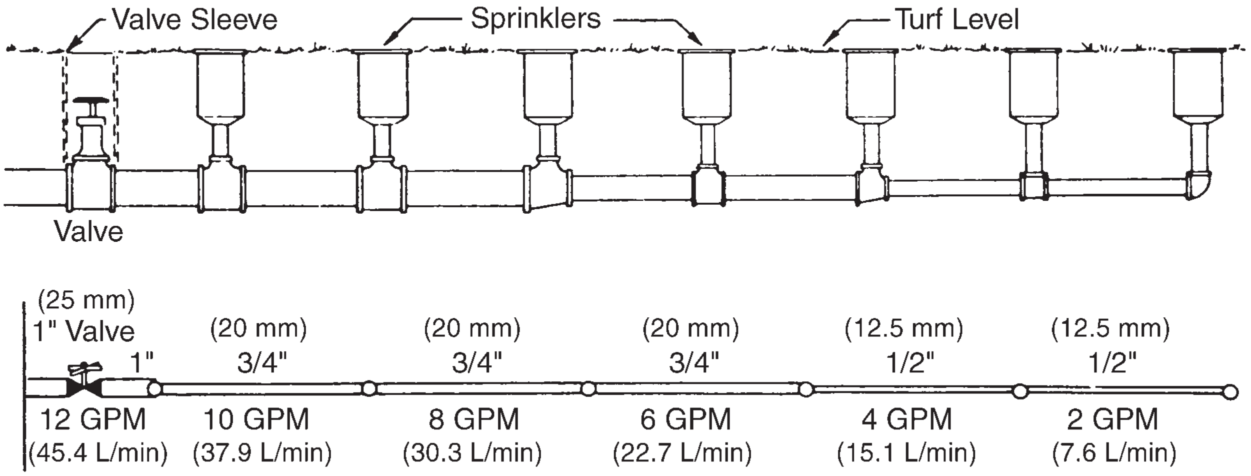
SYSTEM COMPONENTS

Sprinklers

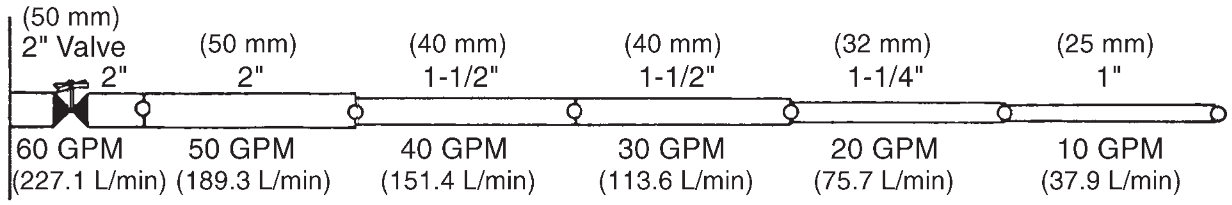
One of the most important steps when designing an irrigation system is selecting the sprinklers, which are mechanical devices with nozzles used to distribute water by converting water pressure to a high-velocity discharge stream. Many different types of sprinklers are manufactured for a variety of system applications. The plumbing engineer should become knowledgeable of the various types before selecting the sprinklers, as the flow rates and operating pressures must be nearly the same in each of the irrigation system's circuits.

Spray Sprinklers

Surface-type spray and pop-up spray sprinklers (see Figure 4-4) produce a single sheet of water and cover a relatively small area, about 10 to 20 feet (3.05 to 6.10 m) in radius. These sprinklers can operate on a low-pressure range of 15 to 35 pounds per square inch (psi) (103.4 to 241.3 kPa). They apply the water at a



2 GPM (7.6 L/min) SPRINKLERS



10 GPM (37.9 L/min) SPRINKLERS

Figure 4-1 Examples of a Block System

high rate of application—1 to 2 inches per hour (25.4 to 50.8 mm/hour)—and are most economical in small turf or shrub areas and in irregularly shaped areas.

Due to the fine spray design, the pattern can be easily distorted by the wind; therefore, these sprinklers should be installed in protected areas.

Impact Sprinklers

Impact sprinklers (see Figure 4-5) can be permanent or movable and either the riser-mounted type (see Figure 4-2) or the pop-up rotary type (see Figure 4-6).

Impact sprinklers have an adjustable, revolving water stream and are available in both single-nozzle and double-nozzle designs. These devices can operate at a higher pressure (25 to 100 psi [172.3 to 689.5 kPa]) and cover larger areas (40 to 100 feet [12.2 to 30.5 m] in radius). The water is applied at a lower rate (0.20 to 0.5 inches per hour [5.08 to 12.7 mm/hour]). Because of its larger, more compact stream of water, this sprinkler is not easily distorted by the wind and is most economical in large, open turf areas.

Freestanding sprinklers are not desirable where they are exposed. In such cases, the pop-up, rotary-type sprinklers shown in Figure 4-6 may be used. These nozzles rise above the ground level only when the water is being delivered to the unit.

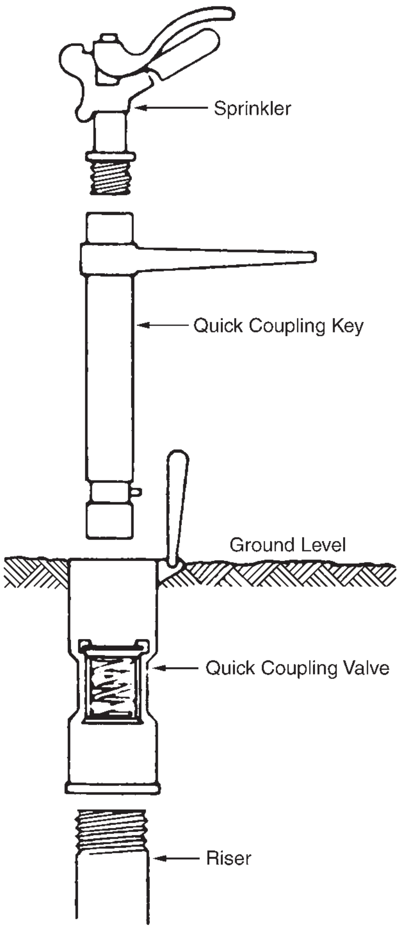
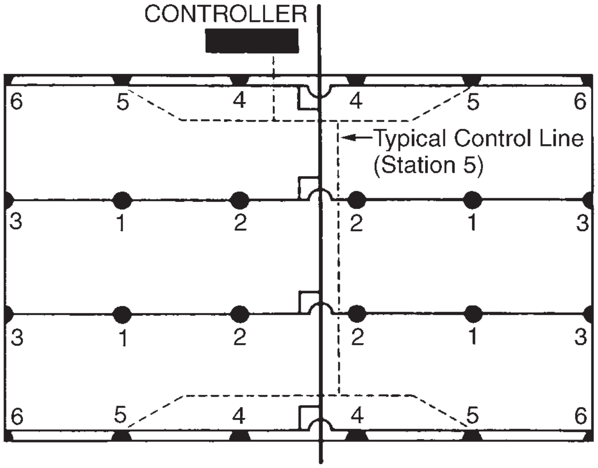


Figure 4-2 Quick-coupling Valve



1. Main can supply four 20 gpm (75.7 L/min) sprinklers at one time.
2. 60' (18.3 m) square spacing
3. Maximum loss per station = 2.3 psi (15.9 kPa)
4. Six control stations required.
5. Similar numbered heads on same control station.
6. All lateral pipe is $1\frac{1}{4}$" (32 mm).

Figure 4-3 Valve-in-Head System

Figure 4-4 Pop-up Spray Heads

Photo courtesy of Rain Bird Corporation

Figure 4-5 Impact Sprinkler

Photo courtesy of Rain Bird Corporation

Figure 4-6 Rotor Sprinkler—Arcs and Full Circles

Photo courtesy of Rain Bird Corporation

Figure 4-7 Nozzles—Adjustable Arcs and Patterns

Photo courtesy of Rain Bird Corporation

Half-circle rotary sprinklers can discharge the same volume of water as full-circle units. A half-circle rotary sprinkler can provide the same amount of water as a full-circle unit over half the area, doubling the application rate. Quarter-circle sprinklers will quadruple the application rate. Some equipment manufacturers use different nozzles to compensate for the reduced area and to provide a uniform application rate. If compensating nozzles are not used in half-circle sprinklers, these units must be valved and operated separately for a balanced application of the water.

Shrub Sprinklers

Several types of shrub sprinklers are available, including bubblers (see Figure 4-7), flat-spray sprinklers, and stream-spray sprinklers. Shrub sprinklers can be mounted on risers to spray over plants. If the plants are tall and not dense near the ground, shrub sprinklers can be used on short risers, and the spray can be directed under the plants. The spray also can be kept below the plant. Flat-spray shrub heads are best employed for these applications.

Trickle Irrigation

Trickle irrigation is commonly used in vineyards and orchards and routed through tubing with special emitters installed at each planting. Most emitters have flexible orifices and may have provisions for adding fertilizer. These irrigation systems have a low-volume usage and usually are not installed in conjunction with conventional lawn sprinkler systems.

Valves

Remote-control valves are generally classified into three basic categories: electric, hydraulic, and thermal-hydraulic. The electrically operated valve receives an electric signal from the controller and actuates a solenoid in the valve. This solenoid opens and closes the control valve. The hydraulic control valve is operated with the water pressure and has control tubing from the controller to the valve. The thermal-hydraulic control valve uses an electric signal from the controller to heat up the components of the valve to open the unit. The most common use of this valve is to control the water usage to the different zones.

These devices should be installed with access for maintenance. Most control valves have some provisions for manual operation. In some systems, manual control valves are installed in pits or vaults with a long T-handle wrench used for the activation of each circuit.

An irrigation system may be installed with an automatic check valve on the sprinkler heads. When a zone is installed on sloping terrain, these valves will close when they sense a low pressure at turnoff, preventing the drainage of the supply pipe through a sprinkler head installed in a lower area.

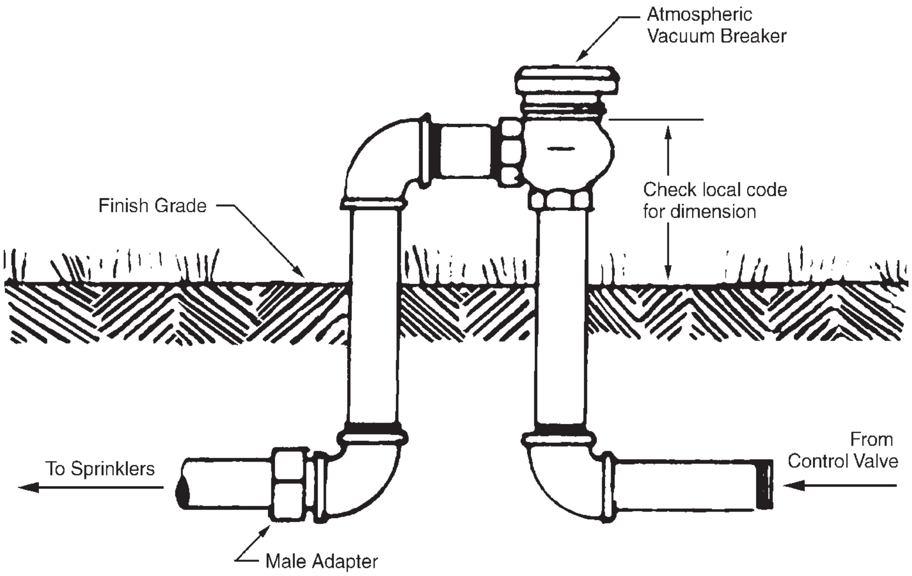


Figure 4-8 Installation of Atmospheric-type Vacuum Breakers

Atmospheric vacuum breakers (see Figure 4-8) must be installed on every sprinkler circuit downstream of the control valve to eliminate the possibility of back-siphonage into the potable water system. Many (if not all) local jurisdictions require this type of valve. The plumbing designer should consult with the local administrative authority and check all applicable codes for such requirements.

Pressure-reducing valves are installed where high street pressures are involved and also are commonly used to maintain a constant pressure where the inlet pressures may vary. Some manufacturers offer remote-control valves with pressure regulation.

Low-flow control valves may be installed to avoid damage to the piping or tubing from pressure surges during the filling of a (dry) system. This control valve allows a slow filling of the piping or tubing until the pressure is established.

In climates where freezing conditions may occur, automatic-type drain valves should be installed at the low points of the system to allow for drainage of the system. This control valve will open automatically when the water pressure drops below a set point. In heavy or dense soils, a pit of gravel should be provided for quick drainage.

Backflow Devices

An irrigation system may be installed with an automatic check valve on the sprinklers. When a zone is installed on sloping terrain, these valves will close when they sense a low pressure at turnoff, preventing drainage of the supply pipe through a sprinkler head installed in a low area.

The use of pressure vacuum breakers to eliminate the possibility of back-siphonage into the potable water system is the minimum level of backflow prevention accepted by most jurisdictions. The plumbing engineer should consult with the local administrative authority and check all applicable codes for such requirements.

Controllers

Presently, many types of controllers for irrigation systems are available. Selection of this device is based on the specific application involved. Controllers are programmed to activate each irrigation zone at a specific time and also will control the length of time that each zone is activated. Some controllers have a calendar that allows the irrigation system to be used only on certain days. Other types of controllers have manual (or automatic) overrides to shut down all systems during rain or to turn on specific zones for extra water. Some controllers have soil moisture monitors, which turn on zones only when needed. Controller panels can be surface mounted, recessed mounted, or pedestal mounted. Figure 4-9 shows a typical illustration of a surface-mounted irrigation system programmer.

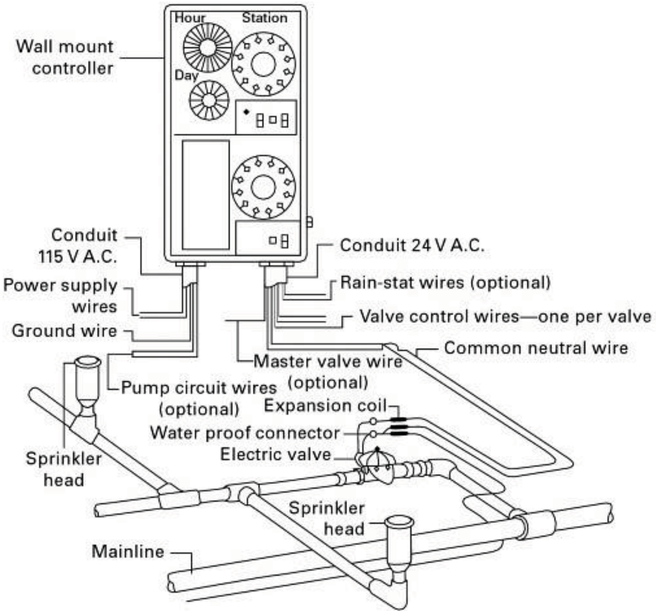


Figure 4-9 Irrigation Sprinkler Programmers

Water Metering

Several municipalities charge sewage fees for water used because the water ends up in the building drainage system and eventually in the sewage treatment plant. Because of this, it is good practice to provide a second water tap and a second meter connected to the irrigation system. This meter will gage the amount of water used for irrigation, and the user will not be charged for sewage fees.

Rain Shutoff Device

A rain shutoff device should always be installed on an irrigation system. This device, which is tied to the controller, detects rainfall and prevents the controller from operating and wasting water.

DESIGN INFORMATION

When designing an underground sprinkler system, the plumbing engineer should consider the following factors: the site plan, type of plants, type of soil, type and source of water, and system location.

Site Plan

An accurate site plan, preferably laid out to scale and showing all buildings, shrubs, trees, hedges, walks, drives, and parking, should be drawn as accurately as possible. The site plan also should include any buried utilities such as electrical wiring and gas lines and their depth. Areas where overspray is undesirable, such as on walkways and buildings, should be clearly noted. Property lines also should be shown on the site plan. The heights and diameters of shrubs and hedges should be indicated.

When an irrigation system is installed on a site with an existing irrigation system, the plumbing designer should review the existing irrigation plans and connect to the existing system to avoid another water tap.

Types of Plantings

The engineer should show the areas that will be irrigated on the site plan as well as the areas that will be omitted. Those areas that require a different style of sprinkler and separate zoning also should be indicated. Some plantings require more frequent watering than others; therefore, they will require a separate zone and control valve. The engineer should determine whether the plantings allow spray on their leaves (or any other special type of spray) and should select the sprinklers accordingly.

Type of Soil

The type of soil determines the proper rate of application of water to the soil. The length and frequency of the applications can be determined by considering the soil and the types of plants.

A sufficient amount of water must be applied during each irrigation period to ensure penetration to the root zone. Table 4-1 recommends acceptable guidelines for several types of soil profiles. Where available, the engineer should secure local soil and weather conditions by contacting the local state extension engineer, a university, or the weather bureau. The local weather bureau usually publishes an evapotranspiration guide, which shows the deficit water required to maintain turf grass. This value is compiled by measuring the rainfall minus the evaporation taking place during a particular period. The balance is the amount of water required. In the absence of any specific information on local soil and weather conditions, the irrigation system should be designed for a minimum of 1½ inches (38.1 mm) of water per week.

Sandy, porous soils (as previously indicated) have relatively high absorption rates and can handle the high output of sprinklers. Steep slopes and very tight, nonporous soils require low precipitation rates to avoid erosion damage and runoffs.

Type and Source of Water

The source of the water should be located on the site plan. If the water source is a well, the pump capacity, well depth, pump discharge pressure, and other pertinent data should also be recorded. If the water source is a city water main, the location, size, service-line material, and length of piping from the service line to the meter should be researched by the plumbing engineer. The water meter size and the static water pressure of the city main are also needed. The engineer should determine whether special meter pits or piping arrangements are required by the utility company.

System Location

Due to the influence of physical and local climatic conditions, the general area may require specific design considerations, such as drain valves on systems subjected to freezing temperatures. Windy areas require closer spacing of sprinklers, and the wind velocity and direction must be considered. For areas on sloping terrain, the outlet pressure will differ from the inlet pressure, and consideration must be made for system drainage.

The engineer must review local codes to determine acceptable piping materials, installation, requirements, and the approved connection to municipal water works.

REFERENCES

- *The ABCs of Lawn Sprinkler Systems*, Irrigation Association, Fairfax, Virginia.
- Pair, Claude H., ed., *Sprinkler Irrigation*, 4th edition, Sprinkler Irrigation Association, Silver Spring, Maryland.
- *Architect-engineers Turf Sprinkler Manual*, The Rainbird Company, Glendora, California.
- *Design Information for Large Turf Irrigation Systems*, The Toro Company, Riverside, California.
- Young, Virgil E., *Sprinkler Irrigation Systems*, Mister Rain Inc., Auburn, Washington.

RESOURCES

- The Irrigation Association: irrigation.org

APPENDIX 4-A

SUGGESTED INFORMATION SHEET FOR SPRINKLER SYSTEM DESIGN

All available information should be contained on this sheet, plot plan, or both.

1. Project name ______
   Address ______
2. Water supply:
   a. Location and size of existing tap, meter, pump, or other ______
   b. Existing meter, pump, or tap capacity: Residual pressure ______
      GPM ______
   c. Power supply: Location ______ Voltage ______
   d. Length, type, location, and size of existing supply line (identify on plan) ______
3. Area to be watered. Identify all planted areas whether shrubbery or trees; indicate clearance under trees. (Identify on plan.)
4. Soil type: Light ______
   Medium ______
   Heavy ______
5. Hours per day and night allowed for irrigation ______
6. Amount of precipitation required per week ______
7. Area to be bordered or not watered (identify on plan)
8. Elevations and prevailing wind conditions (identify on plan)
9. Type of system:
   e. Automatic electric ______
   f. Automatic hydraulic ______
   g. Manual pop-up ______
   h. Manual quick-coupling ______
   i. Other ______
10. Indicate equipment preference ______
11. Indicate preferred location for valves and controllers ______
12. Indicate vacuum breaker and/or drain valve requirement ______
13. Indicate pipe material preference: 2½” and larger ______ 2” and smaller ______
14. Indicate any preference for sprinkler riser types ______

Special Notes (use additional sheet if necessary)

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5

Reflecting Pools and Fountains

This chapter provides the necessary information for plumbing engineers and designers when a client wants to install a water feature on their project. The client may be the owner, architect, or landscape architect, and the water feature might be indoors, outdoors, or both. The plumbing engineer's responsibilities might be limited to plumbing and sewer design, or they could include other disciplines.

In the first meeting with the client, the plumbing engineer must determine what visual effect the client expects and also if they desire to add sound to the space or minimize sound in the space. They might want to add sound to mask other noises or to minimize sound from the water feature in the case of a restaurant or library. The engineer also should determine if the client expects the existing maintenance personnel to service the water feature or if they will contract with an outside maintenance service. The engineer must also determine if the budget will allow automatic chemical water treatment equipment or if hand-broadcasting of the chemicals will be utilized.

The next step is to determine where the equipment will be placed. To allow the use of flooded end-suction pumps, locating the equipment in a room in the building—preferably 2 feet (0.61 m) below the level of the water feature—is preferred. A less efficient, more costly, and nosier option is self-priming pumps, which have limits on their lift. A building may not even exist or might be so far away that placing the equipment therein may not be practical. (Several hundred feet away is usually not a problem.)

In projects with a low budget, the water feature might need to use submersible pumps. If that is the case, the pump selection should be limited to high-quality bronze submersible pumps that are Underwriters Laboratories (UL) listed for fountains. Filtration cannot be used in such cases unless the water feature contains a very small volume of water. Submersible pumps normally last about five to seven years, if they are high quality, before needing to be replaced, whereas flooded end-suction pumps can last 20 to 25 years, with only the pump seals needing periodic replacement.

Some of the leading fountain equipment manufacturers offer prepackaged, pre-assembled units containing a submersible pump in a number of UL-listed capacities as well as the necessary electrical junction boxes and drain valves, with all of the equipment concealed in a prefabricated box assembly with a grate to cover the opening.

USING THE BUILDING'S MECHANICAL AREA FOR FOUNTAIN EQUIPMENT

Installing the required equipment in a building's mechanical area is ideal for a number of reasons:

- The maintenance personnel are more apt to perform their work if the equipment is easily accessed.
- The equipment cost is less than that of furnishing the equipment in an underground vault since the costs of the vault and its installation are eliminated.
- The utilities that must be interconnected to the equipment are in close proximity to the equipment, thereby shortening pipe runs.

Many of the leading fountain equipment manufacturers provide equipment skids with all of the required equipment mounted and pre-plumbed on the skids (see Figure 5-1). Usually the equipment skids are no more than 30 inches (0.76 m) wide to afford them access through a 3-foot (0.91-m) door buck. In some situations, more than one skid might be required—one for the water display and another for the filtration equipment.

Oxidation reduction potential (ORP) equipment such as a bromine or chlorine feeder should not be located in the same area as the fountain equipment. When the tablets become moist, they tend to emit a gas that, when combined with water, creates an acid that will quickly deteriorate electrical contacts and also make it hazardous to service the equipment.

This also applies if a vault outside the building is used to house the equipment. Usually, a separate mini-vault or container is provided to house the bromine or chlorine feeder.

The equipment that might be housed in the mechanical area include:

- Silver ion generator system
- UL-listed electrical panel in a sealed enclosure such as NEMA 4X-rated enclosures
- Wind control device (with the anemometer mounted externally)
- Display pump
- Filtration system (either cartridge or some media such as silica sand or diatomaceous earth)
- Timers for lighting, water display, and filtration (either mechanical or electronic)
- Pump strainers, valves, etc.

The space should be ventilated by means of an exhaust fan with a minimum capacity of 5 cubic feet per minute (cfm) (0.14 m^3/min) per horsepower of the display pump, with 300 cfm (8.49 m^3/min) as a minimum in the case of a small display pump. A small pit (about 1 cubic foot [0.03 m^3]) with a 4-inch (101.6 mm) open drain to waste should be included to receive the filtration discharge or excess water if an equipment failure with the piping or pumps occurred.

Many times, a building owner might place the equipment in a garage area, in which case it can be separated from the public space by a chain-link fence with a lock on the gate.

USING A SUBTERRANEAN VAULT FOR THE FOUNTAIN EQUIPMENT

A below-grade vault may be used to house the fountain equipment and the site electrical equipment. The vault must include a hatch or workable and lockable door for access, an interior light, sump pump, and access ladder. If site electrical equipment is installed in the vault, a number of code requirements in addition to the plumbing codes must be followed.

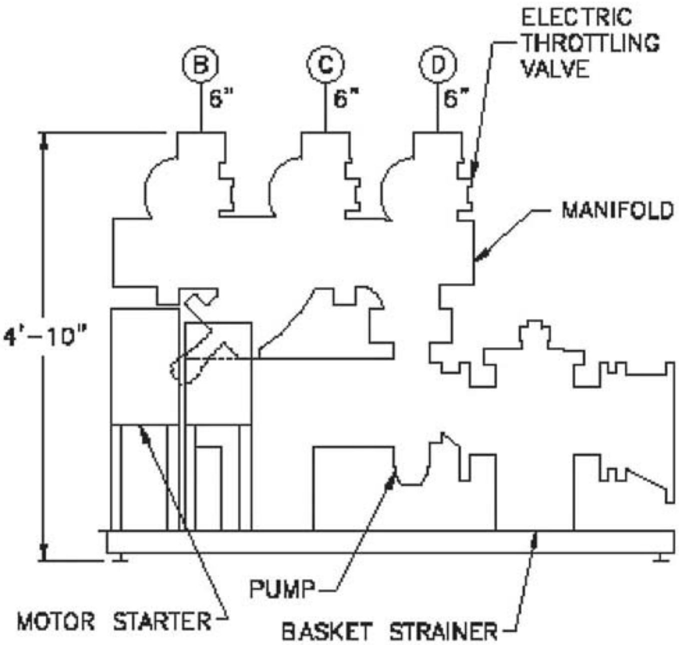
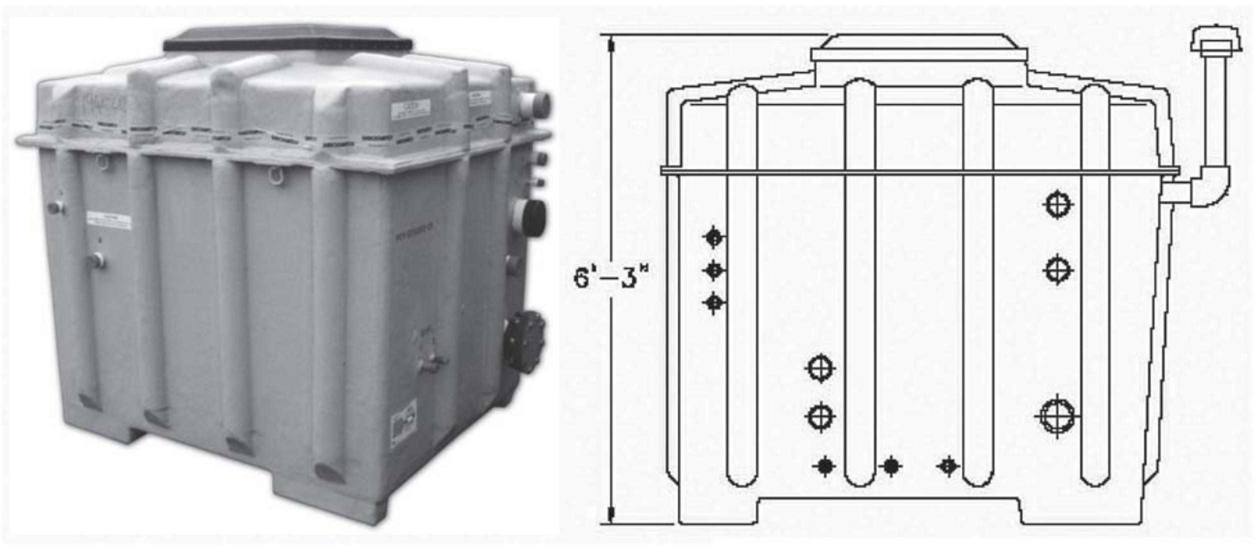


Figure 5-1 Pre-plumbed Equipment Skid

The underground vault should be built with a concrete floor, either reinforced concrete block or precast, as well as poured-in-place concrete walls. It should be large enough to allow code-mandated clearances around the equipment.

Pre-plumbed vaults with all of the above-mentioned devices pre-installed are available (see Figure 5-2). These vaults are structurally certified and complete with stainless steel wire hold-downs to anchor



Source: The Fountain People, Inc.

Figure 5-2 Equipment Vault

the vault to the concrete slab on which it sits. They come with features such as stainless steel access doors or a hatch with ventilation, eliminating the requirement for additional round ductwork for the vault's ventilation. They also have interior lights, an exhaust fan, sump pump, ladder, UL-listed electrical panel in the required NEMA enclosure, and the necessary valves.

In situations where both the site electrical and the fountain equipment are to be placed in an underground vault, it may be beneficial to utilize more than one vault (depending on the required size of the equipment to be installed in the vault), thereby separating the site electrical equipment from the fountain equipment. In such a situation, the vault with the fountain equipment would include the fountain's electrical panel. The vaults should have flat flange connectors on the exterior to prevent the need for penetrations to be created in the field.

Some systems, depending on the sophistication required, can have remote devices that send signals into the building, dial a particular telephone number, or e-mail a building automation or monitoring system to notify personnel that the filter needs to be backwashed or that the chemicals are out of balance.

It is important for the individual specifying the vault to require a licensed structural engineer to certify the vault, as well as a licensed electrical engineer to ensure that all electrical items installed in the vault are UL listed.

Note: Fiberglass vaults should be avoided because they do not have the structural integrity to withstand the elements or groundwater infiltration, and many do not come with UL-listed electrical assemblies.

SIZING THE DISPLAY PUMP

The basic calculation to size the pump uses the required gallons per minute (gpm) per nozzle and the maximum feet of head required to establish the requirement for the nozzles in the display, if any.

If the feature contains any weirs due to a water wall, waterfall, or multiple levels, the lineal footage of the weir and the thickness over the weir must be determined using the Francis formula:

Equation 5-1

$$Q = 3.33(L - 0.2H)H^{1.5}$$

where

Q= Water flow rate, cubic feet per second

L= Length of the weir opening, feet (typically four to eight times H)

H= Head on the weir, feet

If the horizontal distance from the back of the weir edge to the front is extensive, keep in mind that the width of the flow will diminish slightly by the time it reaches the front weir edge. Also consider any losses due to pipes, valves, and possible abnormal changes in direction.

Applying these three considerations will provide the required pump gpm and head requirement, which will help choose the required pump. Then the electrical power required for the pump can be determined. (The various controls and lights would be added to determine the full electrical load.)

Once the pump and electrical requirements are determined, then the required vault dimensions, if using a vault, or the required floor area if the equipment is to be located in a mechanical room can be sized.

SAFETY

While safety is addressed late in this chapter, don't assume it is not important. In fact, it is a primary factor in the design. Safety cannot be sacrificed to accomplish any desired effect or cost-cutting by the client.

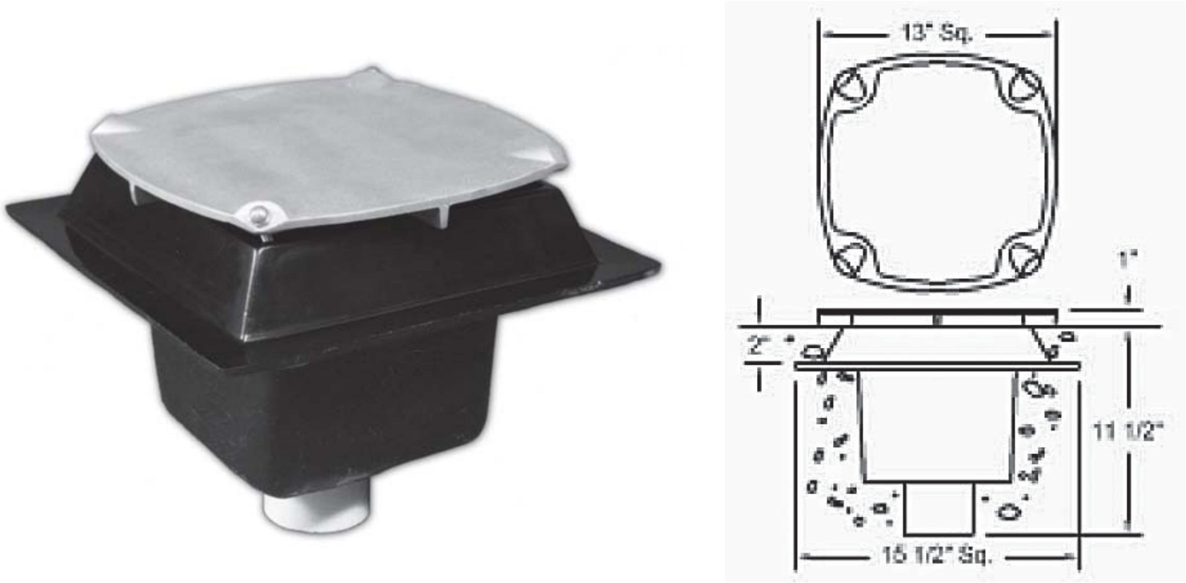
While electrical safety should be obvious, certain plumbing-related items also must be addressed very carefully. For instance, extreme suction pressure at return openings on either the fountain pool bottom or sidewall has caused injury and even death in some very prominent water features. It is wise to add additional suction fittings where the suction levels approach near-high levels to reduce the suction pressure and the size of each opening.

Water depth is another item to scrutinize very carefully. In many jurisdictions, water 24 inches (0.61 m) or deeper must follow the swimming pool code. As such depths can be a hazard for small children and animals, the tendency today is to keep water levels shallow to minimize liability issues. A water feature with a pool at the bottom or lowest level can be accomplished with a 16-inch (0.4-m) depth or less. Many of today's designs are just a wet surface, with the water going to a reservoir—either a tank or one formed of concrete—hidden from view. Minimum water depths also benefit chemical treatment. The illusion of depth may be achieved by merely painting the pool and all the devices therein black.

If the water feature even appears to be one that either people or small animals might enter, governing approval bodies are erring on the safe side and labeling them as "interactive."

CODES AND STANDARDS

In most states, the water feature design must be submitted to the Health Services Department, which might mandate following the swimming pool code or at least strongly suggest conformity. Unfortunately, many of the states differ in their water treatment requirements, and some states offer only guidelines, not mandated codes, to follow. It is strongly recommended to determine the local requirements, if any, prior to beginning the design.



Source: The Fountain People, Inc.

Figure 5-3 Combination Suction Sump Pump and Discharge Plate

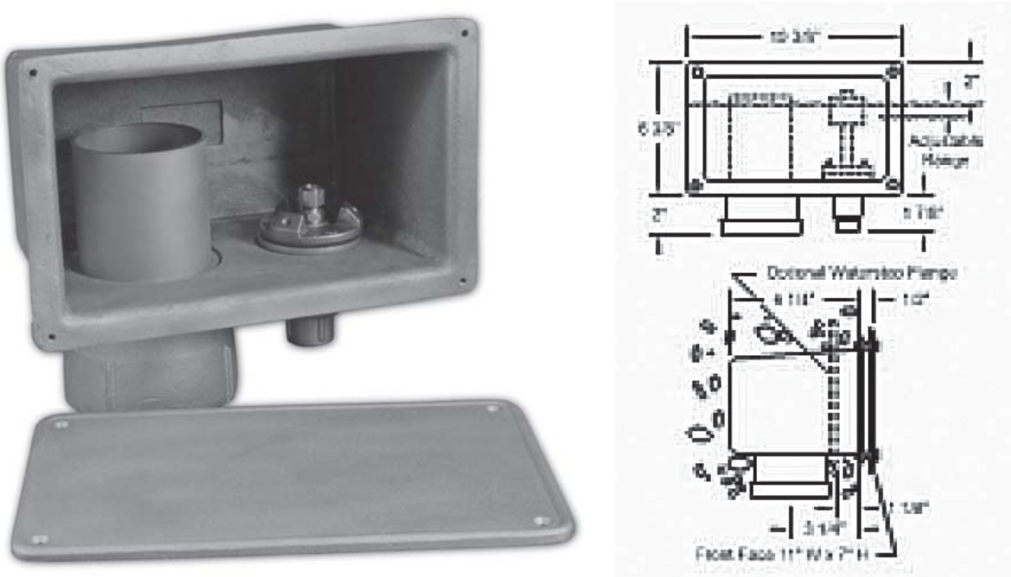
A number of design architects and landscape architects, either on their own or directed by owners, are dictating that the Virginia Graeme Baker Pool and Spa Safety (VGB) Act be implemented in their designs. This act is so sweeping in nature that it is retroactive in certain respects. Under the act, many fountains that are purely decorative in design are being subjected to local health codes. Additionally, the VGB Act supersedes any state law or rule regarding the manufacture, sale, or distribution of any suction outlet cover that does not meet ASME A112.19.8 (2007): *Suction Fittings for Use in Swimming Pools, Wading Pools, Spas, and Hot Tubs* or subsequent editions.

In addition to the VGB Act, many governing bodies also request the use of UV systems for both aquatic playgrounds and interactive fountains.

The regulatory environment for water feature design can be very frustrating, as it not only affects time, but also equipment costs, which affect the overall project costs.

MATERIALS

The use of ferrous materials for both plumbing and electrical piping and fittings should be avoided as ferrous and iron materials will deteriorate and cause discoloration in the water feature. If pipe runs are very long, the material may be changed outside the actual water feature, but a dielectric fitting must be



Source: The Fountain People, Inc.

Figure 5-4 Combination Overflow and Water Level Sensor

used to prevent electromagnetic fields, which can cause deterioration of the two different materials at the joint.

Polyvinyl chloride (PVC), copper, and brass are the most common pipe materials. Keep in mind that if the PVC will be buried, heavy-duty pipe should be used to minimize the chance of it being crushed during the backfill operation. A number of jurisdictions do not allow the use of PVC for water lines under the theory that PVC could leach carcinogens into the system. However, these same jurisdictions may allow PVC for waste lines.

SYSTEM DEVICES IN POOLS AND MECHANICAL AREAS

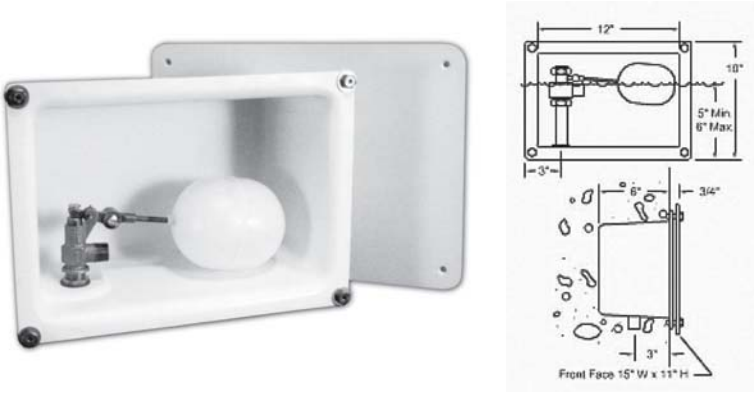
The fountain pool, if the design indicates one or more, should have a return sump with diverter plate going to the display pump suction line (see Figure 5-3). This should be placed in the lowest pool if more than one pool is included.

An overflow fitting is mandatory. It may be placed in the pool floor, in the sidewalls individually, or in combination with water level sensors (see Figure 5-4) or drain plugs.

A water level control, either mechanical or electronic, is a beneficial device. If mechanical, the water fill will be located at the sidewall device. The mechanical device is a modified version of a toilet float in combination with a discharge that is made to fit in a sidewall niche, hidden by a brass plate set out slightly from the wall to allow water into the niche (see Figure 5-5). If electronic, a sensor must be placed in the lowest pool either independently or in a combination sidewall device, both of which send a low-voltage signal to a solenoid valve in the mechanical area that causes water to flow in a pipe and fill the pool to its pre-established level.

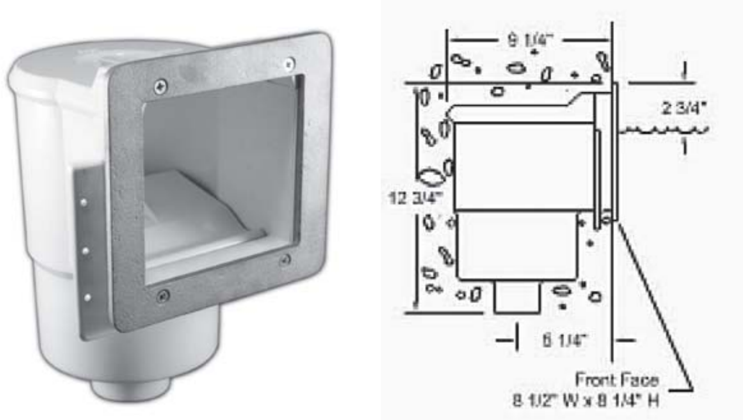
A backflow prevention device must be placed in line with the fill pipe. The type shall be designated by the local code or the national plumbing code if that is the prevailing code in the area.

Other devices that may be placed in the sidewall include a surface skimmer (see Figure 5-6) that connects to the suction side of the filtration pump and



Source: The Fountain People, Inc.

Figure 5-5 Mechanical Sidewall Niche Assembly

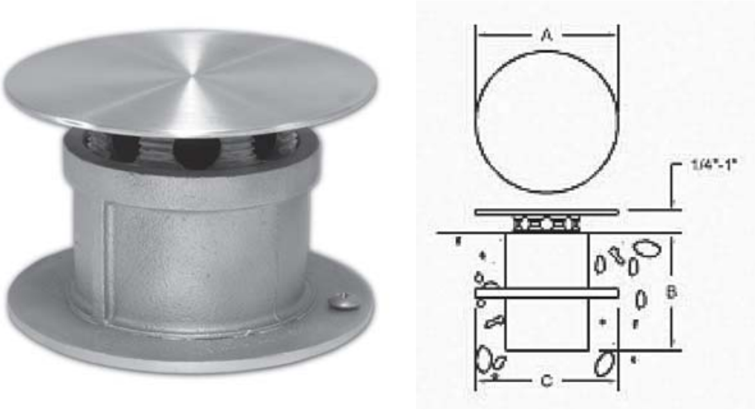


Source: The Fountain People, Inc.

Figure 5-6 Surface Skimmer Fitting

Source: The Fountain People, Inc.

Figure 5-7 Eyeball Fitting



Source: The Fountain People, Inc.

Figure 5-8 Adjustable Diverter Inlet Fitting

eyeball fittings (see Figure 5-7) that connect to the discharge side of the filtration pump.

An adjustable diverter plate (see Figure 5-8) may be inserted in the pool floor to allow the ability to fine-tune the discharge from the display pump. This may be a better option than closing the pump display discharge valve, which can shorten the pump's life by running it with too much back-pressure.

Many designs consist of a small wet surface with the water going to a reservoir, which could be either a tank or a reservoir formed of concrete hidden from view.

CONCLUSION

A water features pipe sizing or pipe layouts do not differ essentially from basic plumbing systems. A good source of further information is a high-quality fountain equipment manufacturer, not just the companies who market the various pieces of equipment. The manufacturers or their representatives are in a better position to provide very accurate information, as these companies actually make the equipment and have tested it along the way.

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Public Swimming Pools

This chapter discusses public indoor and outdoor swimming pool design and the selection of pool plumbing, piping components, and the equipment required for operation in conformance with the codes of the authority having jurisdiction (AHJ). The goal of any quality pool design should be to maximize the safety of the patrons while providing an enjoyable water-based environment. The design approach should be to develop a system that provides maximum water quality, from both a clarity and bacterial safety standpoint. Potential hazards such as suction or limb entrapment, hair entanglement, or tripping concerns must be examined. Local health department codes are designed to ensure that this criterion is met, but these codes merely provide minimum standards. A quality design should go well beyond minimum requirements.

The chapter is organized to assist a designer, possibly unfamiliar with swimming pool design, in undertaking such a project. The first three sections can be used for the preparation of an initial scope outline of the project's size, type, and location. The "Pool Operating Systems" section discusses the key elements that are required for a complete circulation, filtration, water-heating, chemical-control system. It can be used to make initial decisions on the basic type of system to consider. The section titled "Component Evaluation and Selection" provides guidelines for making specific equipment selections. It will assist the designer in collecting pertinent data on the various products to assist in the writing of specifications.

CODES AND STANDARDS

In addition to the plumbing codes, swimming pool construction and operation are usually governed by state health department regulations and the requirements of local authorities. Publications of the Association of Pool and Spa Professionals (APSP) and the National Swimming Pool Foundation (NSPF) are often-referenced standards. The codes usually govern recirculation rates, filtration rates for various types of filters, and the spacing of main drains, as well as maximum velocities (feet per second {meters per second]) through main drain grate-free areas. Also of importance are the locations and types of inlets, spacing and capacity of gutter drains, and requirements for the use of surge tanks or skimmers. Heating requirements and feed capacities of disinfection systems are other areas requiring review. In addition to the standards noted above, if the pool is to be used for competitions, the rules and regulations of the International Amateur Swimming Federation (FINA) must be reviewed to ensure that the pool meets international standards. In the remainder of this chapter, any entity governing the various aspects of public swimming pools will referred to as the authority having jurisdiction.

Virginia Graeme Baker Pool and Spa Safety Act

In December 2007, a new federal law was enacted called the Virginia Graeme Baker Pool and Spa Safety Act (VGB). This federal act set more stringent requirements on main drain sizes, velocities, and piping configurations and requires testing protocols to be regulated according to ASME A112.19.8 (2007): *Suction Fittings for Use in Swimming Pools, Wading Pools, Spas, and Hot Tubs*. At a minimum, all existing main drain cover/grates must be replaced with a compliant cover/grate bearing the VGB stamp provided by the manufacturer or be field-certified by a licensed professional engineer attesting to its compliance with ASME A112.19.8. In cases where a single main drain is direct-connected to pump suction, some form of automatic vacuum release or some form of piping that provides an air break to prevent suction entrapment is required. (Refer to ASME A112.19.8 for specific details on sumps, piping, and cover/grate requirements.)

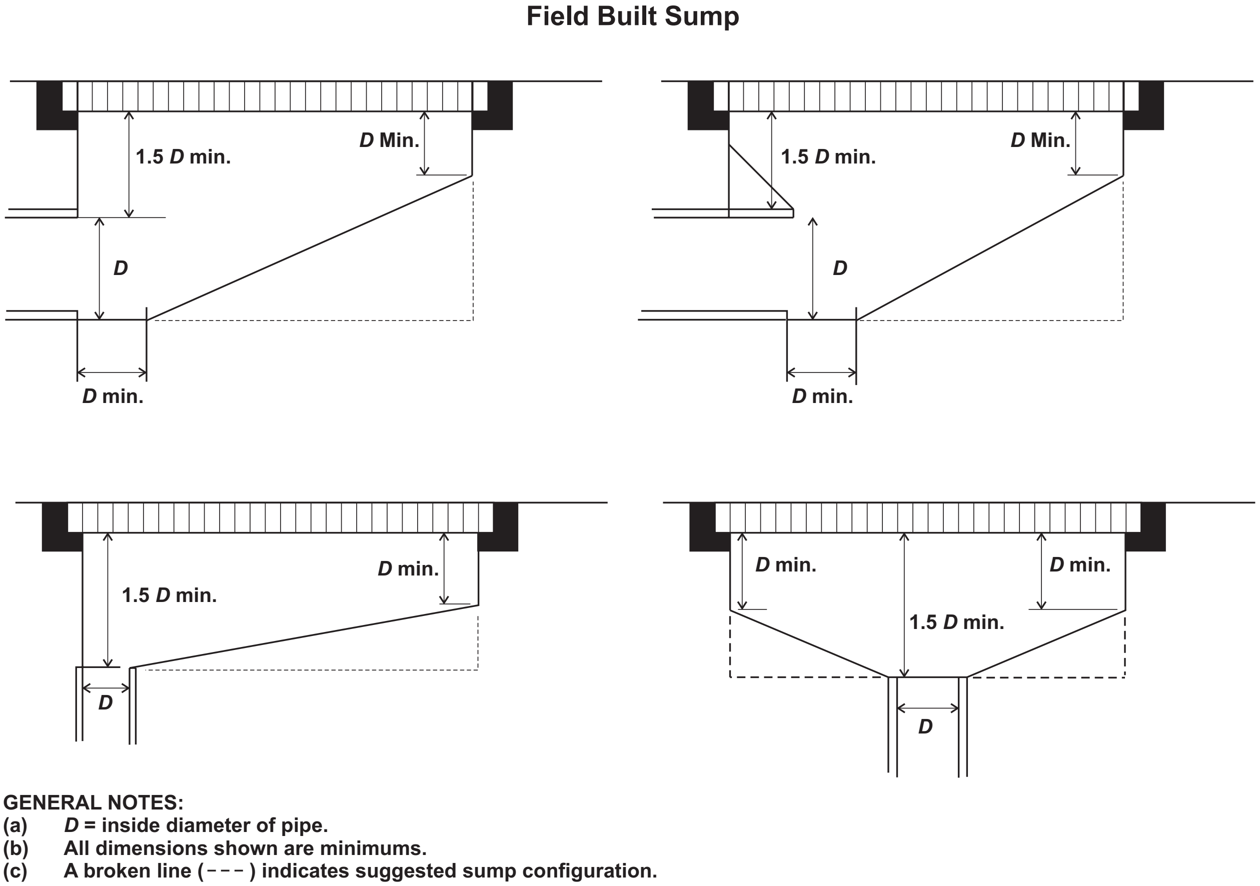
The intent of the VGB is twofold: prevent suction entrapment and prevent entrapment due to hair entanglement. The second issue (hair entanglement) is the reason why velocity through main drain grates is an issue. Hair entanglement, consistently the No. 1 cause of entrapment in pools, is caused by high velocities through main drain grates. When a swimmer's hair is drawn through the grate, high velocity can cause it to swirl and become tied in a knot on the other side of the grate.

Suction entrapment has nothing to do with velocity through the grate. Suction entrapment is addressed in VGB by requiring all pools to have multiple main drains spaced at least 3 feet (0.91 m) apart, which makes them "unblockable" in the verbiage of VGB. In instances where there is only one main drain, it must flow by gravity back to a surge tank (i.e., not be direct-connected to pump suction), be of an "unblockable" size (i.e., larger than 18 x 23 inches [0.46 x 0.58 m] or with a diagonal dimension greater than 29 inches [0.74 m]), or have another means of preventing suction entrapment. The most common means of accomplishing this is the addition of some type of automatic vacuum safety release. Several products are on the market, but all manufacturers insist that installation of their device be done by an installer certified on the proper installation of their product. However, all manufacturers of these products add the disclaimer "will not prevent disembowelment" to their product literature.

ASME A112.19.8 also details tests for finger entrapment, measuring the force needed to pull the cover/grate out of the frame, and resistance to UV degradation, which could make the cover/grate brittle and cause attachment failure. These are an important part of the ASME testing because many of the entrapment accidents that occur are due to detached cover/grates. However, the primary issue that the designer needs to be concerned with is the maximum flow rating in gallons per minute (gpm) (L/sec).

VGB also requires main drain cover/grates to be sized for the maximum flow of the system. The combined maximum possible flow that the system pumps can produce (which is usually greater than the design flow) must not exceed the maximum flow rating for the cover/grate intended for installation. In fact, VGB goes one step further. In the instance where one cover/grate is blocked or partially blocked, the remaining main drain cover/grates on the system must be sized to handle the full flow of the system. In other words, where there are two main drains, each cover/grate must be sized for the full flow of the system. With three main drains, each cover/grate must be sized for 50 percent of the system flow.

It is important to note the use of the term "system." That is because many pools have water feature pumps that pull from the same surge tank as the circulation pumps. The total possible flows of all of those pumps must be added to determine the full flow of the



GENERAL NOTES:
(a) *D* = inside diameter of pipe.
(b) All dimensions shown are minimums.
(c) A broken line (- - -) indicates suggested sump configuration.

Figure 6-1 Field-fabricated Sump Dimensions

swimming pool system. The fact that the cover/grates flow by gravity back to the surge tank might eliminate the first concern of VGB—entrapment—but it has no bearing on the second concern, hair entanglement. The velocity through the cover/grates is the same when water flows to the surge tank by gravity as the velocity when the main drains are direct-connected to pump suction.

The final important requirement of VGB is the ASME A112.19.8 protocol regarding main drain sump dimensions. Many field-fabricated sumps, as well as most previously installed fiberglass sumps, do not meet ASME requirements (see Figure 6-1) and are considered noncompliant. The reason for these required sump dimensions is somewhat complicated, but basically it is to ensure even flow across the cover/grate, which is the only way to ensure that velocities calculated for flow through the free area of the grate are uniformly less than 1.5 feet per second (fps) (0.46 m/s) at all points on the face of the cover/grate. Attachment of a new, compliant cover/grate to a noncompliant pre-fabricated sump may not create a secure attachment that will meet ASME pull test requirements. The Consumer Product Safety Commission (CPSC) has expressed concern that VGB doesn't address this attachment issue thoroughly enough since most entrapment occurrences have been due to a missing or displaced cover/grate.

A misconception that raises additional concern is the belief of some owners that their system is fully compliant once the state approves changes to the cover/grates. That is not the case. Most state codes do not address sump dimensions, and they also don't all require multiple cover/grates to be able to handle full system flow or some percentage of full flow based on the number of main drain sumps. Thus, in addition to the state public health code, the design must adhere to the requirements of VGB.

State Swimming Pool Health Code Requirements

State health code requirements become an issue when changes are made to main drains. Any changes in a pool's circulation piping or main drains are considered alterations, and in most states alterations to a pool design require submission by a Professional Engineer licensed by that state. Many owners are unwilling to adhere to this requirement because it adds costs to their attempts to become compliant with VGB.

One of the primary areas of conflict between VGB and state health codes is a result of the approach taken by manufacturers to design compliant grates. Most of the designs for grates that will prevent suction entrapment result in cover/grates that are raised anywhere from ½ inch to 2 inches, which results in protrusions from the floor of the pool when these new "compliant" cover/grates are installed. This is not allowed by most state codes because it can present a tripping hazard. However, many states have made, or are making, changes to their codes to allow main drain protrusions no greater than 2 inches above the pool surface.

Important Considerations

When investigating what steps to take to comply with the regulations in the Virginia Graeme Baker Pool and Spa Safety Act, the designer must keep in mind that anything done to meet the requirements of the federal act must not be in conflict with the state code. This does not mean that the state code takes precedence; it is merely meant to draw attention to the fact that there are two AHJs and that satisfying one set of requirements does not automatically mean full compliance. Pool compliance inspections will be done by both the local code authority for adherence to the local code and by the CPSC for adherence to the requirements of VGB.

PRELIMINARY DESIGN PARAMETERS

Before the plumbing for a swimming pool project can be designed, the following information should be obtained: occupant capacity, size of the facility (including pool volume), facility location and configuration, style of pool, times of use, availability to infants and children (which may necessitate a separate pool), tournament and racing requirements, toilet requirements, concession and vending requirements, and bathhouse requirements.

Occupant Capacity and Size of the Facility

Assuming that the swimming pool is part of a complex that includes other outdoor facilities (such as ball fields, tennis courts, and basketball courts), following are the generally accepted criteria for estimating the number of swimmers:

- The total membership of the facility can be estimated to be 10 percent of the total population of the community it serves.
- The maximum attendance on the peak day can be estimated to be 68 percent of the total membership.
- Maximum attendance at the public swimming pool facility can be estimated to be 40 percent of the projected maximum attendance on the peak day.
- The maximum number of swimmers is approximately 33 percent of maximum attendance.

This method of determining the maximum number of swimmers cannot be applied to all swimming pools. The social and economic conditions of a particular local community must be taken into account when designing a public swimming pool facility. Swimming pool occupancy, or capacity, restrictions are subject to local regulations and vary from one jurisdiction to another. Supervision capability also may limit pool capacity.

The desirability of accommodating competitive swimming should be considered when designing a swimming pool. The requirements for such events are 25- and 50-yard lengths for U.S. competitive meets and 25- and 50-meter lengths for international events. Normal competition pools are divided into a minimum of six swimming lanes, with each lane having a minimum width of 7 feet (2 m). An additional 3 feet (0.9 m) should be divided equally between the two outside lanes to aid in wave quelling. The shallow-end depth should be a minimum of 4.5 feet (1.35 m) for competitive pools and 3.5 feet (1.1 m) for recreational pools, depending on local codes. The deep-end minimum depth of pools with springboards is between 9 and 12 feet (2.7 and 3.7 m) for a 3-foot (1-m) board and 11.5 and 13 feet (3.5 and 4 m) for a 10-foot (3-m) board, depending on local codes. Platform diving is performed in specially designed pools, which are outside the scope of this chapter.

Location of the Facility

There are no generally accepted rules for choosing the location of a public swimming pool facility. Only careful investigation of the available sites and the use of common sense will result in a suitable location.

First, consideration must be given to the accessibility of the location. A public swimming pool will be used in direct proportion to the local population's convenience in reaching the facility. Distance is a barrier, and so are stop lights and railroad tracks. The engineer also must consider the traffic flow in the area and the relative safety for pedestrians and bicycle riders of the routes normally taken to and from the public swimming pool facility.

Equally important at this stage are the physical properties of the proposed swimming pool site, including its soil quality, groundwater locations, and subsurface obstructions such as rocks. Attention also must be given to the availability of water, gas, sewers, and electricity. If all utilities are not available or extensive clearing, grading, or difficult excavation is required at or near the proposed site, significant additional expenses may be incurred.

The availability of an adequate water supply is essential. The water supply system provides the means to fill the pool initially with water and to make up water lost through wastewater discharge and evaporation. The preferred supply source for filling the pool and maintaining adequate volume is potable water. In areas with a limited water supply or where the system capabilities are in doubt, consideration should be given to filtration equipment, which requires minimum backwash water, or an off-peak filling and servicing schedule. Well water is often of good quality and may be used directly; however, the mineral content may be sufficiently high to require treatment. All water should be given a detailed chemical analysis in the early planning stages to determine whether treatment (e.g., softening or pH control) should be considered. In general, using softened water for filling and makeup water is not recommended for swimming pools.

Protection of the potable water supply system through air gaps or backflow prevention equipment is mandatory. The type required must be determined by checking with the local AHJ. Some codes may not allow direct connection, even with reduced pressure zone backflow preventers installed on the freshwater supply.

The rate of water evaporation from the pool should be estimated to determine the average makeup water required. Direct discharge of swimming pool water into the local storm sewer system or a watercourse without proper treatment may not be allowed, since chlorinated water is harmful to the environment. The chemistry of the proposed effluent should be approved by the AHJ.

General Physical Character

Deciding on the general physical character of a proposed public swimming pool facility involves determining such things as the type of swimming pool, its style, the intended use of the pool, its shape and dimensions, indoor versus outdoor design, bathhouse planning, and the location and type of equipment. A swimming pool complex with separate recreation pool, diving well, and wading areas accommodates all possible uses, including recreation, training, diving, water sports, exercise, therapy, and competitive swimming. There is a definite aesthetic trend toward luxury in contemporary swimming pool design. The use of color, walks, deck areas, and plantings creates a pleasant and interesting personality, but also substantially increases costs.

Before commencing the design, it is important to determine the style of pools the facility requires and the impact this will have on the space available for mechanical systems. Many facilities are now being designed with multiple pools or a multiuse pool. Pool styles can range from leisure pools to swimming pools with a wave pool component to 25- and 50-meter competition pools with diving facilities.

Many leisure pools that allow younger children to play with interactive water toys and water slides are being designed in conjunction with other pool facilities. These pools usually have water depths that range from 1 to 4 feet (0.3 to 1.22 m) and may have an uneven bottom, depending on the location of the interactive play toys. The number of toys and the size of the pool will impact the space requirements for pumps and filters.

Wave pools and zero-depth pools have become common components of public swimming facilities in the last few years. These designs allow swimmers to experience the sensation of swimming in ocean-like conditions. Many wave pools are designed so that the wave generator can be set to come on at certain times of the day and/or night or when requested by patrons. Both zero-depth and wave pools usually have a beach component at one end of the pool, which requires special consideration to be given to the gutter systems and water pickup at the beachhead, or zero-depth end. The wave-generation equipment requires additional space within the mechanical room, and this needs to be taken into consideration when planning a facility with this component.

Competition pools have very specific regulations that govern the water quality, clarity, turnover rates, temperature, size, depth, and markings that are permitted within the pool. These requirements may be more stringent than the local health department requirements and may require more or larger components to be located within the mechanical room.

Many alternatives of shape and/or dimension are available to the designer. However, public pool configurations most commonly use straight lines and right angles. Pools of this nature are much more adaptable to the use of automatic pool-cleaning equipment. Often, there are good reasons for unconventional designs and shapes in private swimming pools and, perhaps, in hotel swimming pools where architectural interest (or uniqueness) may be of prime consideration.

The question of indoor versus outdoor swimming pool design is considered during the preliminary planning of the facility. It is well established that, although about 10 percent of the public likes to swim outdoors in the summer, less than 1 percent is interested in swimming in the winter, even if indoor facilities are provided.

Therefore, the need for outdoor swimming is addressed first. Then, if the budget permits, indoor facilities can be added. An indoor swimming pool facility costs approximately three to four times more than a comparable outdoor swimming pool facility. If the total cost is of little consideration, the same swimming pool facility can be used for both indoor and outdoor swimming.

A possible solution to the problem of providing indoor swimming is the cooperative funding, planning, and construction of a swimming pool facility adjacent (or connected) to a school. This requires the cooperative effort of the school board, park district, recreation department, and any other taxing body. The engineer should plan such a swimming pool facility to have the following:

- An indoor swimming pool of sufficient size to meet the needs of the school and the local community
- An outdoor swimming pool complex planned and constructed to meet the needs of the local community
- A central shower and toilet area
- Mechanical equipment for water treatment designed to serve both the indoor and the outdoor swimming pools

During winter, the indoor swimming pool can be used for the school's and community's training and recreational needs. During summer, both indoor and outdoor swimming pools can be scheduled and used. This arrangement allows one pool to be out of service for maintenance while the other remains operational. A facility of this type saves a considerable amount of money and provides a swimming pool facility for year-round comprehensive scheduling, with revenue sufficient to cover the operational and maintenance costs.

Many technical problems are involved in the design of an indoor swimming pool facility. First, there is the obvious problem of maintaining the proper relationship between air and water temperatures to control condensation and fogging. To be properly balanced, the water temperature should be in the range of 75 to 80°F (23.8 to 26.7°C), and the air temperature in the building should be maintained 3 to 5°F (1.6 to 2.6°C) above the water temperature. If this relationship is inverted, the swimmers will become uncomfortable when they exit the pool, and both fogging and condensation are likely to occur.

Secondly, there are the additional considerations of acoustics, ventilation, and air movement. Maintaining maximum air quality in an indoor pool facility is essential. Evaporation of the pool water and the gassing off of disinfection by-products such as trihalomethanes and chloramines require careful consideration of relative humidity, the introduction of large quantities of fresh, outside air, and proper air movement in the space. Refrigeration-loop dehumidification systems, as well as physical heat-transfer systems to allow some pre-heating of incoming outside air, are frequently employed.

The rules for the bathhouse design generally are specified in great detail by the local governing public health authority. The preliminary planning of the bathhouse facility must be carried out within the limits of established regulations. Apart from these rules, however, the designer may exercise imagination with considerable latitude in several areas: achieving a pleasing and aesthetic architectural balance, providing an adequate floor area for traffic, and providing adequate storage and management facilities.

Equipment locations should be established during the preliminary design phase. It must be decided, for example, whether equipment is to be located in the bathhouse or in a separate enclosure (keeping in mind that it is usually desirable to combine all of these facilities under a single enclosure). The filter assembly should be housed in an area with heat for

Table 6-1 Minimum Number of Sanitary Fixtures Required at Public Pools and Water Attractions

Facility (example of location and type)	Cumulative Area of Surface Water (in square feet)	Number of							
		Public Toilets		Public Urinals	Public Lavatories		Public Showers		Public Drinking Fountains
		F	M	M	F	M	F	M	
1. Swimming pools, wading pools and whirlpools in conjunction with sleeping or dwelling units having plumbing, except for items 2 - 5, No open swim lessons permitted. (i.e. apartments, hotels, motels, condos and mobile home parks)	< 2000	One unisex		0	One unisex		0	0	1
	2000 - 7500	1	1	0	1	1	1	1	1
	>7500	See note ^{a} below for requirements							
2. Swimming pools, wading pools and whirlpools without living units, except for items 3. to 5. Swimming pools,wading pools, and whirlpools with sleeping or dwelling units where open swim or lessons are permitted and water attractions where lessons are conducted (i.e. municipal pools and campgrounds)	<2000	1	1	0	1	1	1	1	1
	2000 - 3999	3	1	2	1	1	2	2	1
	4000 - 5999	4	2	2	2	2	4	4	1
	6000 - 7499	4	2	2	2	2	5	5	1
	7500 -8999	8 4	2	2	3	2	5	5	1
	9000 - 9999	10	2	3	4	3	6	6	1
	10000 - 12999	12	3	3	4	3	6	6	1
	13000 - 15000	14	2	4	5	4	7	7	1
	>15000	See note ^{a} below for requirements							
3. Water attractions and water attraction complexes with sleeping or dwelling units. No open swim or lessons permitted. Use 300 sq. ft. for slides without basins (i.e. activity pools, waterslide plunge pools, leisure river or tubing pools and wave pools)	<7500	1	1	0	1	1	1	1	1
	7500 - 9999	4	1	1	2	2	2	2	2
	10000 - 14999	8	2	2	2	2	2	2	2
	15000 -22499	12	3	3	3	3	3	3	3
	22500 - 29999	12	3	3	3	3	3	3	3
	30000 - 37500	16	4 1	4	4	4	4	4	4
	>37500	See note ^{a} below for requirements							
4. Water attraction and water attraction complexes without sleeping or dwelling units. No lessons permitted. Use 300 sq. ft. for slides without basins (i.e. activity pools, waterslide plunge pools, leisure river or tubing pools and wave pools)	<7500	2	1	1	1	1	1	1	1
	7500 - 9999	6	2	2	2	2	2	2	2
	10000 - 14999	8	2	2	2	2	2	2	2
	15000 - 22499	12	3	3	3	3	3	3	3
	22500 - 29999	16	4	4	4	4	4	4	4
	30000 - 37500	20	5	5	5	5	5	5	5
	>37500	See note ^{a} below for requirements							
5. Slash pad (independent of any other pool or attraction)		One unisex		0	One unisex		One rinse-off Shower		1
	Patron Load								
	Up to 10	One uisex							
	11 to 20	2	1	1	1	1	1	1	1
	21 to 30	2	1	1	2	2	3	3	1
	>30	Per departmental approval							

[a] For water attractions in excess of 37,500 sq. ft., use the following additions:

- * For each 7,500 sq. ft. or fraction thereof add one sanitary unit - 0.7 male water closets, 1.0 male urinal, 0.85 male lavatories, 1.0 male showers, 0.6 drinking fountains, 4.0 female water closets, 1.0 female lavatory, and 1.0 female shower

For pools in excess of 7,500 sq. ft. and Type 1. above, and for pools in excess of 15,000 sq. ft. and Type 2. above, use the following additions:

- * For each 4,000 sq. ft. or fraction thereof, add one sanitary unit - 1.0 male water closet, 1.0 male urinal, 1.0 male lavatory, 4.0 male showers, 1.0 drinking fountain, 4.0 female water closets, 1.0 female lavatory and 4.0 female showers

For the requirements listed for additional sanitary facilities, each fraction represents an additional fixture the off-season and with ample storage space. The filter equipment also should be located in the filter room for easy and efficient operation and maintenance. Consideration needs to be given to the location of the pumps in relation to the water levels in the pools. Wherever possible, the pool pumps should be located below the water level determined by the gutter system or surge tank so the pumps will have positive suction. Self-priming pumps are used for a number of pool applications, but the use of this style of pump is subject to greater startup problems and maintenance issues.

The construction of a major swimming pool facility with the filter equipment located outdoors or under drop lids to save costs is false economy and is not allowed by some codes. This type of installation will cause rapid deterioration of the pumps, hoses, motors, and other specialized equipment during the off-season, as well as make operation during the season difficult and costly.

Finally, the designer must select the type of filtration and purification equipment to be used. The most obvious considerations are pool size; available space; the type, location, and availability of sewer facilities; soil, rock, and groundwater conditions; and the location, availability, chemistry, and cost of the fill water. If the water is plentiful and inexpensive and space is not a problem, sand filtration may be considered. Scarce or costly water and limited equipment room floor space, plus a desire for maximum water clarity during heavy use, might dictate the use of diatomite filtration. The size of the swimming pool facility, as well as the chemistry of the fill water, will usually determine the type of disinfection equipment to be used.

In areas where freezing temperatures are possible and if the pool is not used year-round, provision must be made for draining the water lines, exposed drains, and plumbing fixtures to prevent damage by freezing. Alternatively, all areas must be provided with minimum heating equipment.

Bathhouses, Toilets, and Showers

Adequate dressing and toilet facilities must be provided. Each swimming pool complex must have separate facilities for male and female bathers, with no interconnections between them. The rooms must be well lighted, drained, and ventilated. They must be constructed of impervious materials, finished in light colors, and developed and planned so that good sanitation can be maintained throughout the building at all times.

The partitions used in dressing rooms, showers, and toilets must be made of durable materials and not subject to water damage. They should be designed with spaces under the partitions to permit a thorough cleaning of the walls and floors. If these partitions are subject to vandalism, block walls and vandal-proof devices should be considered.

The showers and dressing booths for females should have curtains or some other means of providing privacy. This rule may not apply for schools and other institutional facilities where a swimming pool may only be open to one sex at a time or where supervision is necessary.

Facilities for the physically challenged that meet all federal, state, and local regulations for private and public facilities also must be provided.

The floors of a bathhouse must be free of joints or openings, be continuous throughout the area, have a slight texture to minimize slipping (but also be relatively smooth to ensure positive drainage of all parts of the building), and have an adequate slope toward the drains. An adequate number of floor drains shall be provided. Floor drains should be positioned based on the requirements of the plumbing and building codes, but in no case should the floor slopes be designed for less than 0.25 inch per foot (6.35 mm/m) to ensure proper drainage of all floor areas.

An adequate number of 0.75-inch (20-mm) hose bibbs must be provided for the washing of the dressing rooms and the bathhouse interior. At least one drinking fountain should be provided for bathers of each sex in the bathhouse, with additional drinking fountains provided at the pool.

The minimum sanitary plumbing facilities, as mandated by the local plumbing code, should be provided. (A sample of a representative code is offered in Table 6-1 as a reference.) These minimum criteria for bathhouse plumbing facilities must be based on the anticipated maximum attendance.

If the local code does not address swimming pool facilities, the following minimum facilities should be provided:

- Three showerheads for the first 150 male users and one showerhead for each additional 50 male bathers
- Two showerheads for the first 100 female users and one showerhead for each 50 additional female bathers

Tempered water at a temperature of approximately 90–100°F (32.2–37.8°C) should be provided to all showerheads. Water heaters and thermostatic mixing valves should be inaccessible to the bathers.

Soap dispensers, providing either liquid or powdered soap, must be furnished at each lavatory and between each pair of showerheads. The dispensers should be constructed of metal or plastic; no glass is permitted. Mirrors must be provided over each lavatory. Toilet paper holders must be furnished at each water closet combination. As previously stated, vandal-proof devices should be considered, if applicable.

POOL OPERATING SYSTEMS

Most provincial and state regulations now require pool system components to be certified by an independent testing agency, such as NSF International. This certification ensures that all piping and other components meet a national standard for quality of materials and that public health and safety issues are addressed. This standard also ensures that the equipment meets consistent quality controls and builds a level of confidence in the product.

When considering the broad spectrum of approaches used for pool design, the designer should attempt to evaluate the major cost and performance differences between lower-quality residential or hotel, motel, and health club-type equipment and higher-end products used on major commercial pool installations. If the owners have not already made some of these assessments on their own, the designer should be prepared to appraise them on the pros and cons of the available choices so they can make an informed decision on the value they wish to place on the quality of the end product.

If designing a commercial installation for a high school, university, park district, or YMCA, the designer must follow certain basic board of health requirements beyond the scope of the plumbing codes that must be met.

Design Parameters

Turnover Rate

The turnover rate (turnovers per day) refers to the time it takes to move a quantity of water, equal to the total gallons (liters) in the pool and surge vessel, through the filtration system.

Minimum turnover rates for various types of pools are determined by code. Typically, they fall within the following ranges:

- Swimming pool: Six hours (four turnovers per day)
- Wading pool: Two hours (12 turnovers per day)
- Therapy pool: Four hours (six turnovers per day)
- Hot tub and whirlpool: 30 minutes (48 turnovers per day)

Keep in mind that these are minimums. In heavily used pools, quicker turnovers will help maintain water clarity by means of increased filtration and better chemical distribution. Also, pool designs that combine shallow areas, such as zero-depth pools, with deeper swimming areas require a turnover rate that combines the characteristics of both types of pool.

A calculation of the flow rate required to move a quantity of water equal to the gallons (liters) in the shallow area (usually up to 18 inches [0.46 m] in water depth) within two hours is combined with the flow rate required to achieve the minimum turnover requirements for the deep area of the pool (six hours). This combined flow requirement will result in a greater number of turnovers per day, usually in the range of six per day (or one turnover every four hours).

One additional point to consider in deciding on a turnover rate for pools projected to experience heavy usage is the fact that one turnover refers to a volume of water equal to the total gallons (liters) in the pool system. It has been calculated that it takes more than three turnovers for 95 percent of the actual molecules of water in the system to pass through the filter. This is due to the physical characteristics of the pool. The only way to remove the dirt load being introduced into the pool by the users and the environment is through filtration or oxidation. No matter how efficient the filter, it can't remove what isn't put through it.

Filter Media Rate

The filter media rate is the rate, measured in gallons per minute (gpm) per square foot (L/min per m^2) of filter surface area that water is allowed to pass through various types of filters. These maximum rates are established by NSF/ANSI 50: *Equipment for Swimming Pools, Spas, Hot Tubs, and Other Recreational Water Facilities,* as well as local health department codes. This rate becomes the determining factor in the sizing of the filter area needed for a given minimum turnover rate and the resultant minimum flow rate.

Flow Rate

The flow rate is the rate at which water moves through the filtration system. It is calculated based on the minimum turnovers per day. The flow rate has a major bearing on pipe sizing in the distribution system.

Many codes limit velocities in suction piping and return piping. In swimming pool parlance, return piping is the piping carrying filtered water returning to the pool. Some common maximums are 5–8 feet per second (fps) (1.52–2.44 m/s) in suction piping and 8–10 fps (2.44–3.05 m/s) in return piping.

Required Surge Capacity

The term "surge" describes all water that comes off the top of the pool, either displaced by the bodies of the swimmers or splashed into the gutters through wind or heavy activity. It must flow to a surge vessel attached to the swimming pool circulation system. Continuous skimming is required even during times of no activity. The skimming that takes place during these quiescent periods is intended to draw material near the water surface into the gutters and back to the filtration equipment.

The skimming action is essentially accomplished by maintaining the level of the water in the pool no more than ¼ inch (6.35 mm) above the rim of the gutter As the water just barely breaks over the lip of the gutter, the velocity of the skimmed water increases and creates a pull on the water surface. If the water level is too high, little skimming action occurs.

Many years ago, this skimmed water went to waste. Water conservation, as well as the cost of reheating replacement water, has resulted in code requirements for the capture of this water. It now must be filtered, chemically treated, and returned to the pool. Most codes mandate a minimum volume requirement for the vessels that receive and hold this water until it can pass through the filter. The volumes are based on the estimated water displaced by swimmers plus wave action caused by their activities. A common requirement is for 0.6–1 gallon (2.27–3.79 L) of surge capacity for each square foot (m^2) of pool surface area. The various means of achieving this are covered under the "Surge Vessel or Surge Trench Selection" section of this chapter.

Some smaller pools are allowed to use skimmers to return water from the top of the pool. There are restrictions to their use, usually based on the size of the pool. Skimmers are covered in more detail in the "Component Evaluation and Selection" section of this chapter.

Main Drain and Grate

VGB states that where one cover/grate is blocked or partially blocked, the remaining main drain cover/grates must be sized to handle the full flow of the system. In other words, with two main drains, each cover/grate must be sized for the full flow of the system. With three main drains, each cover/grate must be sized for 50 percent of the full flow of the system.

ASME A112.19.8 also details tests for finger entrapment, measuring the force needed to pull the cover/grate out of the frame, and resistance to UV degradation, which could make the cover/grates brittle and cause attachment failure. These are an important part of the ASME testing because many of the entrapment accidents that occur are due to detached cover/grates. However, the primary issue that the designer must be concerned with is the maximum flow rating. VGB also requires main drain cover/grates to be sized for the maximum flow of the system. The combined maximum possible flow (which is usually greater than the design flow) that the system pumps can produce must not exceed the maximum flow rating for the cover/grate intended to be installed.

To address hair entanglement, VBG requires all existing main drain grates to be replaced with new cover/grates that have been tested to ASME 112.19.8. They must bear a stamp indicating the maximum flow allowed through the cover/grate as determined by that ASME testing.

Most of the designs for grates that will prevent suction entrapment result in cover/grates that are raised, which results in protrusions from the floor of the pool. This is not allowed by most state codes because it can present a tripping hazard. However, many states have made, or are making changes to their codes to allow main drain protrusions no greater than 2 inches (50.8 mm) above the pool surface.

In instances where the grates are installed in a wall, the installation of the anti-suction entrapment cover/grates results in a protrusion from the wall, which is a separate hazard addressed by most state codes.

No manufacturer is allowed to manufacture or distribute a cover/grate that has not met VGB requirements. All cover/grates or cover/grate and sump systems must bear the VGB-required stamp on the face of the cover/grate. The CPSC is tasked with inspecting all commercial facilities, and they have the authority to shut down and fine facilities that are found noncompliant.

Main Drain Piping and Location

The typical pool has main drain connections at the deepest point of the pool structure. These main drain pipes are connected to a formed concrete sump, stainless steel sump, or prefabricated fiberglass sump covered by a grating.

These connections provide a means of drawing water off the bottom of the pool for filtration purposes. They also usually provide a means of pumping the pool water to waste or draining the pool via gravity to a remote sump for pumping to waste.

In some cases, a reverse flow design is allowed. In this type of design, all filtered water is returned to the pool through inlets in the bottom of the pool. All dirty water is skimmed off the top of the pool. In such a design, a main drain is simply used to drain the pool. Not all codes allow such a design.

Due to entrapment concerns, multiple main drain sumps, piped hydraulically equal, are usually required. Velocities through the gratings covering these sumps are usually mandated to not exceed 1–1.5 fps (0.3–0.46 m/s) to reduce the chance of hair entanglement.

The free area of the covering grate typically must be at least four times the area of the connected main drain pipe. Codes also require minimum distances between main drain sumps, as well as distance requirements from the pool wall.

Hydrostatic Relief Valve

In areas where hydrostatic forces are a concern, such as in areas with high water tables, protection of the pool structure must be provided. This typically necessitates sufficient underdrain piping below and around the pool structure. A pumped drainage scheme also may be employed.

However, even with proper groundwater removal systems in place, a hydrostatic relief valve should be installed in the main drain sump. This device serves as a spring-loaded water stop and relief valve. If the main drain sump is poured concrete, a 2-inch (50.8-mm) pipe, along with a no-leak flange, is situated in the bottom of the pour. The HRV is threaded into the pipe on the pool side of the sump, and a pebble stop is threaded onto the backfill side of the concrete. If the pool is drained, the HRV may be the only way to prevent the pool from being lifted out of the ground (floated like a boat) by releasing hydrostatic forces into the pool. There have been cases where large (up to 200,000-gallon [757,082-L]) outdoor pools have popped as much as 24 inches (0.61 m) out of the ground.

If the pool is internal to a large building with a large basement area and a substantial drainage system in place, the use of an HRV may not be a concern. For a diagrammatic representation of this, see Figure 6-2.

Filtered Water Return Piping

In swimming pool system terminology, return piping refers to piping returning filtered, chemically treated water back to the swimming pool inlets. The quantity, location, and spacing of these inlets is covered by the plumbing code. If the volume of these inlets cannot be adjusted, care must be taken in the pipe layout and sizing to ensure equal distribution of chemical treatment throughout the pool volume.

Basic Piping Schemes

Numerous acceptable piping schemes are available. The major factors determining which approach to take are decisions on the following:

- Where the mechanical equipment room will be located (above or below the pool level)
- The type of surge-holding vessel to be used
- Whether to use skimmers instead of a surge vessel (if the pool is small enough)

Some typical piping layouts are given in Figures 6-3 and 6-4. For simplicity's sake, chemical feed systems and heating systems are not shown on these drawings. Those items will be added to these diagrams in the specific section covering those components.

Filtration, Circulation, and Water Chemistry Control Components

Surge Vessels

Surge vessels are basically large holding tanks. They accept water flowing by gravity from the top of the pool and hold it until the circulation pump can move it through the filter. To reduce the potential for suction entrapment, the main drain piping should, ideally, flow by gravity to the surge tank.

Gutters

The water from the top of the pool is usually collected by a gutter. In the past, these were simply formed out of concrete with drain connections spaced evenly around the pool. Though this is still done on occasion, the following types of gutters are much more the norm.

Stainless Steel Gutter This is a dual-function system. It not only collects the skimmed water from the top of the pool, but it also provides the distribution inlets for returning filtered water. The skimmed water flows into one chamber of the gutter. Through another chamber, separated from the gutter water by a stainless steel wall or plate welded in place internally in the unit, the filtered water is pumped back to the pool. This pressurized chamber has holes, spaced around the entire perimeter of the pool, that serve as filtered return water inlets.

One disadvantage of this system is the fact that the inlets are placed very close to the surface of the pool, and distribution throughout the entire pool volume can be affected. Short-circuiting of filtered water back into the gutter is also possible. Of additional concern is the potential for internal breaches between the two flows (gutter water and filtered water). These may develop over time due to corrosion and/or expansion and contraction. These breaches are difficult to detect, and they will result in less-than-minimum turnovers due to short-circuiting of filtered water right back to the filtration system through the gutter system. To address this concern, some stainless steel gutter manufacturers weld a rectangular stainless steel tube to the face of the rear gutter portion of the assembly, which provides a completely independent chamber for the flow of filtered water back to the pool.

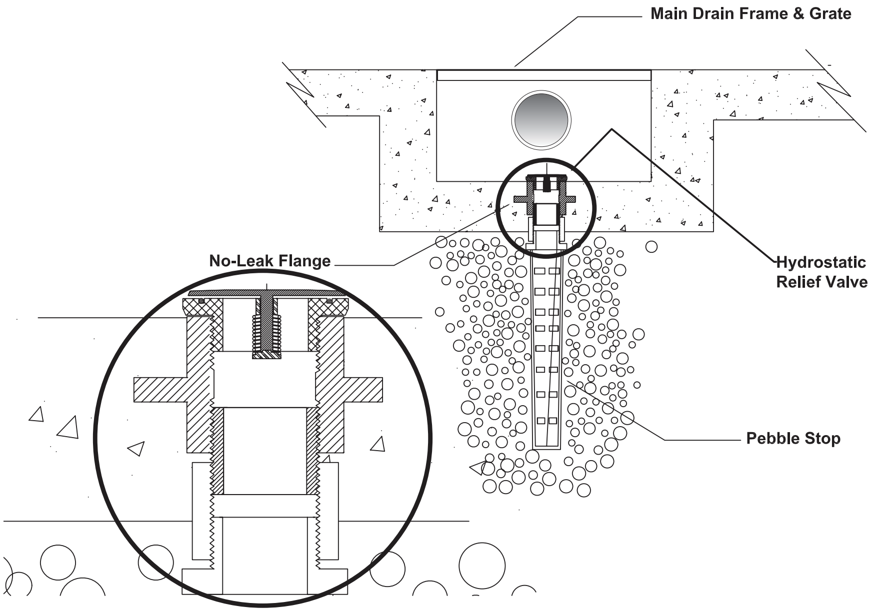


Figure 6-2 Formed Concrete Main Drain Sump with Hydrostatic Relief Valve

Surge Gutter Trench This is a formed concrete trench of sufficient width and depth to hold the required surge volume. It extends around the entire perimeter of the pool and is usually covered by a grating, which can be as simple as fiberglass bars sitting on a formed lip or as substantial as polymer concrete coping stones. The concrete coping stone is even considered part of the deck, which can be useful when minimum deck widths might otherwise be hard to accomplish. See Figure 6-5 for details of this approach.

Skimmers

On smaller pools, codes allow the use of skimmers. These are devices made of various types of plastics that have a floating weir (flapper door) that creates a skimming action at the water surface. They are set in the concrete when it is poured at one or more locations spaced around the perimeter of the pool or hot tub. Since they are directly connected to circulation pump suction, they should be piped to an equalizer fitting that is located well below the pool's operating level (see Figure 6-6). VGB considers this equalizer fitting a suction outlet and requires it to be covered by a compliant cover/grate or to be removed or disabled.

Skimmers are not as effective as a continuous gutter at skimming debris off the entire surface. That is why they are limited to use on pools with a small surface area. They also are used when budget concerns dictate.

Filters

The filter component of a pool system mechanically removes debris from the pool water. Measurable removal efficiency differences exist between the various types. In selecting a filter type, consideration should be given to the following items:

- Equipment room floor space and ceiling height
- Availability of backwash replacement water
- Filtration efficacy (turbidity of water leaving the filter)
- Water and sewer costs for replacement water
- Ability to handle a possibly large volume of backwash water
- Cost of heating replacement water
- Ease of operation
- Equipment longevity
- Budget requirements

Two basic media types are used in filters: sand and diatomaceous earth. Cartridge filters are sometimes used on smaller pools and spas, but they merely use replaceable cartridges, not loose media.

Sand is a granular media (usually #20 or #30 grade filter sand), and a uniformity coefficient is associated with each grade. The filter manufacturer will indicate the recommended grade of sand, as filtration efficiency is affected by the grade used, with #30 sand having particulate removal efficiencies that are more efficient than #20 sand. However, more restrictive sand beds result in higher friction losses through the filter.

Diatomaceous earth, known as DE, is considered a disposable media. It is a fine white powder material made up of skeleton-like fossilized diatoms. This powder is mixed with the water in the filter vessel and deposited in a layer on the filter element or septum. DE also comes in various grades. Typically, for swimming pool use, the product used should have permeability in the 3–5 Darcy range. Particulate removal capabilities basically track the permeability range, so the 3-Darcy media would be expected to achieve 99 percent reduction of 3-micron particles.

The filter area required depends on the media selected and the minimum flow rate requirement for the facility being designed. The various filter configurations for each of the two primary media types are covered in the "Component Evaluation and Selection" section of this chapter.

Circulation Pump

Circulation pump selection must be based on the ability of the pump to move the required amount of water through the circulation and filtration system under worst-case conditions. As the filter becomes dirty (loaded), it restricts the flow. As piping ages and becomes calcified, it also can substantially restrict flow.

For these reasons, many codes mandate that a pump be selected with a design performance point of the minimum flow required, with an available total dynamic head (TDH) capability of 70–80 feet. In the absence of such a code requirement, the designer must assume the expected pressure drop through a dirty filter, usually 15–20 pounds per square inch (psi) (103.4–137.9 kPa).

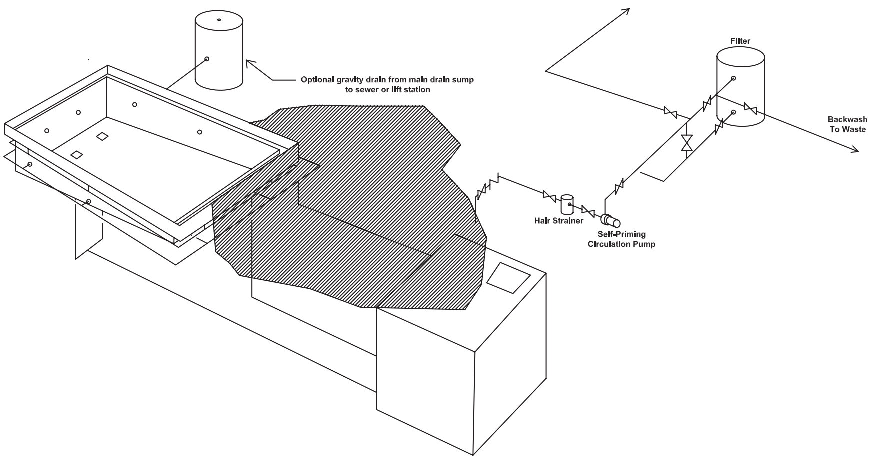
In addition to the dirty (loaded) filter, all pipe and fitting losses on both the suction and discharge sides of the pump, friction losses through a dirty hair strainer, and losses through a pool heater or heat exchanger must be calculated. The resultant estimated system head requirement dictates the proper pump selection.

Hair and Lint Strainer

These are devices with removable strainer baskets. They are installed upstream of the pump and are required by code. Their primary purpose is pump protection. Most codes require two strainer baskets, which decreases shutdown times when cleaning and changing a basket.

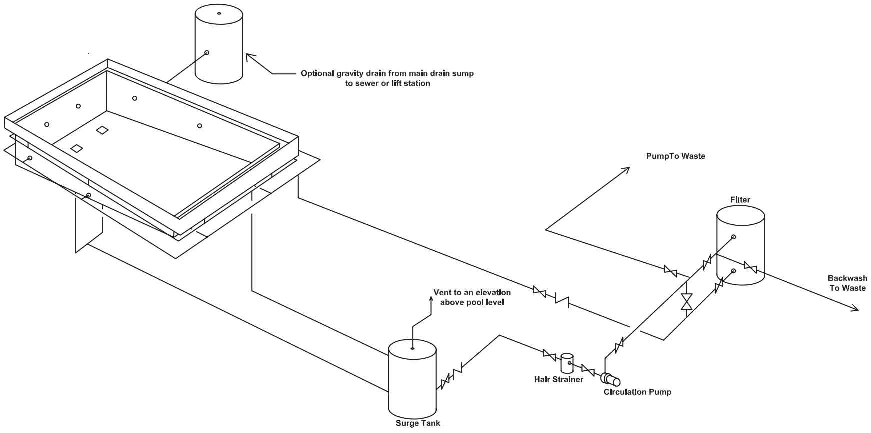
Flow Sensor and Display

All systems must include a device to indicate that the minimum flow rate and resultant turnover rate are being achieved. Numerous types are available, and their costs versus accuracy and life expectancies vary considerably.



Typical Piping Layout - Swimming Pool with Perimeter Formed Gutter
Above Grade Equipment Room
Buried/Vented Surge Vessel/Pressure Filter

Figure 6-3 Typical Above-grade Piping Scheme



Typical Piping Layout - Swimming Pool with Perimeter Formed Gutter
Below Grade Equipment Room
Free Standing/Vented Surge Vessel/Pressure Filter

Figure 6-4 Typical Below-grade Piping Scheme

Many codes require gauges to be located properly on the suction and discharge sides of the circulation pump. These gauges, together with a pump curve for that particular pump, provide the ability to accurately check the performance of the pump and to verify the accuracy of the flow-measuring device.

Flow Control Devices

Consideration must be given to the means that will be used to control the rate and direction of flow to and from the pool. The circulation pump is selected for a worst-case scenario, so if it is allowed to run wide open when the filter, hair strainer, and piping are free and unobstructed, then over-pumping of the filter and heater will result.

Manual butterfly valves also are needed as isolation valves to enable the servicing of system components without draining the system. Valves must be provided to isolate the hair strainer to allow the replacement of a dirty hair strainer basket.

Codes also require control of flow from the pool. Usually, 80 percent of the circulated water is taken off the top of the pool, and the remaining 20 percent is drawn from the bottom of the pool through the main drain. Some type of float-operated butterfly valve or manual valve usually is used to control this.

For more accurate control, diaphragm-type air-operated butterfly valves or piston-operated butterfly valves with pilot positioners are used. The various types are covered in the section titled "Component Evaluation and Selection." Even if variable-frequency drives (VFDs) are used to control the rate of flow to the pool, some type of manual valve should be in place in case the VFD fails. Manual operation must be able to be controlled while the VFD is out of service.

Pool Water Heating Systems

The basic types of heating systems are gas-fired water heaters, steam/hot water heat exchangers, and, infrequently, electric heaters. One possible disadvantage of using heat exchangers is that they require year-round operation of a boiler (if the pool is a 12-month operation). The rest of the facility may not require the use of the boiler, which may make the case for the use of a supplemental electric heater.

Venting capabilities, corrosive ambient air, and equipment space requirements are the primary issues to be given consideration. Many facilities are designed with dehumidification systems that use the heat of condensation to heat the pool water or pool space. The various choices are listed in the "Pool Water Heating Systems" section under "Component Evaluation and Selection."

Chemical Control and Feed Systems

Commercial pools must have systems in place that are capable of maintaining the pH and oxidizer/sanitizer levels in the pool water within a code-mandated range. These systems can be as simple as adjustable-rate feed pumps for acid and chlorine solutions. Some codes require the use of an automatic water chemistry controller to constantly measure pH and sanitizer levels in the pool. These controllers will turn on the associated chemical feed pump or system as needed.

Level Control Systems (Surge Tank)

Level control systems can vary from a simple float-operated main drain valve installed on the main drain pipe after it enters the surge tank to a complex bubbler system (differential pressure controller) controlling an air-operated modulating valve. The decision typically is based on cost versus accuracy. Diagrams and specific operational characteristics of these systems are covered in detail later in this chapter.

Fresh Water Makeup

Fresh water makeup can be accomplished by an operator regularly checking the pool water level and turning on the manual freshwater fill valve until the pool is filled properly. Most codes require a skimming action to take place constantly, and a good way to ensure this is to provide some form of automatic fresh water makeup system.

From an operational standpoint, since most contaminants in the pool water are introduced at the top portion of the pool, the top layer of water should pass through the filter the quickest. Such a water makeup scheme is closely associated with the water level control scheme employed. (Informational diagrams are provided later in this chapter.)

Specialty Systems

The complexity of pool designs has increased dramatically from the days of the simple rectangular lap pool with basic filtration and chemical feed systems. An seemingly endless variety of water play features are now available, as well as supplemental sanitation systems designed to offset the increased demand created by heavy bather loads.

This places an increased responsibility on the shoulders of the pool designer. The designer must investigate and understand the capabilities and special considerations required of the design when using these products. Some basic information can be found in the “Component Evaluation and Selection” section that follows.

COMPONENT EVALUATION AND SELECTION

Surge Vessels (Surge Tanks)

One method used to create a surge-holding capacity is a buried concrete tank. This type of surge tank is buried somewhere between the pool and the equipment room, usually under the deck, which extends around the perimeter of the pool. It is also frequently located under the equipment room floor slab. Water from the perimeter gutter, and ideally the main drain, is piped to this holding tank.

Although the buried tank saves floor space, it complicates accessibility to key components. Access must be provided for cleaning or adjustments. Pump strainers and/or level control devices are often difficult to access. Frequently, draining of the surge tank is necessary.

This type of buried concrete structure is considered a confined space, so the operator will be required to follow Occupational Safety and Health Administration (OSHA) guidelines before working in this area, which should be taken into consideration before deciding on this approach. Figures 6-3 and 6-4 show how a buried surge tank would be piped into the circulation system.

A freestanding vessel is another type of surge tank that is located in the equipment room. It can be an open or a closed vessel. Open-tank vessels are still very common in installations where the equipment room is in a basement or where the location prevents venting of a closed tank. The obvious concern is how to provide protection from flooding if the system shuts down unexpectedly. Properly functioning check valves on the piping downstream of the filter, as well as between the main drain piping and the surge tank (if the main drain isn’t connected to the surge tank), are an absolute necessity. The open-tank design provides a convenient way to add fresh water with the required air gap.

The closed and vented tank is a much better option for a basement equipment room. A closed vessel, with flanged connections for the gutter piping, pump suction, and possibly the main drain piping, is vented through piping extending above the water level of the pool. Venting is essential, as it allows incoming water from the gutter and/or main drain to displace air in the tank. It also prevents a possibly damaging vacuum situation from occurring if isolation valves are inadvertently closed while the circulation pump is in operation or are left closed when starting the pump. The vent, if of sufficient size, also provides a means of adding fresh water with the required air gap. Figure 6-4 shows such a piping scheme.

Surge Gutter Trench

The surge gutter trench is a continuous concrete trench formed on the exterior of the pool walls around the entire perimeter of the pool. The trench is sloped to an area closest to the pool equipment room. At that low point, a single pipe connection is made to allow the water collected in the trench to be combined with main drain water at the circulation pump suction.

The trench is sized to meet or exceed the minimum surge-holding capacity requirement of 1 gallon per square foot (3.79 L/m^2) of pool surface area. The trench typically is covered by a fiberglass or Cycolac (a type of ABS plastic commonly used for pool components) grating. A slightly raised handhold must be provided at the water’s edge of the covering scheme used for this trench to provide swimmers with a place to securely grip, if needed.

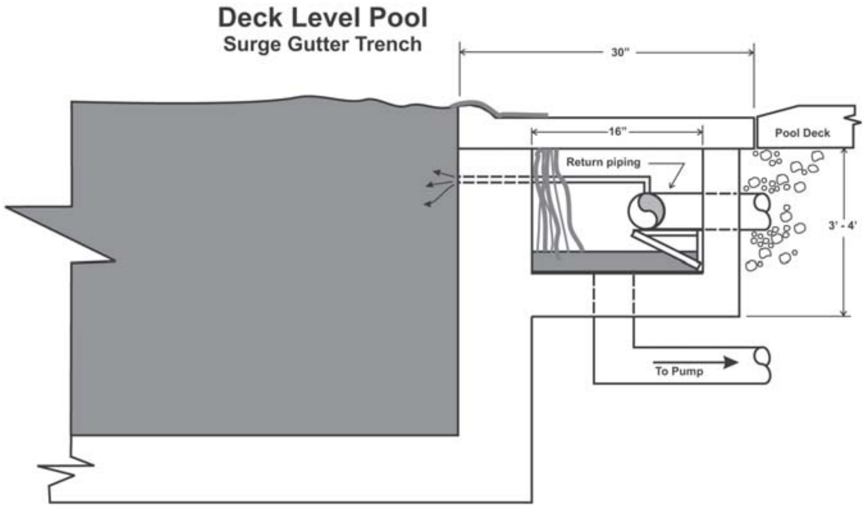


Figure 6-5 Deck-level Surge Gutter Trench

Another design employs precast polymer concrete coping stones. This type of pool operates with the pool water essentially at deck level, and the coping stone is considered an extension of the deck. Return piping often is run in this trench around the perimeter of the pool, which facilitates pipe repairs, when needed, without breaking up the concrete deck. Figure 6-5 gives a diagrammatic representation of this approach.

Skimmers

Skimmers can be used only on small pools, usually pools less than 20 feet (6.1 m) in width or less than a certain amount of water.

They don't effectively skim a very large surface area, and they are directly connected to pump suction. If the pool's operating level isn't properly maintained and the water level drops below the opening of the skimmer, the circulation pump may possibly suck air and be damaged by cavitation conditions.

To prevent air from reaching pump suction when using skimmers, it is important to require the installation of an equalizer fitting, located in the wall of the pool a few feet below the skimmer. An equalizer valve and float are then installed inside the body of the skimmer. In this way, if the pool level drops, water still will be drawn through the equalizer fitting. These items are offered as options with most commercial skimmers. (See the diagram in Figure 6-6.) A VGB-compliant fitting is required for this equalizer connection to the pool since it is considered a suction outlet. Some codes may even require the removal or disabling of these equalizer connections to comply with VGB requirements.

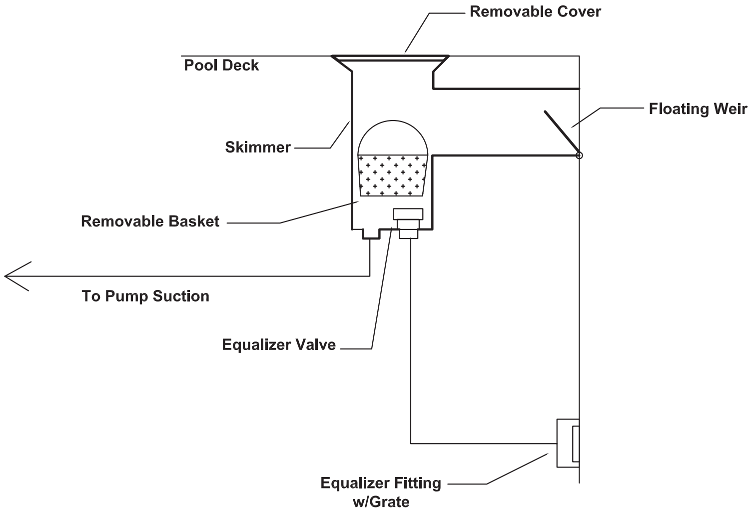


Figure 6-6 Skimmer Detail

High-rate Sand Filters

The high-rate sand filter is currently the most common type of filter employed on swimming pool systems. High-rate sand filters have acceptable particulate removal capabilities, and they are simple to operate.

These filters are pressure type, meaning the filter is installed downstream of the circulation pump, and the pump creates pressure to force the dirt-laden pool water through the filter. The water enters the filter at the top of the media bed and is forced through the sand to a set of slotted laterals, which are connected to a collection manifold.

The most common media used in high-rate sand filters is #20 or #30 filter sand, with a specific uniformity coefficient. The #20 sand has a particle size of 0.018 inches (0.35 mm) to 0.022 inches (0.56 mm) or an effective size of 0.45 mm and a uniformity coefficient of 1.5 maximum. The #30 grade of sand is not as common as #20. It is finer sand and is sometimes used when higher filtration efficiency is desired. Not all filters are designed to allow the use of #30 sand, as the underdrain laterals must be manufactured with very close tolerances regarding opening size to disallow the passage of the smaller sand particles back to the pool. Check the filter manufacturer's specifications to ensure that #30 sand can be used.

In general, the flow rate of the water being filtered through this type of filter is in the range of 15–20 gpm per square foot (56.8–75.7 L/min/m^2) of filter surface area. All pool filters must be tested by NSF International, given an NSF/ANSI 50 listing, and bear that label on their exterior. This listing prescribes the maximum allowable flow for each listed filter, and many codes use this listing as their design requirement criteria.

The backwash rate for any sand filter is based on research done by the Hydraulic Institute. It has been determined through testing that a minimum of 15 gpm per square foot (56.8 L/min) of filter area is required to "fluidize" the sand bed. At less than 15 gpm per square foot (56.8 L/min), the filter bed doesn't lift up and allow debris that is deeply embedded in the sand bed to be released. If this lower-than-required backwash rate continues, "mud balls" eventually will develop and effectively decrease the usable filter area.

Properly designed high-rate sand filters, using the most common #20 grade media, can effectively capture particles as small as 15–20 microns when the filter is clean. As the filter becomes dirty ("loaded" is a better description), the filtration efficiency of a sand filter actually increases. The interstitial spaces between the grains of sand media become smaller and can possibly capture particles as small as 10 microns.

Horizontal High-rate Sand Filters

Horizontal high-rate sand filters may require more equipment room floor space than vertical sand filters, but they lend themselves to more accurate design possibilities regarding flow during filtration and backwash. Backwash functions are also more easily automated and are at a lower backwash flow for each individual tank. Multiple tank arrangements may be used to alleviate concerns about the ability of waste piping or transfer pumps to handle large backwash flow rates. A three-tank horizontal system is shown in Figure 6-7.

Figure 6-7 Horizontal High-rate Sand Filtration System, Multi-tank

Vertical High-rate Sand Filters

Depending on the required filter area and the shape of the equipment room, vertical high-rate sand filters sometimes can be a more space-conscious option. An 8-foot (2.44-m) diameter vertical filter would have more filter area than two 3-foot-diameter by 6-foot-long (0.91-m-diameter by 1.83-m-long) horizontal filters with a 6.25-foot by 6-foot (1.91-m by 1.83-m) footprint. Three horizontal filters, each with a footprint of 9.5 feet by 6 feet (2.9 m by 1.83 m), would be required to provide a filter area equivalent to that of the 8-foot (2.44-m) diameter vertical filter.

The equipment room floorplan will probably dictate which type of filter is best suited for the application. However, the designer also must consider the backwash water removal capabilities. Since the vertical system is forced to backwash the entire filter area at one time, the backwash flow rate for the vertical filter will be three times that of each individual component of the horizontal system where each tank is backwashed individually.

Multi-cell Vertical Sand Filters

Multi-call vertical sand filters offer even more floor space savings. That same 8-foot (2.44-m) diameter footprint can accommodate two or three filter cells stacked one above the other. If even distribution across the sand bed is a concern, the method of distribution through each cell should be examined. Lower filtration efficiencies can result if flow distribution is not uniform. Non-uniform flow results in higher velocities in certain areas of the sand bed, and these higher velocities can drive contaminants through the sand bed. Automated backwash of each cell, individually, is difficult if not impossible.

Vacuum Sand Filters

A vacuum filter system is one in which the circulation pump is located downstream of an open filter vessel. As the filter media restricts pump suction, a vacuum is created that allows atmospheric pressure to force the dirt-laden water through the media. The contaminants are left embedded in the media.

The media used in these filters is usually one or two grades of gravel covered by several inches of #20 filter sand. Media requirements vary by manufacturer. The gravel layer is intended to enhance backwash capabilities.

The NSF/ANSI 50 listing for these filters indicates the maximum allowable flow rate for each listed filter size. These are listed as high as 15–20 gpm per square foot (56.8–75.7 L/min/m^2) of filter surface area. Individual manufacturers may recommend an even lower filter media rates than allowed by NSF International. The lower flow, frequently in the 5-gpm per square foot (18.9-L/min) range, is intended to allow smaller

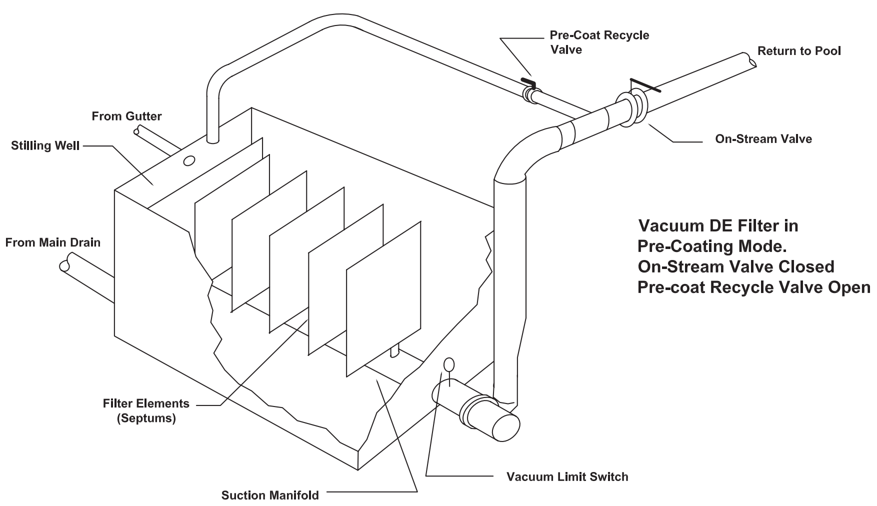


Figure 6-8 Vacuum DE Filter in Pre-coat Mode

particles to be captured by the media. However, this requires a larger footprint.

As for any sand filter, the backwash rate needs to be at least 15 gpm per square foot (56.8 L/min/m^2) of filter surface area. This is the minimum flow needed to fluidize the sand bed and release trapped particles. Due to the large surface area of these filters, this rate can translate into excessive amounts of wasted water.

Some manufacturers have introduced an air-scouring system in which bubbles of air rise through the sand bed during backwash. The air bubbles are intended to lift the sand bed and allow lower backwash flow (e.g., 10 gpm per square foot [37.9 L/min/m^2]), while still achieving an acceptable removal of the dirt load. This is somewhat questionable and may not be allowed by some codes, but manufacturers of these systems claim better filtration efficiencies at lower filter media rates than those achieved with high-rate sand filters. This might seem a logical conclusion, but no definitive independent testing of the turbidity of the water leaving these filters supports that claim. At higher rates, near 15 gpm per square foot (56.8 L/min) of filter surface area, they are at least as good as high-rate sand filters.

Diatomaceous Earth (DE) Filters

Fossilized skeletons, primarily of sea plankton, are called diatoms. Large deposits of this fine powder are mined and graded according to particle size. The mined white powder is then heated and milled, resulting in diatomaceous earth (DE) products with varying properties. A coating of DE on a filter element or septum is used to trap and remove debris from the pool water passing through the filter. DE with a permeability of 3–5 Darcy units is common for commercial filtration.

In many locales, spent DE must be captured when draining or backwashing the filter to prevent the DE from settling in the sewer system in areas of low flow velocity. Since DE is a light, fine, white powder, proper breathing protection should be worn if the DE could potentially become airborne. Vacuum DE filters require the broadcasting of the DE powder over the water surface of the filled filter vessel, so making the DE airborne in that case is unavoidable.

Respirable (airborne) DE is considered a Class I carcinogen by the International Agency for Research on Cancer (IARC), but skin contact or ingestion is not considered dangerous. In fact, due to the prevalent use of DE for food preparation, such as soda and beer manufacturing processes, DE is classified as an incidental food additive. For purposes of comparison, beach sand, filter sand, sawdust, and drywall dust also are listed as Class I carcinogens.

Vacuum Diatomaceous Earth Filters

Vacuum DE filters are one of the oldest and most efficient (regarding particulate removal) forms of pool filtration. As with any vacuum system, the pump is located downstream of the filter.

The filter itself consists of an open-top vessel, filled with multiple filter elements or septums. The number and shape depend on the filter area needed and the design preference of a specific manufacturer. The septums are covered by a cloth bag or cover (usually polyethylene) that is coated with DE during a precoating process. The DE media performs the actual filtration, not the bag or the filter element.

A vacuum safety switch is required between the filter and the suction connection to the circulation pump. This safety switch is connected to the auto-control circuit of the circulation pump. Whenever a vacuum of 10–13 inches (254–330.2 mm) mercury (Hg) occurs, the pump is automatically shut down. Otherwise, this high vacuum condition could possibly collapse and destroy the filter elements.

The septums can remain coated with DE only through continuous sufficient flow through the media, as the flow of water through the media holds the DE in place. If pump operation is inadvertently interrupted, the DE will drop off the elements. If the pump is then restarted without going through a pre-coat process, some of the DE initially will be pumped out to the pool.

The pre-coat process is a manual operation in which the filter vessel is filled with water and valves are adjusted to direct water pulled through the filter straight back to the stilling chamber of the filter tank. The pump is then started, and the required amount of DE (approximately 1 pound per 10 square feet [0.5 kg per 0.93 m^2] of filter area) is broadcast over the surface of the water in the filter tank. Pre-coating is continued until the cloudy water (DE slurry) in the vessel clears sufficiently. Without stopping the pump, the pool return valve is slowly opened to allow filtered water to flow out to the pool. The pre-coat recycle valve is then slowly closed, and the filter is considered online, or in filtering mode. Figure 6-8 shows the piping configuration for the pre-coat loop.

Contingent on the quality of the media selected, these filters can achieve a 99 percent reduction of water impurities in the 3-micron range. The configuration of these filters can also play a major role in their particulate-retention capabilities.

The procedure for cleaning a vacuum DE filter is simply draining the filter completely, hosing off the filter elements, and flushing the old, or spent, DE completely out of the filter tank. This can be a laborious, time-consuming task. If the filter vessel is poorly designed, with a floor that doesn't have sufficient slope to the drain, the old DE will be difficult to wash over to the drain opening.

Once the filter and elements are sufficiently cleaned, the filter is filled with water. DE is then added by either broadcasting it over the surface of the water or mixing the required amount of DE in buckets of water and dumping it into the filter vessel. The pre-coating process is then initiated, and after approximately three to five minutes, the filter can be put back online. Typical piping for a vacuum DE filter is shown in Figure 6-8.

Slurry Feed Systems

When DE is mixed with water it forms a DE/water slurry. To extend the time between DE changes in the filter, additional DE often is added on a continuous basis. For filter media rates above 1.5 gpm per square foot (5.68 L/min/m^2), continuous DE slurry feed (sometimes called body feed) may be required by code. The rate of addition is prescribed by the same code.

A dry slurry feeder uses a rotating auger mounted below a DE holding funnel. As the auger rotates, it carries DE from the funnel out to the end of a trough. The dry DE then drops off the end of the trough into the water-filled filter tank and adds an additional thickness to the coating of DE on the filter elements. These units have digital controls and adjustments for setting the rate of feed in pounds per day.

Wet slurry feeders employ a holding tank filled with water in which a predetermined amount of DE is mixed. An agitator pump is required to keep the DE from settling out on the bottom of the holding tank. A feed pump, usually a diaphragm-type feed pump with a timed auto-flush solenoid keeping the check valves clear, is used to draw the slurry out of the holding tank and to inject it into the water stream entering the filter from the pool. Peristaltic pumps also may be used, and since they don't require check valves, they may not require the auto-flush feature.

Pressure Diatomaceous Earth Filters

Pressure DE filters are the most economical regarding equipment room floor space. They are of a vertical configuration, with internal elements that provide a large surface area for filters having such small footprints. Like vacuum DE filters, they provide a high level of filtration efficacy.

Again, in a pressure system, the pump is located upstream of the filter and forces the water requiring cleaning through the filter elements. The actual configuration of the elements varies by manufacturer, but their purpose is to provide a surface for the DE to coat and to act as a filtering media.

Static Cake Diatomaceous Earth Filters

Static cake DE filters receive an initial charge of DE and then are pre-coated in a manner similar to the process described for vacuum DE filters. They filter continuously until the DE becomes plugged to a point where the flow through the filter is dramatically reduced below design operating parameters. Some form of wet slurry feed usually is employed to extend filter cycles. Due to the required frequency of cleaning, these filters are not usually found on large commercial systems.

Regenerative Diatomaceous Earth Filters

Regenerative DE filters are similar to static cake filters in their basic design, but they are far different in their performance characteristics. They typically have a higher initial cost than any other type of filter system, so care must be taken to ensure that the initial cost is commensurate with improved performance.

To eliminate the need for slurry feed and to greatly reduce the frequency of changing DE, regenerative DE filters employ an automatic regenerative process in which the original DE pre-coat is periodically forced (bumped) off the filter elements. The circulation pump is automatically turned off; the filter is automatically bumped; and then the circulation pump is automatically restarted, and a pre-coat cycle is automatically reinstituted. This procedure essentially clears free paths through the DE that is coating the elements and reduces the pressure drop through the media. It allows for complete use of all the surfaces of the initial DE charge. A regenerative DE filter, of sufficient size to handle flows up to 2,300 gpm (8,706 L/min), is shown in Figure 6-9.

Both static cake and regenerative DE filters are subject to NSF/ANSI 50 testing requirements. They are NSF listed by model number regarding the maximum allowable flow. Typically, these flows range between 1.3–1.6 gpm per square foot (4.92–6.06 L/

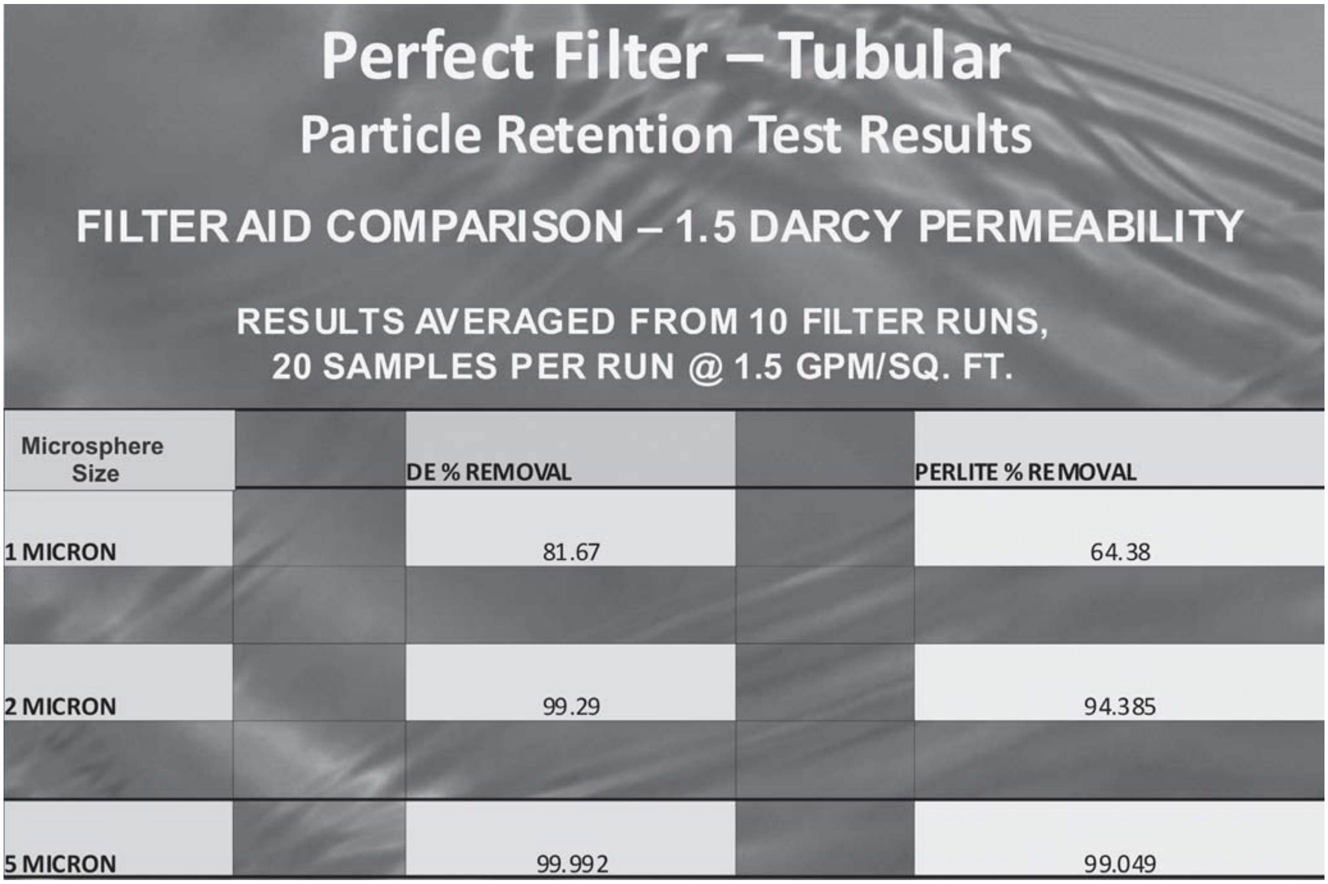
min/m^2) of effective filter surface area. For particle retention test results, refer to Figure 6-10.

Filtration efficacy is very dependent on the design and construction of each specific filter. Flow characteristics regarding velocity uniformity and uniform turbulence have a measurable effect on the DE-retention capabilities of each filter design. If the equipment choice is based on quality of filtration, investigation of previously installed operating systems of this type should be undertaken.

In general, particulate removal efficacies in a well-designed filter can be expected to track directly with the permeability of the DE media used. With the most common grade of DE used in commercial filters having a permeability of 3 Darcy units, at least a 99 percent removal of 3-micron particles can be expected. Some filters of this type have proven performance in the 1.5-micron range. In this range, a 2-log removal of bacteriological contaminants is possible. That is well worth consideration with the current interest in removing Cryptosporidium bacteria from pool environments. Again, this should be closely investigated to justify the use of these systems.

As stated, static cake filters require more frequent cleaning. They also require a pumped backwash to force the DE and dirt out of the weave of the multi-filament fabric of the filter elements. The fil-

Figure 6-9 Regenerative DE Filter



Perfect Filter – Tubular

Particle Retention Test Results

FILTER AID COMPARISON – 1.5 DARCY PERMEABILITY

RESULTS AVERAGED FROM 10 FILTER RUNS,
20 SAMPLES PER RUN @ 1.5 GPM/SQ. FT.

Microsphere Size	DE % REMOVAL	PERLITE % REMOVAL
1 MICRON	81.67	64.38
2 MICRON	99.29	94.385
5 MICRON	99.992	99.049

Figure 6-10 Particle Retention Test Results

ter elements themselves require removal and more thorough cleaning, usually on a yearly basis. That is not the case with regenerative DE filters.

The cleaning requirements of a regenerative DE filter vary greatly depending on the load and filter size. In a heavy-use indoor facility, a regenerative DE filter should be recharged every three to four months. For a heavily used outdoor pool, if long filter runs are desired, the filter is sized for a filter media rate of approximately 1 gpm per square foot (3.79 L/min/m^2) of filter area, which usually results in four- to five-week filter runs. When filters are selected for operation near their maximum allowable filter media rate, they will probably require a DE change approximately every two to three weeks.

The procedure for replacing the DE is quite simple. The filter is bumped and then drained. No pumped backwash is required. After one or two additional fills with pool water for rinsing, the filter is refilled with DE, usually through a specially designed vacuuming system, which eliminates the concern about airborne DE. The infrequent need for DE changes, along with the fact that these filters don't require a pumped backwash, can be a major factor in reducing the water replacement and reheating requirements inherent in other systems.

Regenerative Alternative Media Filters

In recent years, some filters listed as regenerative DE filters under NSF/ANSI 50 have been tested using alternative media, and perlite and cellulose have been approved under NSF/ANSI 50 as DE substitutes. However, the challenge particulate material (U.S. Silica SCS 106) used in NSF test protocol is largely incapable of evaluating the particulate reduction characteristics of any filter aid, including DE products of varying permeability at or below the 12-micron level. Other independent test results indicate that cellulose has filtration efficacies only slightly better than sand media filters.

A paper presented at the National Swimming Pool Foundation (NSPF) World Aquatic Health Conference in October 2009 offered findings resulting from careful testing of the filtration efficacy of perlite compared with DE. When the two media were tested at the same permeability (1.5 Darcy), same coating thickness (0.125 inch) on the filter elements (tortuous path), and same filter media rate (1.5 gpm per square foot), the DE gave a reasonable expectation of a 4-log (99.99 percent) capture of cryptosporidium sized particles, compared with a 2-log (99 percent) capture by perlite. That is a sizeable difference when a single diarrheal accident can contain millions of crypto oocysts. If a million oocysts are filtered by a DE filter, less than 100 will make it through. The same million oocysts encountering a perlite-coated filter have a much better chance of making it through and out to the pool. At a 2-log removal capability, perlite would allow almost 10,000 oocysts to pass through. Since it only takes 10 oocysts to infect a susceptible swimmer, the media choice is an important consideration.

If the choice of a regenerative DE filter is predicated on crypto-removal capability, some type of performance specification should be established. The above test results were arrived at through the use of a "perfect" filter for testing. Actual results in the field will be affected by the design of the filter selected, as well as the piping layout in the equipment room.

Circulation Pump Selection

Centrifugal pumps are the type of pump used on swimming pool circulation systems. They can be of an end-suction form or a vertical turbine configuration. The most common end-suction centrifugal pump is the horizontal, either base mounted or motor mounted. In some instances, an owner may opt for a horizontal or vertical mounted, inline, split-case design, but the instances of this are rare.

Horizontal End-suction Centrifugal Pumps

A flooded suction centrifugal pump should be used only when it can be installed below the pool's operating water level. In some installations, they are placed on grade, and a check valve or foot valve is used, supposedly, to maintain a filled suction pipe. This configuration is not recommended, as these installations always are operationally problematic. Flooded suction pumps are not designed to effectively evacuate air. Once the check or foot valve gets jammed by a foreign object, re-priming the pump is almost impossible. Most flooded suction pumps have a tapped hole in the top of the pump volute to release air if the pump become air-locked.

Self-priming pumps are designed for installations where the equipment room is above the pool's water level. Selection should take into account the lift required for the application when operating at the duty point, as it relates to net positive suction head required (NPSHR). Self-priming pumps are effective at passing air during the priming process, but care must be taken to never operate them dry. A check valve in the suction piping on the vertical run of pipe as it drops to the surge tank is helpful during the priming process. If some form of backflow prevention is in place on the freshwater system, a hose bibb connection on the suction side of the pump also might be considered to assist in the priming process (if this is allowed by the local code).

Since swimming pool water has a constant residual of chlorine, swimming pool pumps should be fabricated of materials that offer decent life expectancy. These pumps are, according to most codes, required to operate 24 hours per day. Pumps with cast iron volutes and impellers can be expected to provide many years of service. Maintaining proper water balance, as discussed later under "Chemical Control and Feed Systems," plays a major role in ensuring this longevity. Proper piping schemes, designed to prevent conditions that might lead to cavitation, will extend the life of the impeller.

For situations in which the pump operates intermittently, such as when its function is to provide flow to a water feature or as a spa jet pump, all wetted components of the pump must be made of noncorrosive materials. If a cast iron pump were used, rust would form during the quiescent period (primarily overnight). Then, when the cast iron pump is restarted in the morning, the operator and patrons will be treated to an initial flow of brown, rusty water.

Stainless steel pumps are available. These are not truly noncorrosive; stainless merely means that the material stains less frequently than other materials. However, stainless steel pumps will not discharge rusty water after an overnight shutdown period.

Also, many plastic pumps with plastic impellers are used in the pool industry. Most of these are self-priming pumps, so they can be used whether the equipment room is above or below grade. The stainless steel pumps are a little more heavy duty and seem to hold up better in conditions where the equipment room is in a basement below the hot tub or water feature. They are not self-priming pumps, so this below-grade location is ideal.

Many swimming pool codes for filtration and circulation pumps contain a minimum performance capability requirement based on the mandated flow rate needed to attain the minimum turnovers per day. The pump must be able to move the resultant minimum required flow at some code-estimated total dynamic head (TDH). This might be a TDH of 70 feet for a sand filter system or as high as 75–80 feet for a pressure DE filter system.

Basically, the pump must be selected to guarantee that it can move the required flow through the filter in a worst-case scenario, or when the filter is the dirtiest. Therefore, even if the code mandates a minimum pump TDH capability, the designer should perform a system head calculation. All pipe and fitting losses on the suction and discharge sides of the pump must be included. The additional losses through system components—hair strainer, valves, dirty filter, heater—and discharge and friction losses through the inlet fittings must be added to the pipe and fitting losses to come to a total system head requirement. This will verify that the code-mandated performance requirement is sufficient.

Vertical Turbine

Vertical turbine pumps can save up to 75 percent of floor space as compared to horizontal end-suction centrifugal pumps. They have smaller footprints mainly due to the location of the pump below the floor. However, accommodations should be made for pulling these pumps for service. If very long shaft lengths are necessary, high ceilings and possibly an overhead I beam may be necessary. These pumps are basically flooded suction pumps that can be installed above the pool's water level. The downside to their use is the necessity for a hair strainer screen or basket on the bottom of the pump. Cleaning during normal use is difficult, so to facilitate this cleaning, some installations use a screen that slides through a slot in the floor and isolates the section of the surge pit where the pump's suction bell is located.

When a buried concrete surge tank is part of the design, a vertical turbine pump is an obvious choice. These pumps require the operating level in the surge tank to be maintained at or above the pump's required minimum submergence. The pressure available at the mouth of the suction bell of the pump is essential to proper pump operation without cavitation. The NPSHR for a particular pump, at the design operation point, controls the water depth above the suction bell entry point (minimum submergence), and the resultant depth-related water pressure at that point must be such that the net positive suction head available (NPSHA) always exceeds NPSHR. This minimum submergence also guarantees that the lowest impeller of the pump is always submerged and that it will start pumping when it begins to rotate. This, in effect, provides the same priming certitude as any flooded suction pump.

These pumps can be used in a wet-pit installation or they can be closed suction (direct piped), possibly in a dry pit. In either configuration, some protection against large debris entering the bowl assembly must be provided. The bowl assemblies can be either semi-open or closed.

Standard materials of construction for clear water service include cast iron bowls, bronze or cast iron impellers, and stainless steel shafts. The column shaft connecting the bowl assembly to the discharge head is usually steel, and the discharge head is cast iron. All components, however, are available in more corrosion- and abrasion-resistant materials.

Pumps can be custom-selected to allow variations in the slope of the head curve to meet the head and capacity system requirements. A pump with a steeper curve will allow for better control when using a variable-frequency drive (VFD) for flow control.

Placement of the vertical turbine pump (or multiple turbine pumps) is critical to non-turbulent operating conditions. This topic includes too many variables to be effectively covered in this chapter. As a starting point, the designer can reference *Hydraulic Institute Standards for Centrifugal, Rotary, and Reciprocating Pumps*, 14th Edition.

Manufacturers of vertical turbine pumps offer various strainer basket assemblies for mounting on the suction bell of the pump. On swimming pool applications where the pump is required to operate all day, these strainers will become fouled quickly, which can present a maintenance nightmare. Often, instead of the factory-provided strainers, pool designs call for a fabricated, perforated, stainless steel wall or other perforated stainless steel enclosure. If properly designed, this can provide much more free area and result in less frequent cleaning requirements (possibly only at the end of an outdoor pool season).

Hair and Lint Strainers

Hair and lint strainers are required on the suction side of end-suction centrifugal pumps and are intended to provide pump protection. The baskets installed in the hair strainer capture debris that could possibly plug the eye of the impeller or damage the impeller. Opening sizes in the basket are usually prescribed by code. Typically, the operator is required to have available two of the removable baskets for ease of changing and cleaning.

The straight flow-through strainer is the most common type. The inlet and outlet flanges are matched to the pipe size on the suction side of the pump. The centerlines of both the upstream and downstream openings in the strainer body are equidistant from the bottom of the strainer.

Offset connection strainers are a specialty type. They are custom-fabricated to simplify alignment of the suction piping to the suction connection on the circulation pump. The centerline of the influent side of the strainer can be at a higher elevation than the leaving side (effluent) elevation.

Change-fitting connection strainers are also a custom fabrication. This type of strainer provides a simplified way to change from the suction pipe size to the actual size of the suction connection on the pump, as the flanged suction opening on most pumps is usually several pipe sizes smaller than the suction piping. A combination of the offset and change-fitting types is also available.

Cast iron hair strainers are no longer used in new construction in the swimming pool industry. The most common types of strainers are made of fiberglass reinforced plastic (FRP) or stainless steel. Removable covers are usually clear acrylic. The removable baskets are stainless steel, but the baskets may be made of plastic in smaller plastic pumps, which are often provided with integral hair strainers.

Flow Sensors

Codes require a device to be provided in the circulation system to verify that the pump is moving enough water to satisfy code turnover requirements. These sensors with displays take many forms.

Impact Type

The impact flow sensor usually has a small opening facing upstream and another opening facing downstream. The downstream opening merely senses static pressure in the pipe, while the upstream opening senses total pressure (velocity pressure plus static pressure). The resultant difference in total pressure versus static pressure forces a movable indicator up inside a vertical measuring tube that has markings for associated flow. This type becomes easily plugged and requires frequent cleaning. It is the least accurate type of flow sensor.

Pressure Differential Style

The pressure differential sensor can consist of an orifice plate with tubing connections on each side of the plate, or it can consist of a tube extending across the interior diameter of the pipe. This tube has two chambers, one on the upstream and one on the downstream side of the tube, each with a single opening or multiple openings spaced across the interior diameter of the pipe. The attached display measures the total pressure on the upstream side of the sensor and subtracts the static pressure on the downstream side to arrive at a resultant velocity pressure, which is converted to flow based on the interior diameter of the pipe.

Paddle Wheel Type

The paddle wheel sensor measures the spinning rate of a paddle wheel inserted in the flow stream. This rate of rotation is converted into velocity and, based on the pipe's interior diameter, gallons per minute. The rotational speed of the paddle wheel can be measured by pulses or magnetically, depending on the manufacturer. With the magnetic type, metallic particles present in the pool water can build up on the sensor and restrict rotation.

Magnetic Sensors

A magnetic sensor can be used in situations where the piping configuration only contains sufficient uninterrupted straight runs of pipe on the dirty side of the filter, or in a section of pipe that is within the pre-coat loop for a DE filter. Since the signal is magnetic and doesn't require a paddle wheel or orifice that could become plugged, these sensors work well for such applications.

Installation Parameters

If at all possible, flow-measuring devices should be installed in the relatively clean water downstream of the filter. In DE systems, they should be outside of the pre-coat loop, unless a magnetic type sensor (listed above) is used. Each manufacturer has specific requirements regarding placement on the pipe. They also recommend the number of pipe diameters of straight, uninterrupted flow upstream and downstream of the sensor. This is intended to ensure that the sensor is measuring uniform turbulence and can achieve its maximum accuracy.

Most codes, regardless of the manufacturer's recommendations, have their own minimum requirements for straight, uninterrupted flow upstream and downstream of the sensor. Since the local board of health most likely is the AHJ in these designs, its prescribed minimums are the ones that must be met.

Pressure differential sensors are problematic when used on installations where the equipment room is above the pool level. They are designed to respond to a difference between the total pressure and the static pressure. If water is siphoning back to the pool, as usually the case in these installations, a vacuum will be on the downstream side of the sensor instead of a measurable static pressure. As such, accuracy under these conditions is totally compromised.

Flow Control Devices

Since all commercial pools have a requirement for minimum turnovers per day (flow rate) and since pumps must be selected for the worst-case scenario of a dirty filter with maximum pressure loss through the filter, some means must be provided to control the flow output of the pump. If the filter is clean, thus placing little or no restriction on pump discharge, the flow through the filter may exceed the acceptable filter media rate, which will result in inefficient filtration.

Manual Butterfly Valves

Manual butterfly valves are disc-type valves with either a lever handle with 10 position stops or a gear-operated drive with either a chain (for valves positioned at high elevations) or an extended operator (for valves in a pit or not easily accessible).

Figure 6-11B depicts a butterfly valve using PVC as the body and disc for better chemical resistance. Figure 6-11C shows a butterfly valve with a polyester-coated cast iron body, nylon II-coated ductile iron disc, and a 416 SS stem. All of these materials are intended to make the assembly impervious to chemicals present in the pool water. The use of the type of valve shown in Figure 6-11A will be described in the section covering level control systems.

Both the PVC and cast iron valves employ EPDM seats for bubble-tight closure. Of the two, the cast iron will probably hold up better to frequent use and/or rough handling.

Diaphragm-actuated Valves

A diaphragm-actuated valve is very accurate in controlling flow. The large weir allows for minor flow adjustments with only a slight movement of the hand wheel, which controls the movement of the diaphragm. The body and bonnet of the valve are solid thermoplastic, PVC, CPVC, PP, or PVDF. Diaphragms are made of EPDM or Teflon with EPDM backing. The valve design is excellent for throttling of corrosive fluids, since only the body and diaphragm are wetted parts. They also provide bubble-tight closure, even in slurry applications or flows with suspended particles.

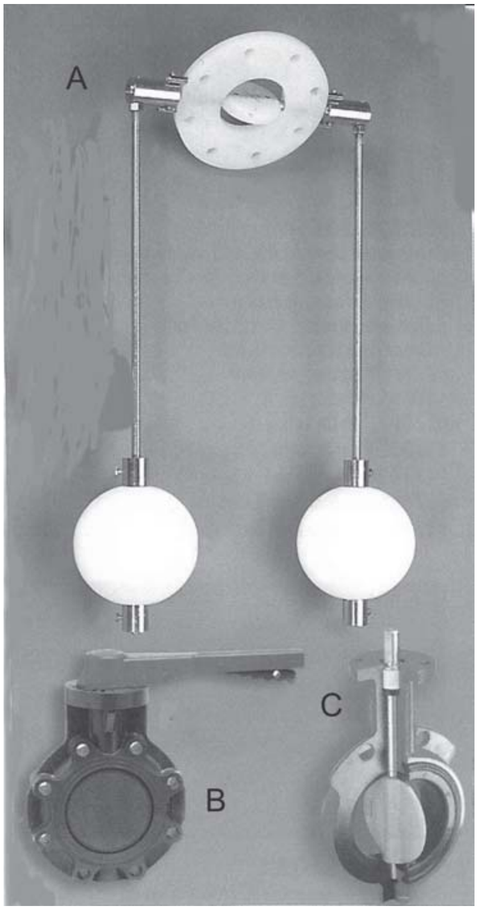


Figure 6-11 Flow Control Valves

Variable-frequency Drives

Though not commonly found on past swimming pool applications, VFDs are slowly gaining popularity, as dramatic energy savings can be realized through their use. The pump Affinity Laws provide the engineering verification of this. With a VFD, the rotational speed of the circulation pump can be slowed when system head requirements are at their lowest (i.e., clean filter, clean hair strainer conditions). Rather than closing a valve to reduce the flow to the design flow, the speed of the pump can be slowed while still maintaining the minimum turnover rate to the pool. As the pump performance is always designed well above the required duty point, use of a VFD offers the potential for substantial speed reduction.

The pump Affinity Laws show the cubed relationship between speed and power:

- $BHP_2 = BHP_1 \text{ x } (S_2)^3 \div (S_1)^3$
- $BHP_2 = BHP_1 \text{ x } (0.80)^3 \div (1.00)^3$
- $BHP_2 = 0.512 \text{ x } BHP_1$

As shown in the calculation above, a mere 20 percent reduction in speed lowers the pump power requirements by almost 49 percent compared to the power the pump would require using a standard across-the-line motor starter. Also, reduced demand charges are incurred when the pump is started gradually (soft started) by the VFD. The demand spike created by the lock-rotor-amp draw inherent with a standard motor starter is not experienced. The resultant system performance when a VFD is employed is sometimes even more appealing than the expected energy savings. The soft start and gradual ramp down during start and stop operations reduce wear and tear on the system components.

Care must be taken when implementing a VFD as a system component. For instance, if the pump selection is marginal, the pump may need to run at or near 100 percent. At this operating point, the use of a VFD will actually result in a higher operating cost due to some minor power transmission losses associated with the circuitry of the VFD. Other system pressure concerns also must be evaluated. Simple solutions to these potential operational problems are available, but they must be dealt with in the initial design stages of a project.

Pool Water Heating Systems

One component of virtually all swimming pools is a system for heating the pool water. In rare cases, the owner may consider this an expensive, unnecessary luxury, but instances of this are rare.

Temperatures generally are maintained in the range of 78–84°F (25.6–28.9°C) and sometimes higher when the facility has an older clientele with many water aerobic classes. Most heater manufacturers provide a general selection criteria table, which can be used to estimate the British thermal unit (Btu) output desired, regardless of the type of heating system chosen.

This method of selection is basically intended to offset an expected average heat loss and is more directed toward maintaining temperature in the pool water. If the Btu output selection is based on how long it will take to heat a total volume of fresh water from the source water temperature to the operating temperature (ΔT), the required Btus must be calculated using the following equation.

Equation 6-1

$$\text{Btus required} = \text{Pool gallons} \times 8.33 \times \Delta T \div \text{System efficiency (percent)}$$

This is usually the method used for hot tub heater sizing. If the desire is to reheat a tub full of water within two hours, divide the calculated Btus required by two to arrive at the Btu per hour (Btuh) output for the heating system.

Another area of consideration when designing the water heating system is providing for the ability to flow the correct amount of water through the heater's tube bundle. Many heaters are provided with integral booster pumps; others are not. The goal, especially on outdoor pools at initial startup, is to produce an optimum temperature rise across the tube bundle. On startup, if the pool water is cold (50–55°F [10–12.8°C]) and the flow through the tubes is too high, condensation on the tube bundle will occur, and sulfuric acid will form. This will quickly shorten the life of the tube bundle and even the burners.

Maintaining optimum inlet water temperatures is greatly facilitated by the use of a VFD. With proper heater by-pass piping and the implementation of a heater booster pump, the heater manufacturer's required inlet temperature can be effectively maintained. Once the pool is at the desired temperature, the pressure and water flow at the suction side of the heater booster pump will remain constant. With the heater firing, a one-time adjustment to the mix of heated water and the pool water being heated can be made to attain a desired inlet temperature. That setting will never change and will ensure a noncondensing situation for the tube bundle.

Direct-fired Gas Heaters

If space is available in or near the pool equipment room, a dedicated gas-fired pool water heater may be used. Two choices are available.

The atmospheric gas-fired heater uses the ambient air from the area in which it is installed for its combustion air needs. Manufacturers of these units have stringent requirements regarding the sizing of air-admittance louvers or grilles serving the operating space. If this type of heater is installed in the pool equipment room, the combustion air may contain high levels of chemicals or corrosive fumes, which obviously will have a detrimental effect on the longevity of the heater. In a sealed combustion gas-fired heater, combustion air is outside air, drawn into the heater by an integral fan. Exhaust gases are evacuated outside of the building by the same fan or a supplemental fan. These units are often rated at high efficiencies, since the exhaust fan can move cool exhaust air out through the vent pipe before any condensation occurs.

Indirect Heating

Often, a dedicated pool heater or boiler will heat a primary water source and pass it through an enclosure that has a secondary coil or tube bundle immersed in the boiler water, which carries pool water. The heat transfer between the two raises the pool water temperature.

These heat exchangers are required by code to be of double-wall construction. The intermediate space must be drip-vented to atmosphere to prevent the intermingling of pool water and boiler water, which may contain unwanted boiler treatment chemicals. In consideration of the pool water chemistry, the more expensive cupro-nickel tubes are worth the additional cost versus life performance characteristics.

Central Heating Boiler

The only difference in the central heating design choice is the lack of a dedicated boiler or direct-fired heater for the pool system. Water from a central boiler is used as the primary loop supplying a heat exchanger for the pool. This will require the boiler system for the whole building to be in operation whenever the pool is in use.

If a central boiler is the main component of the pool water heating system and there are substantial periods when the pool is the only system requiring operation of the boiler, a supplemental system should be considered. An electric heater, piped in parallel with the heat exchanger, is an option. With an electric heater in place, the central boiler can be shut down while the electric heater maintains the pool water temperature.

Dehumidification and Heat Recovery Systems

Maintaining air quality in an indoor pool facility can be quite difficult, yet it is essential to the comfort of the patrons.

The HVAC engineer should try to bring in as much outside air as possible. Humidity must be maintained at an acceptable level to reduce any impact high humidity might have on the building structure and ceiling components. If there are large window areas, excessive humidity will cause condensation and possibly damage the window casings.

Using a refrigerant loop to capture the heat of condensation from exhausted air provides some supplemental heating possibilities. The captured heat can be used to preheat incoming outside air if needed, or it may be used to assist in pool water heating.

Using these systems with a dedicated gas-fired pool heater or in conjunction with a heat exchanger can present some difficult control decisions. Which system will do the primary heating? Will each system have a different temperature control point? Will the heat recovery unit merely be a backup, or will it be used only when the central boiler isn't in operation?

Dehumidification and heat-recovery units are commonly used in current pool design. However, they may present high maintenance costs. The air passing through the heat-recovery or dehumidification coil can be quite corrosive. Special materials should be used for these coils, or the coil should have a special corrosion-resistant coating applied.

These are expensive systems with the potential for substantial repair costs, yet they offer some energy-saving benefits. It is recommended that the pool designer do a thorough psychometric evaluation of the particular installation and make an informed cost/benefit evaluation.

Chemical Control and Feed Systems

The owner or operator of any commercial or public swimming pool is expected to maintain a safe environment regarding water quality. The water environment that is shared by the patrons must be clear and free of debris and contain no bacteriological contaminants. To ensure this safety factor, codes place minimum requirements regarding oxidizer/sanitizer levels in the pool water, as well as a proper range in which the pH of the water must be maintained. In all but extreme cases, these levels provide proper bacteria kill as well as help maintain water clarity.

Proper pH and Sanitizer Levels

Typical sanitizer levels and pH ranges can be found in APSP publications as well as NSPF textbooks. These ranges are as follows:

- Pool sanitizer levels: 1–5 parts per million (ppm) when some form of chlorine is used as the sanitizer/oxidizer and 4–5 ppm when bromine is used as the sanitizer/oxidizer
- Pool pH levels: 7.2–7.8 pH (acceptable), 7.4–7.6 pH (ideal)
- Whirlpool and hot tub sanitizer levels: 2–3 ppm when chlorine is used and 4–5 ppm when bromine is used

Many people do not recognize the importance of maintaining pH in the proper range. In fact, the pH of the water is the primary factor in determining the killing power of the chlorine. When any type of chlorine is dissolved in water, it forms hypochlorous acid (HOCl), which is the most active form the dissolved chlorine can take. HOCl is a strong oxidizer/sanitizer, but the pH of the water is the determining factor for how much of the dissolved chlorine remains as HOCl. Hypochlorous acid easily disassociates into a hypochlorite ion (OCl-) and a hydrogen ion (H+), and this disassociation is much greater at a higher pH. The hypochlorite ion is still an oxidizer/sanitizer, but it is considerably weaker than HOCl. Thus, at a higher pH, less of the chlorine in the pool water is in the strong hypochlorous acid form.

For example, at a pH of 8.0, it will take a residual of 3 ppm of free chlorine to have the equivalent killing power that 1 ppm of free chlorine has at a pH of 7.4. This merely emphasizes the fact that just as much attention must be paid to the output capabilities of the acid or pH adjustment systems as is paid to chlorine feed systems. If proper pH control cannot be maintained, the sanitizing characteristics in the pool water cannot be effectively controlled.

Water Balance

Water balance is based on a combination of factors. It is a measurement of five primary chemical levels that determine whether the pool water is scale forming (oversaturated) or corrosive (undersaturated). The Langelier Index is the most common calculation used to determine this.

Water is the universal solvent. It will try to dissolve anything it comes into contact with until it becomes satisfied (saturated). At this point, any additional solids introduced into the solution cause it to become oversaturated. These solids eventually will settle out or form layers of calcification on the surfaces or components of the circulation system. This calcification can degrade system performance, and oversaturated water also affects water clarity. Undersaturation, or corrosive conditions, can also degrade performance as well as destroy the pool's structure (i.e., tile, grout) and metallic system components.

All of these factors point out the importance of maintaining proper water balance. The chemistry of the fill and makeup water of any facility should be examined. It can be a major factor in determining the proper chemical feed system to use.

Choosing Proper Control Chemicals

The chemistry of the source water at a potential pool location should be examined to see if it could impact a decision on the type of control chemicals to use. If the fill and/or makeup water is essentially balanced, almost any of the various sanitizer/oxidizer and pH-adjustment systems can be used. Balanced water would fall within the following ranges:

- Total alkalinity: 80–120 ppm
- pH: 7.2–7.8
- Calcium hardness: 200–400 ppm
- Total dissolved solids: <1,000 ppm

Gas chlorine is seldom used in new designs. The acceptable sanitizers/oxidizers are primarily chlorines (stabilized or unstabilized) and bromine. Lithium hypochlorite is sometimes suggested by various suppliers but is seldom used. Its relatively low active strength (29 percent) and high cost relegate its use primarily to backyard pools, where it is ideal for use on vinyl-liner pools.

Acid is used to lower pH; soda ash (calcium carbonate) is used to raise pH. The available common acids used are muriatic acid (dilute hydrochloric acid) and sodium bisulfate. Sometimes carbon dioxide is used. When carbon dioxide is injected into the return water, it forms carbonic acid (a weak acid).

Where high total alkalinity is present or when designing an indoor pool facility, care should be taken when considering carbon dioxide for pH control. Since carbon dioxide raises alkalinity when injected into the pool water, it would potentially make an existing total alkalinity problem worse. High total alkalinity encourages high pH levels, and more acid (carbonic acid) is needed to offset this. The required feeding of more carbon dioxide results in even greater increases in alkalinity levels.

Source water with high calcium hardness levels, more than 400 ppm, presents similar difficulties, and using calcium hypochlorite as the sanitizer/oxidizer may compound the problem. It may be necessary to consider sodium hypochlorite as the sanitizing and oxidizing agent.

Other factors to consider are the different effects the unstabilized chlorine products can have on water balance and the need for pH adjustments. Calcium hypochlorite has a pH of approximately 10 when dissolved in water; sodium hypochlorite (a liquid) has a pH of approximately 13. This higher pH can require almost twice the amount of acid used for pH control. Sodium hypochlorite also introduces approximately two times more total dissolved solids (TDS) into the pool water. Most codes limit the amount of total dissolved solids in pool water to a range of less than 2,500 ppm (sometimes as low as 1,500 ppm). Another common criteria is to maintain TDS no greater than 1,500 ppm over the TDS of incoming source water.

Stabilized chlorines are chlorine products that have been combined with a stabilizing chemical (cyanuric acid). The available choices are trichlor (trichloro-s-triazinetrione) and dichlor (dichloro-s-triazinetrione), which are chlorine products that have been chemically combined with cyanuric acid. The addition of cyanuric acid (also called stabilizer or conditioner) is used to reduce the amount of chlorine burned off by the ultraviolet (UV) rays of the sun striking the pool water. Since indoor pools are seldom faced with a problem of excessive sunlight conditions, these stabilized products are normally recommended only for outdoor pools and are sometimes not allowed by code for indoor applications.

The use of stabilized chlorine can, over time, result in the buildup of high levels of cyanuric acid in the pool water, and the cyanuric acid does not degrade. It remains in the pool until it is backwashed away or splashed out. Most codes limit the level of cyanuric acid to 100 ppm because levels exceeding 30 ppm substantially limit the time it takes for the chlorine residual in the pool to oxidize the contaminants or kill bacteria, which can lead to unsafe conditions.

These concerns are frequently enough to relegate the isocyanuric chemicals to private backyard pools because the patron loading on these pools is substantially lower than any commercial facility. Instead of using stabilized chlorines, calcium hypochlorite or sodium hypochlorite with the manual addition of a small amount of cyanuric acid to the pool will have a reasonable resistance to UV degradation. This can be done at a much lower chemical cost and without the unwanted buildup of cyanuric acid.

The final consideration regarding pH control is the effect that the adjustment chemical used can have on the longevity of the mechanical equipment. The strongest form of acid used in the pool industry to lower pH is muriatic acid. If feed equipment handling muriatic acid is not sealed properly, the fumes emanating from the acid will rapidly destroy or corrode all metal components in the equipment room.

Chemical Controllers

Automatic water chemistry controllers have become the norm on almost every design of a new pool facility or the upgrade or retrofit of an older system. Some codes only require controllers on pools; others require them on pools and hot tubs.

Numerous choices are available. Low-cost controllers simply measure pH and oxidizer/sanitizer levels and then send power to the associated feed equipment to bring either back into the proper range.

Most controllers measure these chemical levels through the use of measuring probes immersed in a stream of filtered pool water or in a larger sample cell with pool water flowing through it. These probes produce a millivolt signal, which is the feedback to the controller that allows that control device to maintain proper pH and chlorine levels. The millivolt output of the pH probe is directly related to the pH level of the pool water. The chlorine or bromine level is not given directly by the probe.

The probe measuring the chlorine or bromine level is actually measuring how active the sanitizer is, not the quantity of it in the pool water. This activity is defined as oxidation reduction potential (ORP). In other words, the probe is measuring the potential of the sanitizer for oxidizing contaminants.

As was discussed earlier in this chapter, changes in pH levels affect the activity of chlorine. The controller can only control to an ORP set point, measured in millivolts. If pH rises, the ORP of the chlorine (i.e., the millivolt signal from the ORP probe) decreases. As a result, the controller will turn on the chlorine feed system, often when the chlorine level is actually in the desired range. This relationship reinforces the premise that pH is equal in importance to chlorine in maintaining safe water conditions. High pH results in weak chlorine; low pH results in the controller underfeeding chlorine on a ppm basis.

Other controllers that are programmable actually control to a ppm set point. This type of controller uses curve fitting (high-end floating-point math) to calculate ppm based on standard ppm curves on a pH versus ORP axis provided by the manufacturer of the probe.

The last type of automatic controller treats pool water samples on an intermittent schedule with test chemicals. It then compares the color of the sample to a standardized series of colors and determines pH and chlorine levels directly. This type of controller requires regular replenishment of the test chemicals.

In general, more complex controllers have a higher initial cost. Controllers with unnecessary bells and whistles may require frequent service calls and related service costs. This should be considered when trying to design an operator-friendly system.

pH Control Systems

There are two distinct systems for controlling pH. Chemical feed pumps can be used to pump some form of acid to lower pH. The same style of pump can also feed soda ash to raise pH, if that is what the pool requires.

Typically, if using sodium hypochlorite (a liquid sometimes incorrectly referred to as bleach) or calcium hypochlorite (a dry chemical that is mixed with water) as the oxidizer/sanitizer, acid would need to be used as the pH control chemical. Sodium hypochlorite has a pH of approximately 13, and calcium hypochlorite has a pH of approximately 10. Obviously, using these products to maintain proper sanitizer residuals would increase the pH of the pool water.

The other system that is sometimes employed to lower pH is a carbon dioxide feed system. The carbon dioxide gas is injected into the water returning to the pool, and it forms carbonic acid when dissolved in the stream of water. Carbonic acid is weak, but it will effectively lower pH.

Acid Feed Pumps

Two basic types of chemical feed pumps are used on pool systems. They each have advantages and disadvantages.

Peristaltic pumps use a motor-driven series of rollers that rotate in an enclosed pump head, and as the assembly rotates, it squeezes a feed tube. This creates a vacuum on one end of the tube, which allows atmospheric pressure to push the acid solution into the evacuated area of the feed tube. The next roller then forces that solution toward the other end of the tube and creates a new evacuated area of tube in its wake.

In the past, there were concerns that the pressure developed by peristaltic pumps (usually no more than 25 psi [172.4 kPa]) might be insufficient for injecting chemicals into the circulation system. However, this is seldom true. Chemicals must be injected downstream of all system components, such as heaters, heat exchangers, and dehumidification equipment. At that area of the return piping, the only back-pressure or system head remaining is merely due to elevation head, small return pipe and fitting losses, and friction and discharge losses through the filtered water inlets. It is seldom more than 7–10 psi (48.3–68.9 kPa). In cases where pressures greater than 25 psi (172.4

kPa) are expected, some peristaltic pumps can create output pressures as high as 100 psi (689.5 kPa).

These are relatively inexpensive pumps. The internal components don't usually have a long life expectancy, but they are not costly to replace. The only other concern is that peristaltic pumps must be placed close to the acid solution holding tank. The weak vacuum that they create does not allow for long suction tubing runs.

The other type, the diaphragm pump, uses a rotating cam to move a diaphragm in an enclosed housing. Check valves are used on both the suction and discharge sides of the diaphragm enclosure.

The rotating cam controls the inward and outward movement of the diaphragm. When the diaphragm moves outward, a vacuum is created in the enclosure. This vacuum closes the discharge check valve and opens the suction check valve. Thus, the outward motion allows the chemicals to be drawn from the solution tank. The inward movement of the diaphragm has the opposite effect: Pressure is created in the housing. That pressure closes the suction check valve and opens the discharge side to allow chemicals to be pumped into the piping system.

As many as four check valves can be used with this type of pump. If the chemical being pumped is prone to calcification or particulate buildup, frequent cleaning is required. If sediment impairs the operation of the check valves, pumping will cease.

These pumps usually create pressures in excess of 100 psi (689.5 kPa). Caution must be taken to ensure that the check valve, usually installed at the chemical injection point into the circulation piping, doesn't become blocked. If the diaphragm pump becomes dead-headed, the resultant high pressure in the feed tubing can cause it to burst.

Carbon Dioxide Feed Systems

Carbon dioxide has become an alternate choice for lowering pH. When it is injected into the circulation system, it forms carbonic acid. It also has a tendency to increase total alkalinity in the pool water. If the makeup water for the pool already has high total alkalinity characteristics, carbon dioxide may not be a good choice for pH control.

Carbon dioxide comes in 50-pound (23-kg) or 150-pound (68-kg) high-pressure tanks. For large facilities or especially for outdoor pools, permanent installation of 750-pound (340-kg) tanks can be employed. These are usually set up to be refilled from outside the pool building.

In general, a gas-control electric solenoid is used to regulate the flow of the carbon dioxide gas. The solenoid is most commonly connected to an automatic water chemistry controller. Some system manufacturers use a side stream with a venturi and possibly a booster pump to create a vacuum to assist in drawing in the gas and dissolving it in the return water.

Carbon dioxide is heavier than air. It is best located in a separate, force-ventilated area. The vent fan pickup should be positioned near the floor.

Sanitizer/Oxidizer Feed Systems

Feed pumps are used when the oxidizer/sanitizer chemical is in a liquid form. This can be sodium hypochlorite (sold as a liquid), a dry calcium hypochlorite, or granular dichloro-s-triazinetrione (dichlor) dissolved in water. The pumps used for feeding chlorine solutions are the same as those indicated earlier for pH-adjusting acid feed systems. However, since acid solutions do not generate calcium carbonate (calcification) and do not contain insolubles or sediment, the working parts of the pump operate in a much cleaner environment. Chlorine solutions are much more prone to sediment and calcification concerns. This should be considered when deciding on the type of pump to use.

Erosion feeders are used where the control chemical is manufactured in a tablet or briquette form. The briquettes or tablets are dissolved by either a flow of water across their surface or contact with a water spray. The feeder can be either atmospheric or pressurized. NSF International requires that only the chemical product prescribed by the manufacturer be used in a given feeder. This mandate is directly related to concerns about mixing different chemicals, as well as maintaining NSF-verified feeder output capabilities (pounds per day of available chlorine).

Calcium hypochlorite is often manufactured in a tablet or briquette form and has to be dissolved in some manner. Several types of these systems are available. The feeder can be installed in a side stream, with or without a booster pump. The design can be as simple as a flow-through device or a more complex spray device with a venturi and booster pump. Overflow protection is usually provided as part of the feeder design. Most codes require a certain output capability, in pounds per day based on the gallons in the system being treated. This will be the determining factor for specifying feeder sizing.

The stabilized chlorine product trichloro-s-triazinetrione (trichlor) is introduced into the pool using a pressurized feeder. The feeder is filled with the trichlor tablets and then sealed. When pool water flows through the feeder, the tablets dissolve. Trichlor feeders are usually installed in a side stream with isolation valves. Feed of the chemical can be accomplished by manually opening the isolation valves or by using a normally closed solenoid on the influent side of the feeder. Use of a solenoid requires an automatic water chemistry controller to be part of the system. The solenoid is opened by the automatic chemical controller when it senses a drop in chlorine residual. If

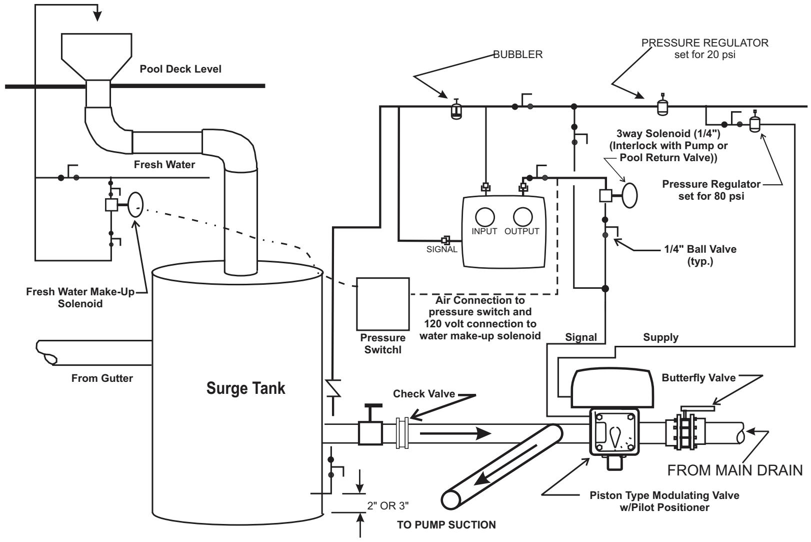


Figure 6-12 Differential Pressure Controller Detail, Piston-actuated Butterfly Valve with Pilot Positioner

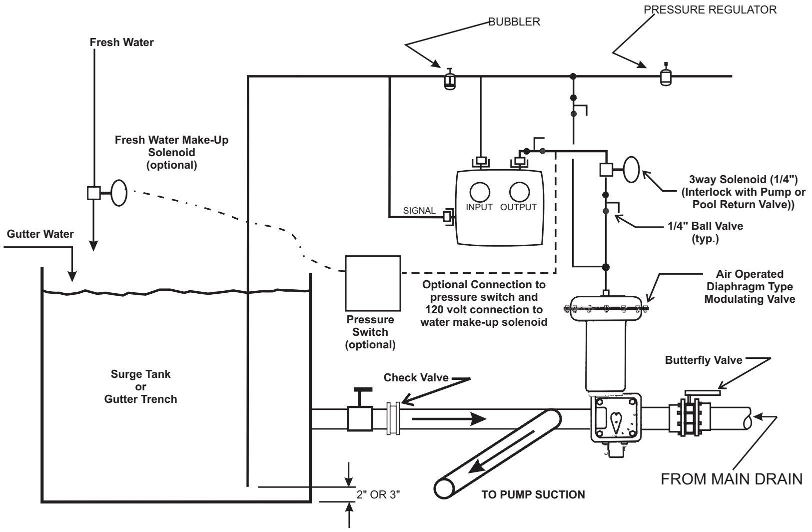


Figure 6-13 Differential Pressure Controller Detail, Diaphragm-actuated Butterfly Valve

trichlor is selected as the oxidizer/sanitizer, there are some concerns regarding buildup of stabilizer in the pool water. As more and more trichlor is fed to replace what is used for sanitation purposes, the stabilizer remains and builds to higher ppm levels.

Automatic water chemistry controllers rely on the millivolt signal from the ORP probe for feedback regarding chlorine levels in the pool water. High stabilizer levels cause inaccuracies in the output of the ORP probes.

Elemental bromine is a heavy reddish-brown liquid. In its elemental form, its use is no longer allowed by U.S. Environmental Protection Agency regulations. Thus, bromine, when used as a spa disinfectant, must be provided in some other form. One form is sodium bromide activated by potassium monopersulfate (an oxidizer). This two-part system is not used on commercial systems, so it is mentioned here for informational purposes only. The second means of introducing bromine into the pool water is by use of an erosion feeder. The pressurized feeder is filled with bromine tablets. The flow-through feeder is installed in a side stream, with isolation valves and possibly a solenoid. The solenoid is only used if an automatic water chemistry controller is part of the system.

Pound for pound, bromine is a much weaker sanitizer/oxidizer than chlorine. It requires approximately 2.25 times more bromine to achieve the same oxidation and sanitation results available with chlorine use. Its main advantage is that it is less prone to degradation due to high water temperatures. For that reason, bromine is often the choice for hot tub and whirlpool applications where 104°F (40°C) temperatures are the norm. If heavy user loads are expected, chlorine, due to its greater oxidizing and sanitizing properties, may still be the proper choice.

Level Control Systems

Some method is needed to maintain a proper level in the surge tank, primarily for pump protection. If the level in the surge tank drops too low, vortex conditions will occur, and the resultant cavitation can damage the pump.

Float-operated Main Drain Butterfly Valve

The float-operated main drain butterfly valve is the simplest form of control (see Figure 6-11A). The main drain pipe is connected to the surge tank, and this valve is installed on the end of that pipe between a set of flanges. As the level drops in the surge tank, the floats drop, allowing more water to flow from the main drain. As the level rises, the main drain is restricted, which results in a higher percentage of circulated water being taken from the top of the pool (not a very accurate means of level control). The surge tank usually ends up at an operating level near the top, with little room for acceptance of actual surge. This is due to the fact that this type of valve is only capable of 80 percent closure.

Pneumatically Operated Main Drain Modulating Valves

Pneumatically operated main drain modulating valves are butterfly valves with either a diaphragm-driven actuator or an air-operated piston actuator. They require some type of control device, which will constantly reposition the butterfly valve disc based on level changes in the surge tank. They are primarily installed on the main drain line. The use of these valves does not require the main drain to be piped into the surge tank. Remote devices measuring the level in the surge tank provide the feedback needed for valve positioning.

The diaphragm-driven type of modulating valve uses a large diaphragm, with pressure applied to one side. The other side of the diaphragm is connected to linkage that moves the disc of the butterfly valve. The pressure source can be either water or a pneumatic air system. If water is used, the controller is a simple float assembly controlling city water or pump discharge pressure.

The piston type with pilot positioner has a piston in a chamber. When air pressure is introduced into one side of the chamber, the piston strokes away from that increased pressure. Linkage attached to the piston changes the position of the disc of the butterfly valve. The actual stroke of the piston is controlled by a pilot positioner that responds to a feedback control signal from the level control device. These are two separate air signals. One air connection merely provides the power to move the piston against system pressure. The other lower-pressure signal is the control signal that tells the pilot positioner how far to move the piston.

Differential-pressure Controller

Using pneumatic air, a differential-pressure controller is an extremely accurate way to control the surge tank level. It is sometimes referred to as a "bubbler" system. As the level rises in the surge tank (a mere quarter-inch), the controller begins to close the main drain modulating valve. If the level continues to rise, the valve may close completely, allowing the flow of water from the top of the pool (where all of the contaminants are being introduced) to be the first through the filtration and chemical treatment systems.

When bathers leave the pool, the pool level will drop below the lip of the gutter. This is because the swimmers displaced water from the pool into the surge tank. Since the main drain modulating valve restricts the main drain flow until the predetermined surge operating level is achieved, the surge water will quickly be sent from the surge tank back to the pool. In this way, skimming action will quickly resume. (See Figures 6-12 and 6-13.)

Fresh Water Makeup

Commercial pools are required to maintain a level where skimming action occurs continuously, which requires the maintenance of sufficient water in the system to offset splash out, evaporation, or any other water losses (leaks).

If there is no means provided for automatic freshwater makeup, the operator will be required to regularly monitor the water level. The simplest form of water level control is for the operator to manually open a water fill valve. The fresh water will usually be discharged from the fill pipe into a surge tank or balance tank with the required air gap. If fill water is directly connected to the circulation system, some form of backflow prevention must be employed.

Level-sensing System with Electric Solenoid

A level-sensing system can be used when automatic water makeup is desired. Numerous control systems are available.

The electronic sensor type of controller requires a reflecting line from the body of water being measured and whose level is being maintained. An encapsulated electronic sensor, connected to the controller, is positioned at the operating level desired. When the water drops and the sensor comes out of contact with the water, the controller sends voltage to a slow-closing electric solenoid that opens and allows fresh water to be added. A time delay is built in before solenoid actuation to limit short-cycling.

The stainless steel probe system is a set of three probes used to measure water level. A reflecting line is also required for this system. The probe module is mounted on the top of the reflecting line, with the probes extending into the water. When the level drops below the medium-length probe, the freshwater solenoid is energized. When the level rises and touches the shortest probe, freshwater fill is discontinued. The difference in length between these two probes determines the sensitivity of this system. If the difference in length is not enough, short-cycling will occur.

Pneumatic

The action of this control system was described under "Pressure Differential Control System." The combination of the air pressure signal to the modulating valve and an adjustable 120-volt pressure switch controls the freshwater makeup solenoid.

When the flow from the pool gutter diminishes, the level in the surge tank begins to drop. In response to this, the pressure-differential controller increases its output pressure to the main drain modulating valve. This allows flow to increase from the main drain piping to make up for the reduction in gutter flow. In this way, the desired surge tank operating level can be maintained.

If skimming action continues to decrease and the controller must continue to increase pressure to the main drain valve, the set point of the adjustable pressure switch will be reached, and it will send power to the electric solenoid to begin freshwater makeup. This is the most accurate means of controlling the total volume of water in the system (pool plus surge). For piping details, see Figures 6-12 and 6-13.

SPECIALTY SYSTEMS

Supplemental Sanitation and Oxidation

In general, the use of a proper oxidizer/sanitizer and pH-adjustment chemicals should be all that is required to maintain a safe swimming environment. For a swimming pool chemical treatment strategy, less is better. While a preponderance of unproven products are on the market, some technologies have possible merit.

Ozone Systems

Ozone is a gas that is heavier than air. It is a very strong oxidizer and bactericide. Since it is very unstable, it must be produced on site. Two methods are used for the production of ozone: corona discharge and UV. Of the two, corona discharge is more applicable to large commercial systems. The lower output of UV ozone units relegates them to small systems or hot tubs.

Ozone gas is usually drawn into the water and dissolved through the use of a side stream off the main circulation system. Since ozone is quickly used up in the oxidation process or converts back to oxygen due to its short half-life, it cannot be used as the primary sanitizer/oxidizer. It must be used in conjunction with one of the other oxidizers/sanitizers that leave a residual in the pool water.

Ozone is a supplemental system. Its use is not required on every pool design. However, on systems such as an indoor facility with multiple pools and water features, it can be a beneficial addition. The heavy bather load experienced at these venues overtaxes the usual water treatment resources. The buildup of objectionable combinations of organic and inorganic materials locked up with the chlorine will rapidly result in unsatisfactory ambient air and water conditions. The addition of a properly sized ozone-generating system can totally eliminate this problem.

The corona discharge ozone system consists of several components. An oxygen concentrator preps the air entering the ozone generator. A side stream off the main return piping, along with a booster pump and venturi, is used to create a vacuum that draws the ozone from the ozone generator and injects it into the side-stream flow.

The water is then piped into a contact chamber. The contact chamber is sized to allow approximately four minutes of contact time between the water and the dissolved ozone. By the time this flow leaves the contact chamber, the ozone has been depleted either through the oxidation and sanitation processes or by reverting back to its basic form of oxygen.

Any ozone gas that bubbles out of solution in the contact chamber is vented out the top of the chamber through an automatic air vent and flows to an ozone destruct unit. The contact chamber and automatic air vent ensure that no ozone remains by the time the ozone side stream mixes back into the circulation system return flow. This protects pool patrons from any undue exposure to ozone.

The installation protocol is quite straightforward. Essentially, the side stream ties in right after the filter at the point of highest remaining system pressure. The side-stream flow is then assisted by the booster pump through the venturi into the contact chamber and reconnected to the main circulation flow after the pool water heater and before any other chemical injection. For details, see Figure 6-14.

UV Systems

In contrast to UV ozone systems that pass air over an ultraviolet bulb, sanitizing UV systems immerse an ultraviolet bulb into the full flow of water returning to the pool. A fine strainer screen is required downstream of the bulb to limit the amount and size of glass particles that might flow into the pool if the bulb shattered. The UV contact cell is piped, full size, into the return piping. Thus, every gallon of water circulated passes through the UV rays on the way back to the pool or water feature.

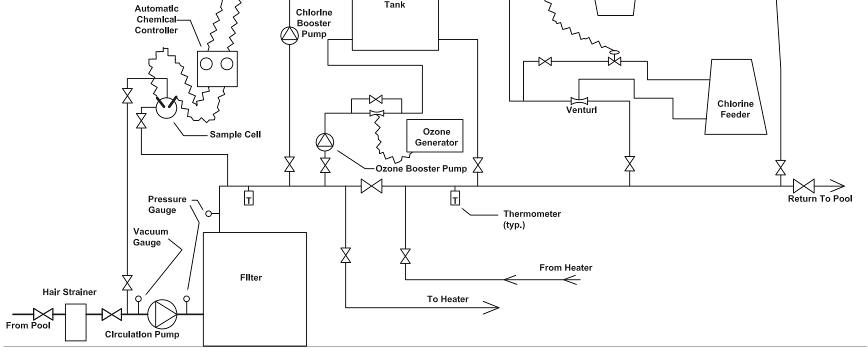


Figure 6-14 Complete System Piping

UV radiation alters the molecular structure of compounds that experience sufficient exposure to the rays. The components remain in the water, only in an altered form. The DNA of most bacteria is changed, rendering most of them harmless. Despite the fact that written promotional material claims that UV has oxidation capabilities, that statement is untrue. Oxidation is a chemical process that requires an oxygen atom to be given up by the oxidizing agent to the material being oxidized.

The prime consideration here is contact time. For this exposure to UV to have the desired results, there must be sufficient contact time. At the velocities common in most circulation systems (8–10 fps), there is little exposure time for the UV rays to do their job.

On outdoor pools, the loss of chlorine from UV degradation caused by exposure to sunlight can be substantial. The same occurs with UV sanitizing systems. The UV will strip most if not all of the chlorine residual from the pool water passing through. This chlorine must be replaced on the way out to the pool; otherwise, the necessary residual won't be maintained in the pool. This chlorine destruction may cause the chlorine consumption of the facility to increase by 40–50 percent. Due to that fact and the cost to replace the UV contact cell bulbs every six to 12 months, these systems can be quite expensive to operate.

Another concern is that these systems place the UV disinfectant bulb in the stream of water returning to the pool. Because of the potential for bulb breakage, a fine stainless steel mesh screen is placed downstream of the UV bulb to limit the size of glass shards that might be pumped out to the pool. This UV disinfecting bulb contains mercury, and when replacement becomes necessary, it must be disposed of as a hazardous waste. With this potential for breakage, the designer should carefully consider if they are comfortable with even a small amount of mercury being present in the water exiting a pool inlet with a patron in the nearby water.

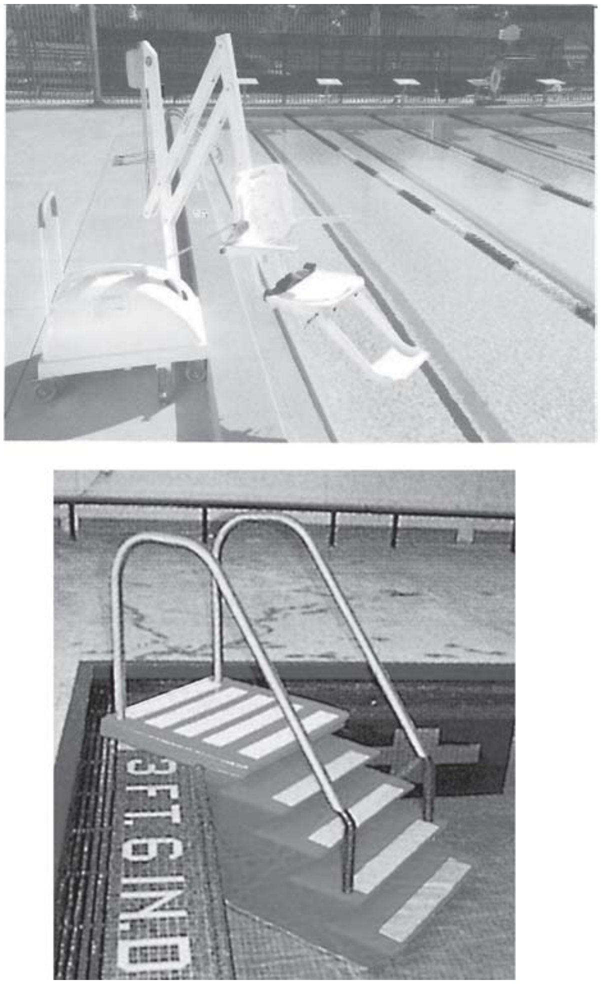


Figure 6-15 Handicapped Access

Water Features

Many different types of playground features—spray features, slides, flumes, vortexes, etc.—are available. See Chapter 5 of this volume for detailed information on their design. Following are some ideas on what should be considered when incorporating these into a pool design.

The primary concern is user safety. Will the structures themselves create tripping hazards on the pool deck or limit free movement around the pool deck? Can the area near the bottom of a slide or flume be kept free of bathers so patrons exiting the play feature will not strike fellow swimmers?

Will separate pumps be used for each feature? If so, from where will they draw their water? If it will be from the dirty water in the surge tank, how can the pump be protected against being plugged with debris? This same dirty water also has the potential to plug any play feature that incorporates small orifices for spray action.

If water will be drawn directly from the pool, the same dirty water concerns exist. An additional concern is protecting against possible hair, limb, or suction entrapment of the patrons. Some codes require the use of a vacuum breaker open to atmosphere through a sizeable pipe connection at pump suction. Exercise caution in the use of these, as many times they are adjusted improperly. If they are triggered inadvertently and the operator is not aware of an open connection at pump suction, cavitation over a long period may destroy the circulation pump.

If these water features are part of the design of an indoor facility, consider some type of sanitation of the water being atomized into the pool facility atmosphere. This can be a good use for ozone or other non-chlorine means of oxidation.

POOL SITE COMPONENTS

Ladders, Ramps, and Handicapped Access

Selecting and specifying ladders and ramps may fall under the responsibilities of the architect designing the pool structure. However, if the design assumes that a pool contractor will do the installation, these items may end up being included in the swimming pool section of the specification (usually Section

13150). Most ladders are made of stainless steel, with an outside diameter of 1.9 inches and a wall thickness of 0.065 inch or 0.109 inch. (0.145 inch is also available.) Recently, ladders and rails for access ramps with an outside diameter of the stainless steel tube of 1.5 inches have been introduced. This is purported to be more user friendly and possibly is soon to be recommended by American with Disabilities Act guidelines.

Handicapped access can be accommodated on rehabs of older pools by the use of portable stairs or battery-powered movable lifts. For an idea of how these systems look, see Figure 6-15.

Underwater Pool Lights

The majority of pool lights are wet niche-type lights, with the wet niche set into the concrete of the pool wall. The light has a long, sealed power cord that can be removed from the niche and lifted to the pool deck for re-lamping.

These lights can be 120 volt or 12 volt with a 120–12-volt transformer. The 12-volt lights are usually available with 300-watt bulbs; the 120-volt lights are available with 400-watt or 500-watt bulbs.

Pool Inlets

Inlets come in many forms. Adjustable floor inlets are shaped like a cone, tapering from the surface of the pool floor to the pipe connections. A movable flat disc with an adjustment screw moves in or out to change the volume of flow through the inlet. Wall inlets can be of an eyeball variety or merely a flat grate with the option of a flow-adjustment mechanism.

Some codes strictly restrict any wall inlets that stick out beyond the surface of the wall. This is to prevent injuring a patron who might slide down the wall. Other designs include hydrotherapy inlets used in hot tubs. Good design for all return inlets employs the use of some type of no-leak flange for pipe penetrations through the pool structure.

Safety Equipment

Safety items typically required are as follows:

- U.S. Coast Guard-approved ring buoys with 60-foot throw lines
- Approved first aid kit
- Life hook with pole
- Spineboard with head immobilizer, body straps, and wrist and ankle straps
- Test kit

ACKNOWLEDGEMENTS

- DE/Perlite Performance Test Data, Ken Bergstrom, President, Filtrex Inc.
- "Improving Bacteriological Safety: A Comparison of DE and Perlite," presented at The World Aquatic Health Conference, October 2009.

REFERENCES

- *Hydraulic Institute Standards for Centrifugal, Rotary, and Reciprocating Pumps,* 14th Edition
- Wisconsin Administrative Code, Table 6-1
- ASME A112.19.8 (2007): *Suction Fittings for Use in Swimming Pools, Wading Pools, Spas, and Hot Tubs*
- "Understanding the Virginia Graeme Baker Pool and Spa Safety Act 2007," *Plumbing Systems & Design,* September 2009.

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7

Gasoline and Diesel Oil Systems

This chapter describes the design, selection, and installation requirements for shop-fabricated atmospheric storage tanks and distribution and dispensing networks for new and replacement systems for liquid petroleum-based fuels. Although mentioned several times in this chapter, rail-type tanker cars are not considered a primary method of fuel delivery. For the purposes of this chapter, trucks are considered the primary method of delivery.

DEFINITIONS AND LIQUID FUEL CLASSIFICATIONS

A storage tank for liquid fuel is any stationary receptacle designed to contain an accumulation of regulated substances. Tanks can be constructed of materials such as steel, concrete, and fiberglass-reinforced plastic or of various combinations of materials that provide structural support.

A storage tank is considered underground if 10 percent or more of the total tank volume of single or multiple tanks, including all associated and interconnecting piping, is below grade or covered with earth.

A regulated substance is any designated chemical that includes hydrocarbons derived from crude oil, such as motor fuels, distillate fuel oils, residual fuels, lubricants, used oils, and petroleum solvents.

Occupational Safety and Health Administration (OSHA) 29 CFR 1926: *Safety and Health Regulations for Construction* further defines storage tanks according to their operating pressure ratings as follows:

- Atmospheric tank: Atmospheric pressure to 0.5 pound per square inch gauge (psig) (3.45 kPa)
- Low-pressure tank: Atmospheric pressure from 0.51 to 15 psig (3.451 to 103.42 kPa)
- Pressure tank: Atmospheric pressure greater than 15 psig (103.42 kPa)

Liquid fuels are governed by the requirements of National Fire Protection Association (NFPA) 30: *Flammable and Combustible Liquids Code*. This standard classifies liquids as either flammable or combustible based on their flash point, which is the temperature at which a liquid gives off vapor in sufficient concentration to form an ignitable mixture with air at or near the surface. In short, the flash point is the minimum temperature at which a fire or explosion could occur.

In addition to classifying liquids as either flammable or combustible, NFPA divides them into Class IA, B, and C; Class II; and Class IIIA and B. (Note: The following definitions are only for the purpose of fire protection.)

Flammable liquids are only Class I. They have a flash point below 100°F (37.8°C) and a vapor pressure no higher than 40 pounds per square inch absolute (psia) (2,086 millimeters of mercury [mm Hg]) at 100°F (37.8°C). Class IA liquids (which include gasoline and gasoline blends) have a flash point below 73°F (22.8°C) and a boiling point below 100°F (37.8°C).

Combustible liquids are only Class II or III. They have a flash point at or above 100°F (37.8°C). Diesel fuel, light heating oil, and kerosene are Class II combustible liquids with a flash point at or above 100°F (37.8°C) but below 140°F (60°C). Class III liquids include motor lubrication and waste oil.

Liquid petroleum and petroleum products are defined as hydrocarbons that are liquid at atmospheric pressure and at temperatures between 20 and 120°F (-29 and 49°C) or are discharged as liquid at temperatures in excess of 120°F (49°C). For the purposes of this discussion, these products include gasoline, gasoline blends, and diesel oil used as fuel for motor vehicles and internal combustion engines. These fuels are classified as hydrocarbons. They are also considered flammable liquids.

Specific gravity is the direct ratio of a liquid's weight to the weight of water at 62°F (16.7°C).

The viscosity of a liquid is a measure of the internal friction between particles that resists any force tending to produce flow. As the viscosity increases, the liquid's flow decreases under gravity conditions. Viscosity is obtained by measuring the amount of time a given quantity of liquid at a specified temperature takes to flow through an orifice. Viscosity is expressed in Seconds Saybolt Universal (SSU), used primarily for pump work, as well as kinematic viscosity centistokes or centipoises, Seconds Saybolt Furol, and Seconds Redwood.

The vapor produced by the evaporation of hydrocarbons is in a category known as volatile organic compounds (VOCs), which are environmentally controlled emissions. Vapor produced by gasoline and gasoline blends is required by code to be recovered. Phase I systems refer only to storage tanks where vapor is displaced when the tank is filled with product. The recovered vapor is returned to the delivery truck or rail tanker car. Phase II systems refer only to vapor recovery from automobiles when their tanks are filled with product. The recovered vapor is returned to the storage tanks. Kerosene and diesel oil storage and dispensing systems do not require vapor recovery at this time. Codes concerning environmentally controlled substances are changed and improved frequently. It is essential that the designer stay abreast of current code requirements.

CODES AND STANDARDS

The U.S. Environmental Protection Agency (EPA) has written basic minimum regulations to protect the environment and people's health from the leakage of hydrocarbons and VOCs from underground storage tanks (USTs), aboveground storage tanks (ASTs), and associated piping. The basic purpose of these regulations is to ensure the proper installation of the various system components, to prevent leaks or spills from occurring, and should a leak or spill occur, to ensure that the leak is quickly found, corrected, and reported.

In almost all jurisdictions where these systems are installed, specific requirements are mandated by local and state agencies concerning permits, registration, fees, and recordkeeping, as well as specific technical rules and regulations regarding system installation, maintenance, materials, and leak detection. Very often, these requirements are more stringent than the federal EPA regulations cited here. A thorough code search is necessary to ensure complete compliance with all applicable federal, state, and local regulations.

Other organizations regulate component testing and make general provisions for system components and installation with regard to fire prevention. Following is a list of commonly used codes, regulations, and guidelines. This list is not complete and must be verified in the locality where the project is constructed.

- NFPA 30, NFPA 30A: *Code for Motor Fuel Dispensing Facilities and Repair Garages,* NFPA 385: *Standard for Tank Vehicles for Flammable and Combustible Liquids,* and NFPA 329: *Recommended Practice for Handling Releases of Flammable and Combustible Liquids and Gases*
- 40 CFR 112: *Oil Pollution Prevention*
- International Code Council (ICC) International Building Code (IBC)
- State fire marshal regulations, as applicable
- Underwriters Laboratories (UL) 142: *Steel Aboveground Tanks for Flammable and Combustible Liquids* and UL 2085: *Protected Aboveground Tanks for Flammable and Combustible Liquids*
- Resource Conservation and Recovery Act (RCRA), Subtitle C
- STI/SPFA (Steel Tank Institute/Steel Plate Fabricators Association) regulations
- Public Law 98-616: *Hazardous and Solid Waste Amendments of 1984*
- Clean Air Act
- Superfund Amendments and Reauthorization Act of 1986 (SARA), Title III, Section 305(a): Emergency Planning and Community Right-to-Know Act (EPCRA)

SYSTEM COMPONENTS

Liquid fuel storage and dispensing, whether in an AST or UST, require many interrelated subsystems and components for proper operation and for compliance with applicable codes and standards. They are:

- Storage tanks, including tank filling and accidental spill containment, atmospheric tank venting, overfill protection, and a vapor recovery system
- Leak detection and system monitoring
- Motor vehicle vapor recovery system, if applicable
- Pump and piping systems for dispensing and distributing product from the storage tank into motor vehicles or directly to engines

Due to the significant differences between USTs and ASTs in terms of materials, installation, and operation, these systems are discussed separately.

UNDERGROUND STORAGE TANKS

Storage tanks are designed and fabricated to prevent product releases due to structural failure and/or corrosion of the tank from the time of installation to the end of the expected useful life of the system. This requires the tank manufacturer to fabricate the tank in conformance with applicable codes and nationally recognized standards for structural strength and corrosion resistance. Since the tank must be installed in a manner that prevents distortion and stress, the installation must be done by contractors trained and approved by the manufacturer of the specific tank. The tank foundation, bedding, and backfill must be done only with materials and methods approved by the manufacturer, local code authorities, and nationally recognized standards.

Prior to tank installation, the groundwater conditions, soil composition, and potential for corrosive action should be determined. When deemed necessary, tests should be performed to determine the allowable soil pressure. The excavation for the storage tank should be sufficient to permit safe installation and proper backfilling on all sides of the tank with a minimum of 18 inches (0.46 meter) of noncorrosive inert materials, such as clean sand or gravel. The suggested backfill material should be a naturally rounded aggregate such as pea gravel, with particles ranging from 0.13 to 0.37 inch (3.2 to 9.5 millimeters) in diameter, clean, and free flowing. An illustration of a typical UST installation is shown in Figure 7-1.

Other conditions that should be considered when installing underground storage tanks include the following:

- High water table levels: Proper tank strapping, pads, or deadman anchors should be installed to counteract tank buoyancy and to keep the tank from popping out of the ground. Deadman anchors are strip footings located under the tank that are engineered to counteract empty tank buoyancy.
- The possibility of flooding from an adjacent water body or source: Again, installation on an anti-floatation pad and strapping should be used.
- Established flood plains for the local area
- Seismic conditions
- Corrosion protection (soil conditions)

Since tank dimensions for the same size tank differ among manufacturers, consult the manufacturer of the proposed tank for the exact dimensions.

Tank Materials

The materials used to manufacture primary and secondary tanks include the following:

- Steel, with thin coating or thick cladding depending on the corrosion protection method selected by the manufacturer (cathodic protection sometimes required)
- Fiberglass-reinforced plastic (FRP) (no corrosion protection required)
- Steel and FRP composite
- Pre-engineered, cathodically protected steel

Clad steel is manufactured by applying a layer of plastic, usually FRP, over the exterior surface of the steel tank. This offers the strength of steel with the corrosion protection of FRP. Care must be taken to prevent damage to the cladding during shipping and installation. Since cracks and crevices in the cladding may allow corrosion to occur, some authorities require the installation of sacrificial anodes.

FRP tanks are manufactured by several proprietary processes from thermoset plastic reinforced by fiberglass. Reinforcing ribs are built into the tank for increased structural strength. Generally, a resin-rich layer contacts the product. The specific plastic materials are listed by the manufacturer as being suitable for the intended product. These tanks are completely resistant to corrosion; however, they have the disadvantage of being more susceptible to damage from mishandling and distortion during backfill installation. In addition, FRP tanks are susceptible to ultraviolet (UV) light. It is important to minimize exposure to UV light (i.e., sunlight) for extended periods.

With a composite tank, the steel tank is wrapped in a jacket of high-density polyethylene that is not bonded to the tank itself. This provides a very thin interstitial space that can be monitored. Experience

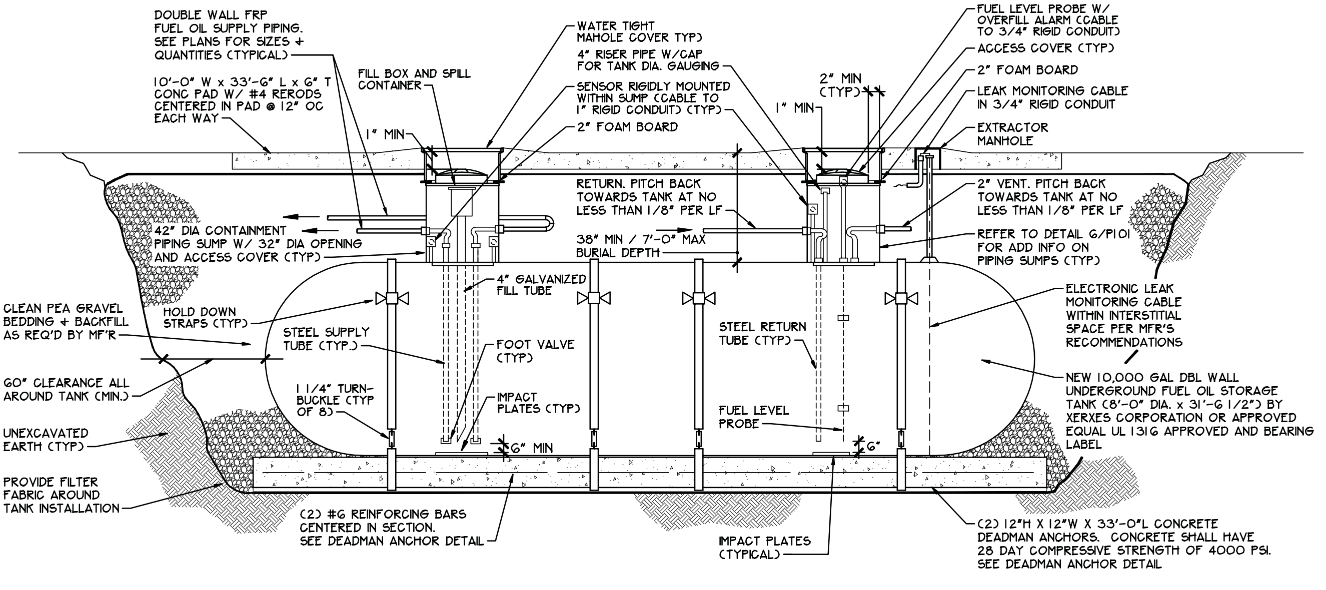


Figure 7-1 Typical Underground Storage Tank Installation

has shown that the jacket is the portion of the assembly that fails most often.

Pre-engineered steel tanks are constructed with an insulating coating on the steel tank and sacrificial anodes welded to the tank's sides. The coating is usually coal tar epoxy, although FRP and polyurethane are also used. If steel piping is used, it must be isolated from the tank by special dielectric bushings or unions. This is the least costly material, but it has the disadvantage of requiring constant monitoring of the cathodic protection.

Tank Construction

Typical tanks are cylindrical with a round cross-section. FRP tanks have half-dome ends, and steel tanks have dished ends. Tanks are available in either single-wall or double-wall construction. In double-wall construction, the inner tank containing the product is called the primary tank, and the outer tank is called the secondary containment tank. This type of construction often is referred to as being double contained. The outer tank may be manufactured from the same material as the primary tank, or it may be a different material if approved by the jurisdictional agency. The space between the primary and secondary tanks is called the interstitial space. The width of the space varies among manufacturers and types of construction. This space is monitored for leakage from the primary to the secondary containment tank. Monitoring systems may sense product leakage from the primary tank, groundwater leakage into the secondary tank, or both.

Tank Connections and Access

Reference applicable codes and standards—local, state, and federal—for mandated connections, access requirements, and overfill and spill prevention regulations. Following are generic, standard features recommended for all installations.

A convenient and leakproof method of connecting directly into the primary tank must be provided to allow for filling, venting, product dispensing, gauging, and leak detection. Where only piping connections are provided, an enclosure connected to all pipes and including an extension to grade should be installed to allow leakage monitoring and access to the connections for maintenance. This arrangement is commonly called a containment sump (see Figure 7-2) because there is no direct connection of the sump to the wall of the tank.

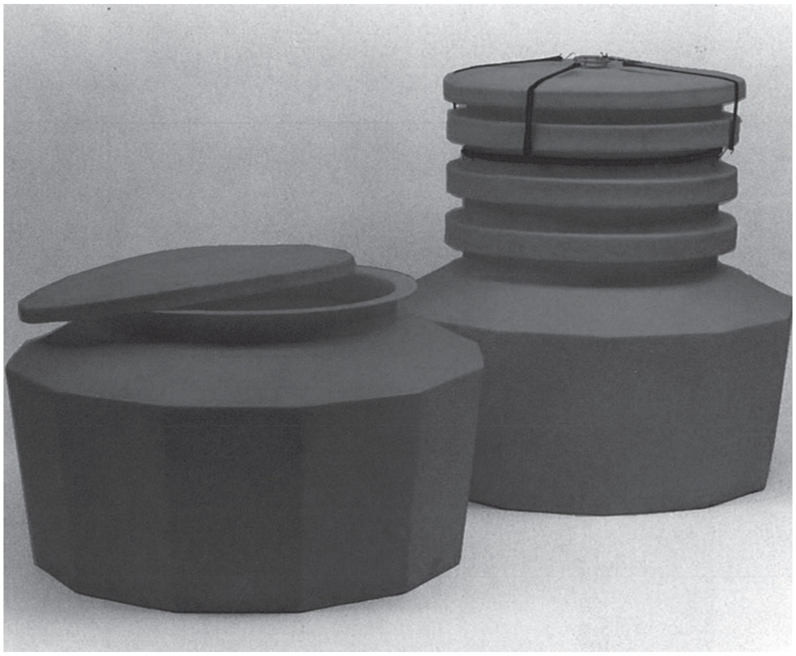


Figure 7-2 Containment Sump

For large tanks, access directly into the tank for personnel also may be desired. Allowance for this may be made by providing a manway (see Figure 7-3), which is formed at the factory during manufacturing. (It should be noted that a tank is considered a confined space, and entrance is specifically regulated by OSHA standards, which require, minimally, the use of self-contained breathing apparatus and an outside assistant or observer. Also, the tank must be marked per OSHA requirements.) The manway often is used for installing equipment and several piping connections. A manway cover on the tank with multiple piping connections in a variety of sizes can be provided. This is done to eliminate the need for secondary containment, and, if the pipes are installed inside the manway, to allow for easier maintenance. Standard fittings are 3- and 4-inch (80- and 100-mm) national pipe thread (NPT). Standard inside diameters (IDs) of manway openings are generally 22, 30, and 36 inches (0.56, 0.76, and 0.91 m), with the size depending on the size of the tank and code or OSHA requirements. These connections can be arranged in a straight line or in a circular configuration.

In addition to the manway, individual half-couplings are usually provided for direct connection of piping to the tank.

Tank Filling

Underground storage tanks are filled from delivery trucks or, in rare cases, rail tanker cars. When done by gravity, this is commonly called a gravity drop or, simply, a drop. When gravity filling is not possible, truck-mounted pumps or remote pump fill stations are used. If the fill port is located directly over the

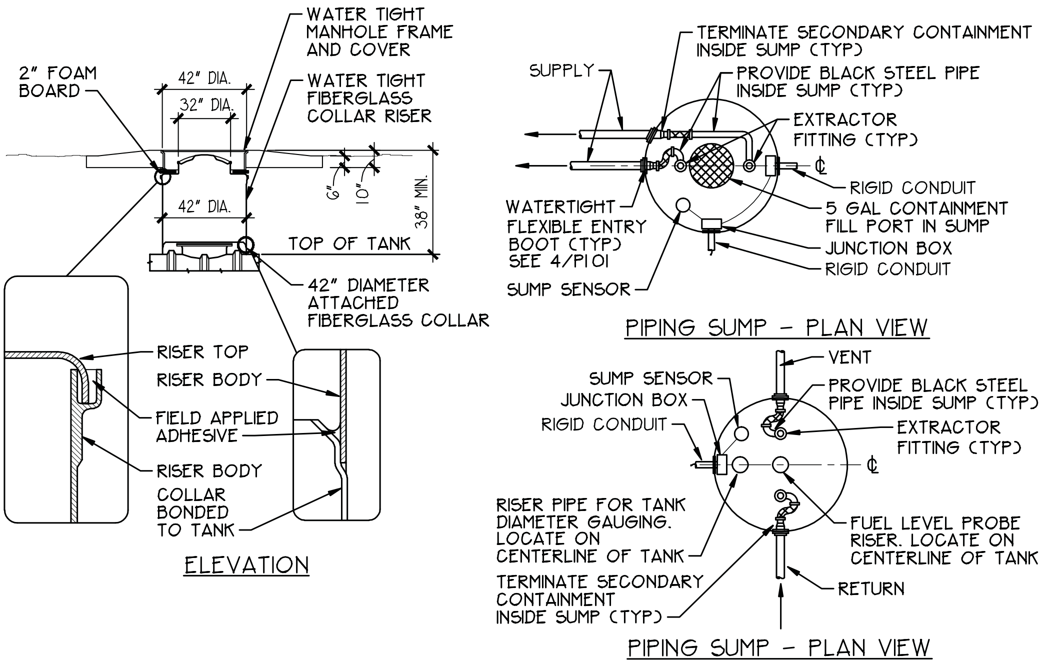


Figure 7-3 Manway

UST, the assembly is called a direct fill port. If horizontal piping runs from the fill port to the tank, it is considered a remote fill port. The surrounding grade should be sloped away from the fill port.

The fill port cover must be watertight. Where multiple tanks containing different products are installed, the fill port covers should be color-coded to distinguish among the various product ports and the vapor recovery ports. The cover plates should be installed a minimum of 1 inch (25 mm) above ground level to minimize the possibility of storm water entering the port.

Another integral part of the filling system is the drop tube or piping inside the tank. The drop tube provides a submerged inlet for product during filling. This reduces the fluid turbulence inside the tank, which can cause foaming of the product. Some drop tubes, called overfill protection valves, restrict tank filling. One example is a float valve that closes when the tank reaches capacity. Overfill protection must be provided.

The fill port assembly is designed to accomplish the following:

- It provides a watertight grade cover allowing access to the fill hose connection.
- It provides a fill hose connection for the tanker truck delivery hose. The hose end has a standard end connection, so an adapter may be required on the fill pipe leading to the tank. The gravity drop delivers approximately 200 gallons per minute (gpm) (756 L/min). The flow rate of a truck-mounted pump is generally 50 gpm (189 L/min).
- It allows any fuel spillage from the fill hose to be contained and returned to the tank.
- It allows any storm water to be removed.

Another fill method involves the use of a coaxial (pipe within a pipe) truck delivery hose to both fill the tank and recover vapor. This requires only one connection from the truck to the tank fill port and a different type of adapter than is used for a fill connection alone.

Spill Prevention

The purpose of spill prevention is to provide a safe filling method that is capable of catching spills from delivery hose disconnections. A typical 20-foot (6.1-m) length of 4-inch (100-mm) delivery hose holds 15 gallons (56.8 L). Spilled product must be prevented from entering the soil adjacent to the fill port through the provision of safeguards that are code mandated and recommended as good practice. This is accomplished by installing a below-grade catchment basin with a capacity of 3.5 to 15 gallons (13.2 to 56.8 L) to catch spillage of product from truck delivery hoses. An optional device that could be part of the basin is a drain valve that, when opened, empties the product into the tank fill line. Any water accumulating in the sump must be removed manually and properly treated elsewhere. Catchment basins should be watertight to prevent surface water from entering the tank.

A dry disconnect coupling on the delivery truck hose also could be used to prevent spills.

Figure 7-4 Overfill Protection Valve

Overfill Prevention

All UST systems must be provided with overfill protection by the installation of one or more of the following devices (method must be approved by the local authority):

- A device that alerts the operator when the tank is no more than 90 percent full by restricting the flow of product into the tank or by sounding an audible alarm, which is activated by a high-level alarm probe, and sometimes a visible alarm, which must be located in clear sight of the fill port and the operator
- A mechanical device (see Figure 7-4), typically located on the fill tube, that automatically reduces flow into the tank when the tank is 90 percent full and stops flow entirely when the tank is 95 percent full

The best method of overfill protection is the second, and a number of approved mechanical devices from different manufacturers are available. This is the method most often required by local authorities.

In addition, tanks that do not require a vapor recovery system can have a floating ball device (see Figure 7-5) installed on the atmospheric vent line that closes the vent when the product reaches a predetermined point (usually 90 percent full) at which additional filling may cause a spill. When the vent is closed, the air pressure increases inside the tank and restricts the inflow, alerting the operator that the tank is approaching the full level. If such a device is used, an extractor fitting is required to allow access into the line for maintenance or removal of the float assembly.

Atmospheric Tank Venting

Underground storage tanks are at atmospheric pressure and require continuous tank venting to ensure that no pressure or vacuum is built up inside the tank when it is filled or emptied. These vents are not to be confused with vapor recovery vents, which serve a different purpose.

Since all of the vapors produced from products are heavier than air, the vapors normally do not escape. A release of vapor can occur as the tank is filled (vapor is displaced by the product added), as product is removed, or as a result of a buildup of vapor pressure caused by the evaporation of product at times of high temperature.

Each tank is vented by means of a dedicated vent pipe, typically 2 inches (50.8 mm) in diameter for tanks 10,000 gallons (37,854.12 L) or less.

The vent pipe is directly connected to the top of each primary tank and should be extended to a safe location above the highest level of any adjacent building or to a minimum of 12 feet (3.66 m) above grade. The vent discharge must be directed either vertically or horizontally away from buildings and other tanks.

When not in conflict with other regulations, general practice is to terminate the vent in a pressure/vacuum cap that prevents the entrance of rain and birds and only opens when the pressure exceeds 2 to 15 ounces per square foot (0.86 to 6.46 kPa) or when a vacuum pressure of 1 ounce per square foot (0.43 kPa) is exceeded. If a cap is not provided, a flame arrestor should be installed, if permitted by regulations.

Leak Detection and System Monitoring

Leak detection is required by code. There are three basic requirements for leak detection:

1. Leakage must be capable of being detected from any portion of the tank or piping that routinely contains petroleum.
2. The leak detection equipment must meet the performance requirements described in 40 CFR 280.43 and 280.44.
3. Leak detection equipment must be installed, calibrated, operated, and maintained in accordance with the manufacturer's instructions.

The EPA has established various options, combinations of which may be used depending on project conditions, initial or long-term costs, and product. In addition, state and local requirements may differ from EPA requirements in terms of the number and application of these options. A schematic diagram indicating methods of detecting leaks from tanks and piping is illustrated in Figure 7-6.

Measuring leakage from tanks is accomplished by gauging the level of product in a tank and measuring the amount of product dispensed and the amount of product delivered. If the dispensed and remaining product figures equal the amount of product delivered, there is no leakage. (Many states no longer allow manual or automatic tank gauging or tightness testing with inventory control as methods of leak detection.)

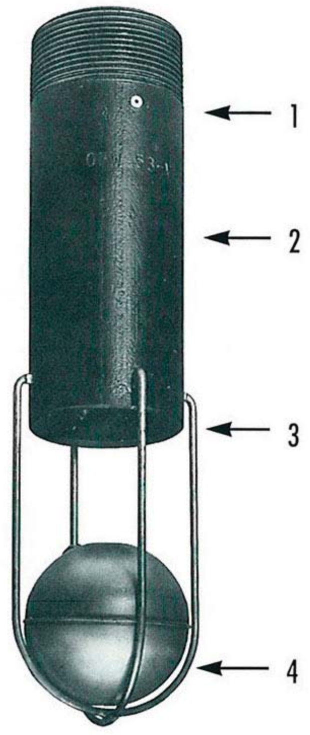


Figure 7-5 Ball Float Overfill Protection Valve

Manual Tank Gauging

In manual gauging, referred to as sticking, a long gauge stick calibrated to 0.125 inch (203.2 mm) is lowered directly into the tank, along the center axis, until the stick rests on the bottom. This requires straight, direct access into the tank, usually through the tank manway. The liquid leaves a mark on the stick that is read by the operator after the stick is removed. This method is generally limited to tanks of 2,000 gallons (7,570 L) or less and is used only in conjunction with tightness testing for tanks with capacities greater than 550 gallons (2,082 L).

With this method, the tank being measured must be completely idle for at least 36 hours. Two separate readings must be taken, one at the beginning and one at the end of that period, and the readings must be taken once a week. If the readings do not meet or match weekly or monthly standards, the tank is leaking.

It is common to provide manual tank gauging to double-check mechanical or electronic methods and to allow measurement if electrical power is lost or if the automatic devices fail.

Automatic Tank Gauging

Automatic tank gauging is accomplished by the permanent installation of a probe, or monitor, in the storage tank. The probe can be mechanical, pneumatic, or electronic.

The least costly tank gauging is a mechanical device, such as a float, that rides on the surface of the liquid. By its movement, the float transmits a reading of the liquid level by mechanical or other means to a remote indicator. General accuracy is about 2 percent.

A slightly more accurate method is a pneumatic tank gauge that uses a bubbler pipe extending down into the liquid. A permanent source of compressed air or a hand-operated air pump forces air out of the bubbler pipe. The gauge operates by measuring the pressure required to force air out of the bubbler pipe. Higher pressures required to produce the bubbles indicate deeper depths of the liquid.

Electronic tank gauging is typically the preferred method of gauging. An electronic tank gauging system consists of a probe, which is mounted in a tank opening and extends to the bottom of the tank, and a remote panel that is controlled by a microprocessor and can be programmable. The probe, which is capable of monitoring several parameters, extends from the primary tank bottom to a termination point above the tank that both anchors the probe and acts as a junction box for the wiring. For underground storage tanks, this point is below grade. Access to the box through a small manhole is required. For aboveground storage tanks, the probe terminates in a junction box on the top of the tank.

The advantage of the electronic gauging system is that it can be programmed to automatically record many functions, such as product and water level inside the tank and product temperature. Overfill and low-product levels are also capable of being monitored. Many manufacturers include probe testing from the control panel, which makes testing and troubleshooting easier, and probes from multiple tanks can be linked to a single panel. In addition, probes extending from various locations can be electronically linked to monitor vapor and liquid leakage from many sources, such as monitoring wells, piping, containment sumps, and tank interstitial spaces.

The electronic probes that are commonly available are the magnetostrictive and the ultrasonic. The magnetostrictive type uses changes in the magnetic field produced by movable product sensor floats, one for water and one for product. Each float has an integral magnet and is free to ride on the probe shaft as the product and water levels change. Ultrasonic devices signal a change in product level via ultrasound waves from the probe on the shaft to a receiver on the top of the probe.

Capacitance-type probes are no longer recommended, having been replaced by less expensive and more accurate electronic probes.

Tank Tightness with Inventory Control

A combination method uses periodic tank tightness testing and monthly inventory control, but it is allowed only during the first 10 years of operation. Many states no longer allow this method in new tank installations. (Check local code requirements.)

Tank tightness testing requires the tank to be taken out of service and temporary testing equipment to be installed. One method uses volumetric testing to exactly measure the change in the level of product over a period of several hours. Another method uses ultrasound or tracer gas detection techniques to detect leaks in the tank wall.

The monthly inventory requires an exact measurement to be taken of the amount of product delivered each month. That measurement then must be compared to the amount stored in the tank plus the amount dispensed. If the two figures do not balance, there is a leak.

Interstitial Monitoring

The interstitial space between tanks is used to detect and contain any leakage from the primary tank. Many states now require some form of this type of monitoring of tanks and connected piping. The monitoring of interstitial space is divided into two general categories: wet and dry.

Dry methods use vapor monitoring to detect the presence of hydrocarbon vapors. Some products can distinguish between water and hydrocarbon, which may be useful in determining the type of leak detected. Vapor monitoring is achieved by placing a probe sensitive to product vapor in the dry interstitial space. The probe typically is placed half the distance into the interstitial tank space. When leakage occurs, the vapor produced by the product is detected, and a signal is given. This method has the advantage of being unaffected by condensed water.

Wet methods monitor for the presence of liquid product using either air pressure or vacuum. In this method, the interstitial space is filled with a brine solution that is monitored for drop or rise in quantity. Liquid monitoring is achieved by placing a probe capable of detecting liquid at the bottom of the dry interstitial space. When leakage occurs, it is detected, and a signal is given. A shortcoming of this method is that water condensation in the interstitial space is detected as leakage. Again, some products provide the ability to distinguish between water and hydrocarbons. However, external groundwater leakage through the secondary containment tank is also detected. Monitors that are sensitive only to product, based on specific gravity, are available.

A hydrostatic monitoring system (see Figure 7-7) is more expensive than the other methods, but it is the most accurate method of interstitial monitoring. It is a wet system in which a liquid, usually brine, which is installed at the factory, completely fills the interstitial space. The system is at atmospheric pressure, with the liquid carried above the tank into a reservoir that contains a level probe. To maintain atmospheric pressure, holes must be made in the standpipe cap. If the possibility of water entering the holes exists, a separate vent line, extended to a point safely above grade, must be installed. Since normal product temperature differences will cause the liquid level to fluctuate, the level probe is set to annunciate only when unacceptable changes occur. Water from a high water table leaking into the interstitial space from a hole in the secondary tank will cause the level to rise. Product leaking out of the primary tank into the interstitial space will also cause a change in the brine level, as will a hole in the secondary tank.

Pressure monitoring of the interstitial space is accomplished by applying air pressure (at 1.5 psig [10.34 kPa]) or creating a vacuum in the space. Any increase or reduction of pressure or vacuum indicates a leak, and a signal is sent to a remote panel for annunciation. Pressure systems are rarely used due to the level of experience and maintenance required.

Groundwater Monitoring

Groundwater monitoring senses the presence of product floating on the surface of groundwater. It

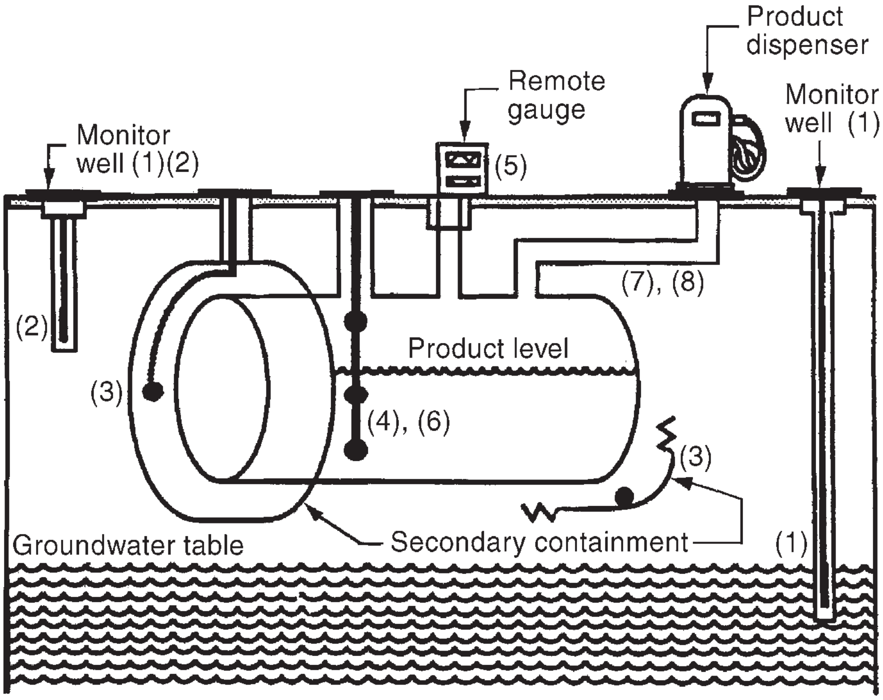


Figure 7-6 Schematic Diagram of Leak Detection Methods for Tanks and Piping

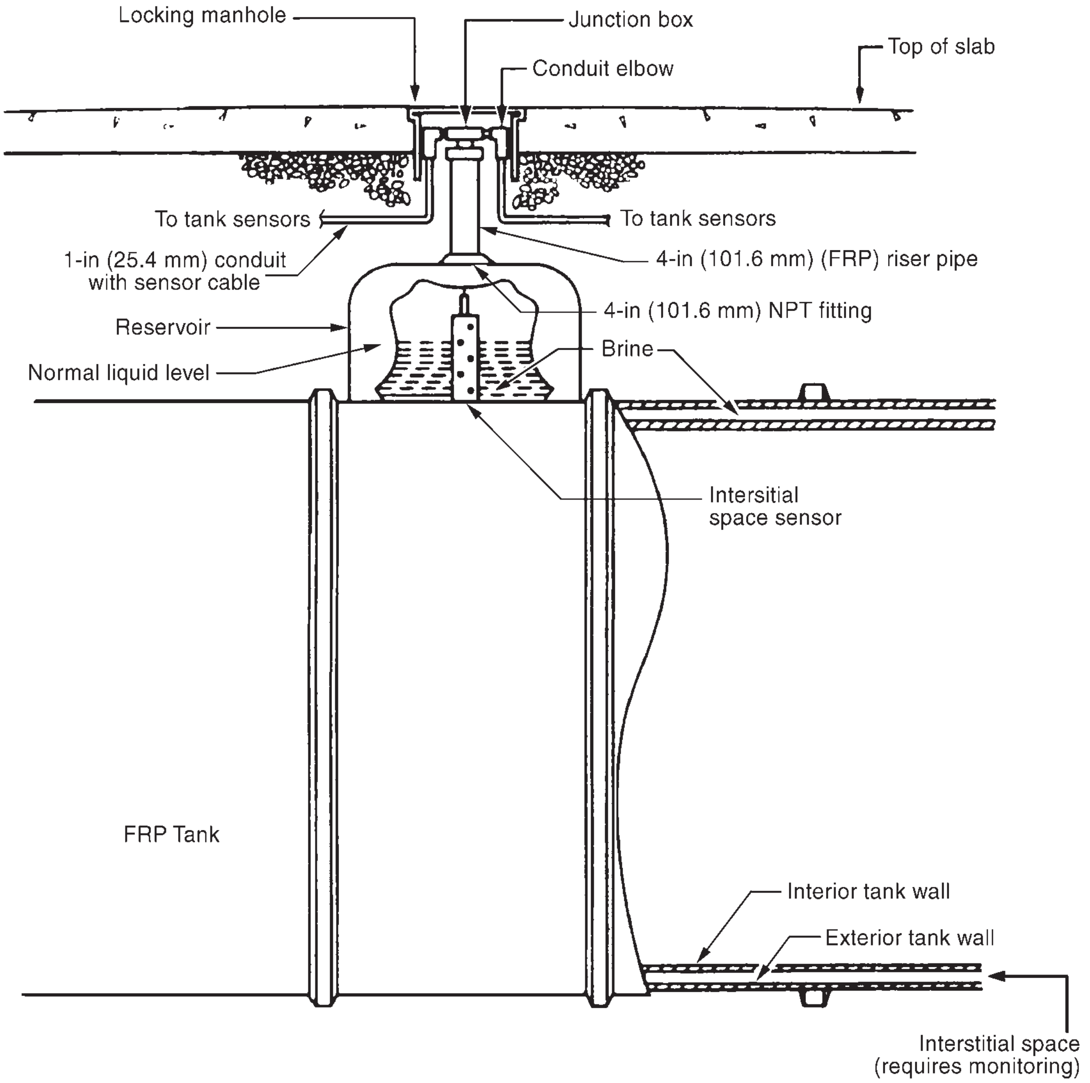


Figure 7-7 Detail of Hydrostatic Interstitial Monitoring

can be used only where water and the product to be measured are immiscible. This method requires the installation of monitoring wells in the groundwater at several strategic locations near the tank. The wells must be properly designed and sealed to eliminate surface contamination. A geotechnical report may be required to determine the flow of underground water and the direction a pollution plume might travel if the groundwater became contaminated.

The wells can be checked either manually or automatically by electronic methods. Manual methods require the use of a bailer to collect liquid samples from inside the well and bring them to the surface. Samples must be sent for analysis once a month. Electronic methods use probes suspended in the well to continuously monitor for the presence of contamination in groundwater. If contamination exists, an alarm is annunciated at a remote panel.

Monitor wells are limited to sites where the groundwater level is 20 feet (6.1 m) or less below the surface, with the best results obtained from depths of between 2 and 10 feet (0.60 and 3 m).

Inground Vapor Monitoring

Inground vapor monitoring measures the fumes in the soil around a storage tank to determine whether spilled product is present. This method, like groundwater monitoring, requires the installation of monitoring wells.

The wells can be checked either manually or automatically by electronic equipment. Manual methods require monthly air sample gathering and laboratory analysis. Electronic methods use a probe suspended in the well and a remote, finely calibrated analyzer. Vapor monitoring should be considered only where the backfill is sand, gravel, or some other material that allows vapors to move readily from the tank through the backfill to the monitor. It is not recommended where high groundwater and excessive precipitation might interfere with the operation of the system for more than 30 days.

Leakage from Piping

Pressurized piping must have one automatic leak detection method and one additional leak detection method, as described below.

Automatic leak detection entails a permanently installed, automatic flow restrictor or automatic flow shutoff device installed in the product discharge piping and/or a continuous alarm system, which could be a probe installed in the secondary pipe that continuously monitors the liquid or vapor release of the secondary containment piping system. If the secondary containment terminates in a manway or containment sump, the lower end of the secondary containment pipe should be open to the sump and should allow any leaking liquid to spill into the sump to be detected by a sump alarm probe.

The following accuracy must be provided for automatic detection: a pressurized shut-down monitoring device that prevents the flow of product when a line tightness test indicates a minimum leakage of 0.10 gallon per hour (gph) (0.063 L/h). In addition, the device must be capable of shutting down the system when a leak of 3 gpm (0.19 L/s) at 10 psi (68.95 kPa) is detected. One commonly used device is installed on the discharge of the submersible pump in the manway. It must act independently of any other pressurized shut-down monitoring device.

An additional method of leak detection may be any one of the following, performed monthly: groundwater monitoring, secondary pipe vapor monitoring, or secondary pipe liquid monitoring. Annual pipe tightness testing also meets the requirement for an additional method, as does a continuous alarm to detect spillage as described above.

Underground suction piping leak detection is not required if the piping is sloped back to the tank from the dispenser and if a check valve is installed in the dispenser as close as possible to the vacuum pump. Due to the increased use of alcohol additives in gasoline, it is general practice to provide double-contained suction piping for gasoline systems. Double-contained piping is not required for diesel fuel, but it is highly recommended.

When the tank is higher than the dispenser, it is necessary to use double-contained piping. A sump is installed at the low point of the piping, and a probe is installed to detect leakage from the secondary pipe. Any product leaking from the primary pipe will spill into the secondary containment pipe and flow by gravity to the low point. The piping is pitched downward to a bulkhead, sump, or manway. Double-contained piping penetrates the side of the bulkhead using special fittings called bulkhead fittings. These fittings are used to terminate double-contained piping so the secondary containment is open and liquid from between the two pipes can spill into the sump to be detected.

Inductive sensors that do not require penetration of the secondary containment pipe are also available. These attach directly to the outside of the secondary pipe to detect leakage by interruption of the inductive path of the sensor.

Leakage from Sumps

Leakage within containment sumps and manways is monitored by means of probes sensitive to liquid or vapor. They are suspended in or attached to the sides of the containment sump. The liquid probe level is adjusted to signal the presence of liquid. Probes that discriminate between water and petroleum products are available. They are connected by wires to a remote panel for annunciation.

Vapor Recovery Systems

Sometimes the local code requires VOC vapors resulting from the displacement of gasoline and gasoline-blended products to be prevented from entering the atmosphere. VOC vapors occur when storage tanks and motor vehicles are filled. Diesel fuel, kerosene, waste and motor oil, and heating oil do not require vapor recovery.

Vapor recovery is divided into two phases. Phase 1 is recovery from gasoline storage tanks; phase 2 is recovery from gasoline dispensers used to fill motor vehicles.

Phase 1 Vapor Recovery

Phase 1 vapor recovery entails a separate and independent closed system installed at the storage tank for use only during the filling of the storage tank. The product flowing into the tank displaces an equal volume of vapor, which must be recovered. The purpose of phase 1 vapor recovery is to prevent the escape of VOCs from the UST into the atmosphere. It can be achieved by means of a two-point or coaxial system.

The two-point vapor recovery system consists of a separate fill line to and a vent from the UST, each piped directly to the tanker truck. A separate hose from the truck is connected to an outlet accessed through a vapor recovery fill port adjacent to the product fill port. It is common practice for the vapor recovery pipe to be the same size as the fill line, typically 3 inches (80 mm). The vapor recovery pipe does not require double containment.

Coaxial vapor recovery is a combination system that uses a single connection point. It is similar in principle to the phase 2 vapor recovery used with dispensers. It consists of a drop tube with a pipe within a pipe and a delivery hose of the same construction. Product is delivered through the center pipe of the delivery hose, and the vapor passes through the outer pipe of the drop tube, which returns vapor directly to the delivery truck through the coaxial delivery hose as the product fills the tank.

Phase 2 Vapor Recovery

Phase 2 vapor recovery is a separate and independent closed system installed at the dispenser only for use during the dispensing of gasoline. Its purpose is to prevent the escape of VOCs from the motor vehicle tank into the atmosphere during tank filling. Phase 2 vapor recovery can be achieved by use of either a balanced or a vacuum-type system. The balanced is the type most often used.

Dispensing Systems

Product dispensing concerns only transferring product from the storage tank into the fuel tanks of motor vehicles.

Two methods are used to transfer product from a UST to the motor vehicle: pressure and vacuum systems. The pressure system uses a small-diameter, submersible pump immersed in the UST to create the pressure and flow rate needed to transfer product from the UST to the vehicle (see Figure 7-8). The submersible pump is sized to fit inside a 4-inch (100-mm) tank connection. Other sizes are also available. In any case, the design should incorporate easy removal of the pump for maintenance purposes.

The vacuum system uses a pump installed in the dispenser enclosure to create the suction pressure needed to draw product from the UST into the vehicle. Vacuum dispensers have a practical upper limit of 10 feet (3 m) of suction lift from the bottom of the UST to the highest point of the dispensing system. (Note: The vacuum system is no longer recommended.)

For USTs, the pressure system is preferred for the following reasons:

- Maintenance is much lower compared to that for vacuum systems.
- The initial cost is lower than that of vacuum systems.
- A submersible pump can supply multiple dispensers, while vacuum pumps must be installed in each individual dispenser.
- Submersible pumps can deliver higher flow rates than vacuum pumps.
- Vapor lock is eliminated with a submersible pressure pump system, as the pump suction is always flooded.

Product Dispensers

Dispensers are commonly available in two flow rates: standard speed for cars, which delivers a flow rate in the range of 7 to 15 gpm (0.44 to 0.95 L/s), and high speed for trucks, which delivers as much as 45 gpm (2.84 L/s). For passenger cars, the average dispenser discharges approximately 10 gpm (0.63 L/s) and requires approximately 30 psi (207 kPa). The size of the hose from the dispenser to the nozzle could be either 0.5 or 0.75 inch (15 or 20 mm), with 0.75 inch (20 mm) being the most often used. High flow rates for large fuel tanks require a 1-inch (25-mm) hose.

Dispensers have a wide variety of features. Following are the major components generally found in a dispenser:

- A register that displays the amount of product dispensed
- A meter used to register the total gallons
- The hose outlet, available in a side or front location
- A hose of the coaxial type for phase 2 vapor recovery (12-foot [3.66-m] length on average, but 15-foot [4.57-m] length is available with breakaway fittings)
- A high hose retractor to keep the hose off the floor or driveway
- A high-capacity product filter
- A dispenser containment mounting pan for installing the dispenser (A shear valve is illustrated in Figure 7-9.)
- An emergency shutoff, located in the dispenser sump pan, to stop flow in the event of a supply or dispenser hose line break
- A nozzle, with a vapor recovery feature where required and an automatic shutoff feature. Two sizes are generally available: 0.5 inch (15 mm) and the more commonly used 0.75 inch (20 mm). Note that the nozzle should not reach within 5 feet (1.52 m) of building openings.

Dispenser Pan

A dispenser pan is required to attach the dispenser to a concrete pad or island. The pan provides a liquid-tight entry for both single- and double-wall product piping and electrical conduit. It is also designed to collect and monitor spills and to prevent product from leaking below the dispenser into the environment.

Fuel Island

Dispensers, including the dispenser pan, should be installed on a fuel island. The purpose of the island is to protect the dispensers against collision damage. The island may be field-poured, or pre-assembled island forms are available to ease construction. Steel or stainless steel are the typical materials. Stainless steel is the preferred material for its ease of maintenance, but it has a higher upfront cost. The dispenser pan is then anchored to the island to create a solid base for the dispenser.

Fire Suppression Systems

For unattended motor fuel dispensing facilities, a fire suppression system may be required. Consult the local code to determine if it is mandated. Pre-engineered chemical extinguishing systems are available for inclusion on the fueling island. Consult the manufacturer's information for engineering data, including nozzle placement, suppressant storage tanks, detectors,

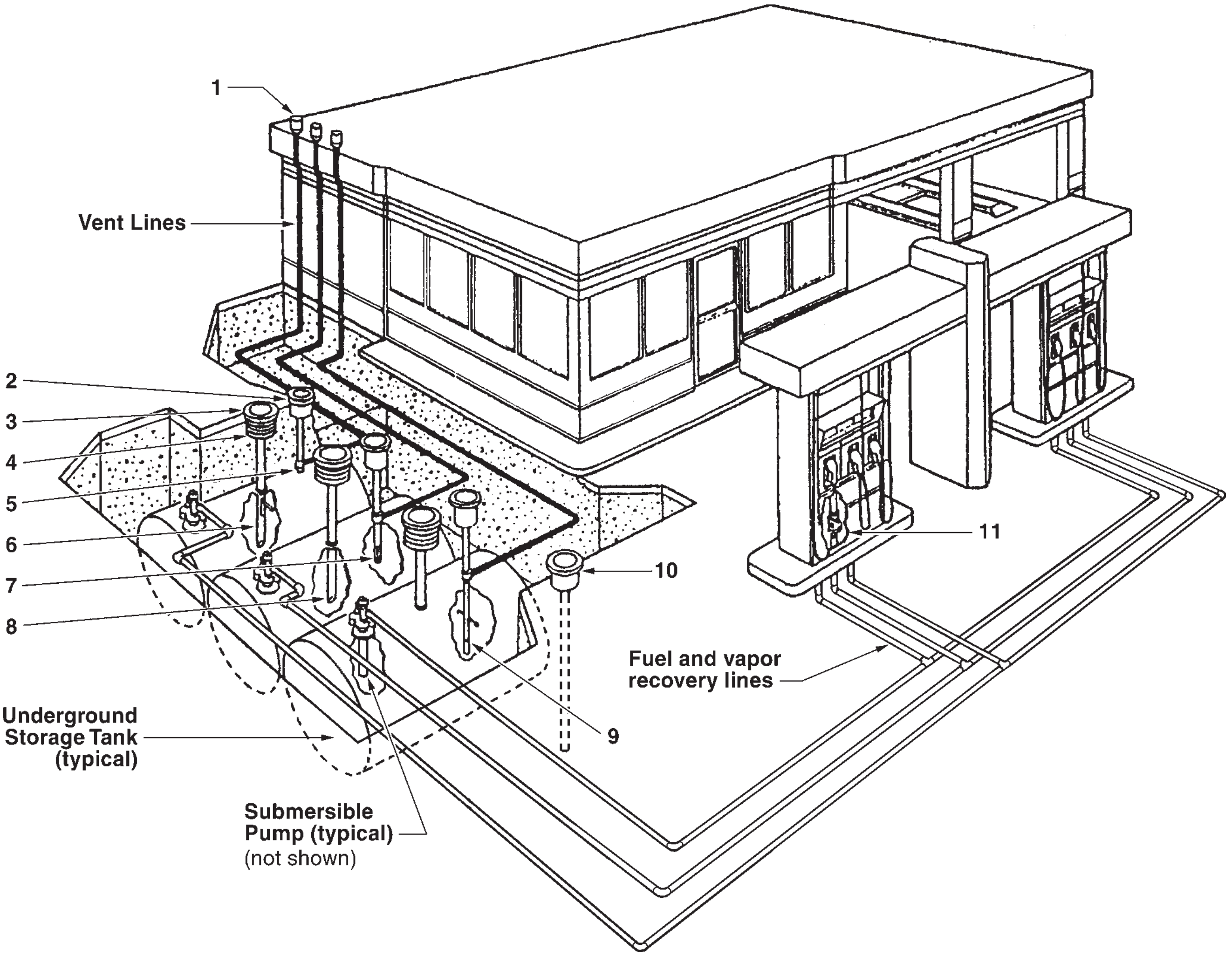


Figure 7-8 Typical Service Station Piping

(1) Vapor vent cap, (2) Vapor recovery port, (3) Tank fill hose adaptor, (4) Spill containment sump, (5) Extractor fitting, (6) Overfill prevention, (7) Ball float overfill prevention, (8) Drop tube, (9) Tank gauge, (10) Monitor well, (11) Emergency shutoff

and other equipment. These systems are customized for each application based on several factors, such as island size, canopy or no canopy, wind direction, and other site constraints.

Fuel Control Systems

On systems serving fleets (e.g., bus companies, school buses, municipalities), it maybe desirable to include a fuel management system to supervise fuel transactions. These units typically are computer based, but less expensive key-controlled mechanical units are available. Operation of the unit requires a key, an electronic key, or a keypad with assigned PIN numbers. Each vehicle and/or vehicle driver is assigned a key or PIN. When a user logs onto the system, the unit turns on the power to the dispensers, lights, etc. It can log fuel capacity dispensed including date, time, driver, and vehicle. Some units even require inputting odometer readings for maintenance such as oil change or tire rotation. Systems can be used simply for pump operation or for a multitude of other tasks. A fuel management unit is illustrated in Figure 7-10.

ABOVEGROUND STORAGE TANKS

The most often used aboveground storage tank (see Figure 7-11) is factory constructed of steel and intended for atmospheric pressure conditions. Such tanks must conform to UL 142, UL 2080: *Fire Resistant Tanks for Flammable and Combustible Liquids,* or UL 2085. Materials such as FRP, reinforced concrete, and FRP clad steel are seldom used for small tanks. If used, code requires the outside of a concrete vault to be protected against corrosion, weather, and sunlight.

Tank Construction

Aboveground storage tanks are factory fabricated in both round and cylindrical configurations. Concrete-encased tanks can come either round or rectangular. Primary tanks are often manufactured with compartments capable of storing different products. NFPA 30 limits motor fuel AST capacity to 6,000 gallons (22,710 L). All ASTs must be provided with some form of product leakage and overfill containment conforming to 40 CFR 112 regulations. This containment can be achieved by including a dike or an impoundment capable of holding 110 percent of the tank's contents or by providing integral secondary containment of the primary tank.

Many small tanks are provided with integral secondary containment and an interstitial space. The width of the space varies among manufacturers. Several proprietary methods are used to construct the secondary containment vault around the primary tank. An often-used material is plastic-lined concrete, which, if sufficiently thick, provides a two-hour fire rating as required by UL 2085. Another material used for external secondary containment vaults is steel. Insulation between the primary and secondary tank is provided by some manufacturers to protect the primary tank from temperature extremes. This also may be used to meet fire safety requirements for a two-hour fire rating.

Stairs or ladders are generally provided to allow inspection and for delivery truck operators to reach connections located on top of the tank.

Corrosion Protection

Since the tank is aboveground, the only corrosion protection required is weather resistance on the tank exterior. This is a code requirement, and each manufacturer has a proprietary method of protecting the outside of the AST.

The exposed piping must be a corrosion-resistant material such as FRP (which also must be impervious to UV light), stainless steel, or protected (painted or coated) black steel.

Tank Connections and Access

Connections are located only on top of the tank and extend through the vault or secondary containment into the primary tank. Except for large tanks, direct access for personnel entry into the primary tank typically is not provided. Standard connections include:

- Tank vent
- Emergency vent used for exposure to fire and the elevated pressures created by the boiling liquid in the tank
- Product dispenser outlet
- Product fill (either coaxial or single as required)
- Phase 1 vapor recovery
- Tank gauging
- Leak detection

A typical aboveground tank installation is illustrated in Figure 7-12.

Spill Prevention

For tanks with integral secondary containment, a containment sump surrounds the fill pipe. The size of the sump ranges from 5 to 15 gallons (18.9 to 56.8 L). For tanks with external secondary containment, spills enter the containment and are manually removed. A remote fill station could be provided with an integral spill containment sump to catch any hose spills. A small hand or electric pump could be provided to empty the containment sump into the primary tank. For detail of a typical fill installation, see Figure 7-13.

Atmospheric Tank Venting

An AST requires two vents. One is the standard atmospheric vent used to keep the tank at atmospheric pressure. This is commonly a 2-inch (50-mm) vent that must extend to a point 12 feet (3.66 m) above grade. The end typically terminates in a pressure/vacuum cap.

The second is an emergency vent required to depressurize the tank if a fire near or under the tank raises the temperature to a point where product vapor is generated faster than the atmospheric vent can pass it. Such a vent is commonly 6 or 8 inches (150 or 200 mm) in size, based on the tank size and the volume stored. The tank manufacturer provides the required emergency vent, with the size based on American Petroleum Institute standards.

Overfill Prevention

Overfilling is prevented by automatic or manual means installed directly on the tank. Automatic overfill prevention employs an overfill-preventing valve similar to that described previously in the discussion of underground storage tanks. Manual methods include a direct reading-level gauge installed in sight of the operator and/or an audible high-level alarm activated by a separate probe installed inside the tank. Alarms shall sound when the product level reaches 90 percent of capacity, and product delivery will be stopped when the level reaches 95 percent of capacity.

Leakage from Tanks

Use of aboveground tanks requires a method of containing any possible product release and preventing contamination of the adjacent environment. Product releases can result from small leaks or the catastrophic failure of the tank. Containment methods that meet requirements include a dike completely surrounding the tank, remote secondary containment, and integral secondary containment.

For ASTs without secondary containment, a dike must be provided. Dikes are required to be capable of containing 110 percent of tank capacity and to be constructed of materials such as concrete, steel, or impermeable soil designed to resist the full head of liquid. Dikes must be constructed in conformance with NFPA 30. For discharge from the dikes, a separator must be provided along with the necessary control valves, which may need to be self-actuating to conform with local codes. It is recommended that an additional impoundment basin be constructed at least 50 feet (15.2 m) from the AST and at a safe distance from other buildings, property lines, or tanks. The purpose is to capture and isolate any flammable liquids released during a fire or tank failure and to remove them a safe distance away from the AST. For ASTs, dikes are seldom used because remote and integral secondary containment have far lower initial costs.

Remote secondary enclosures are usually made of steel. They are totally enclosed and sealed in a manner that prevents the entrance of rainwater by the inclusion of rain shields. They are required by code to have a capacity that is 110 percent of the nominal capacity of the primary tank.

Tank integrity is achieved by enclosing the primary tank with an integral secondary containment, usually of steel or reinforced concrete. This type of tank has an interstitial space that is monitored for leakage in the same manner used for a UST, which was discussed previously.

System Monitoring

System monitoring consists of product level gauging and leakage annunciating. AST systems can be monitored either manually or electronically; however, manual reading is no longer allowed in some states.

Product level gauging in the tank can be achieved by use of a visual level gauge or an electronic gauge, either mounted on or immediately adjacent to the tank or at a remote location. Level gauges similar to those installed in USTs can be used. Remotely mounted electronic gauges capable of recording and placing in memory many functions using probes similar to those installed in USTs are commonly used.

Leak detection for ASTs is much easier than that for USTs because leakage from the tank can be easily observed. Automatic means of system monitoring include a stand-alone alarm panel and alarms that are integral to an electronic panel used for product level indication.

Vapor Recovery

Phase 1 and phase 2 vapor recovery for gasoline and gasoline blends is required. For phase 1 recovery, similar to USTs, either coaxial or two connections from a delivery truck are necessary during the filling operation. Phase 2 vapor recovery for tank-mounted dispensers is usually integral. For remote dispensers, a separate vapor recovery line connecting from the dispenser to the tank is required.

Product Dispensing Systems

For ASTs, the dispenser is usually directly connected to the tank or located a very short distance from it. Some codes require a separation distance between the tank and the dispenser of upwards of 50 feet (15.24 m). For remote dispensers, a vacuum system may offer a lower initial cost, and due to the short piping runs and single dispenser, most of the objections to vacuum systems discussed previously in the UST section do not apply. However, while they often operate acceptably for diesel fuel dispensing applications, vacuum systems may be plagued by chronic vapor lock in gasoline dispensing systems. It is important to include an anti-siphon valve with all AST dispensing systems. This valve is used to automatically shut off the flow of product in case the line is broken.

For ASTs, the dispenser can be mounted either on the tank or as a separate, remote dispenser (similar to those used for a UST). Dispensers are available with vacuum or pressure systems.

The tank-mounted dispensing system consists of a submersible pump, the complete dispenser (nozzle, hose, integral phase 2 vapor recovery system, means of base-mounting, and safety features), product pump, and interconnecting piping. This arrangement has the lowest initial cost.

Tank Protection

All ASTs located adjacent to a road or subject to a possible automotive collision must be adequately protected. Acceptable means of protection are concrete barriers or bollards or a concrete-encased tank. Bollards similar to those used to protect fire hydrants are the means most often used. The entire assembly should be placed within fencing with a lockable gate to minimize vandalism.

SYSTEM PIPING CONSIDERATIONS

For pressurized product pipe, it is common practice to use a minimum of a 2-inch (50-mm) size, increasing it only if the system under design requires a larger size based on a higher flow rate or if the difference in friction loss allows the selection of a lower-horsepower submersible pump. Generally accepted practice is not to use pipe sizes smaller than 1.25 inch (32 mm). A larger-size product pipe is generally used to lower the head requirements of the pump selected.

Piping Materials

Piping aboveground from an AST is for the vent and product delivery. The most common piping material is A-53 steel with threaded joints, and the pipe must be coated at the factory with an accepted and proven corrosion paint or coating. Note that Teflon tape should not be used on the pipe joints as it is incompatible with hydrocarbons. A common practice is to use a baked-on powder. Another material used where a high degree

Figure 7-9 Shear Valve

Figure 7-10 Fuel Management Unit

of corrosion protection and strength is required is stainless steel. FRP with ultraviolet protection added to the pipe is another often-used material. Galvanized steel pipe is not considered acceptable. Adapters are used to connect steel pipe to FRP if an underground run to a remote dispenser is necessary.

Because leakage is visible, double-contained piping is not required for ASTs if the tank is located within a dike or inside a remote containment. If pipe is run underground or aboveground outside diked areas, it must be double contained and provided with leak detection.

For new and replacement USTs, interconnecting piping is almost exclusively plastic or FRP with plastic or FRP secondary containment. Requirements regarding the approval of the specific piping material and connections selected and cathodic protection, if applicable, must be checked with the jurisdictional authority.

Plastic piping is commonly divided into two general types: flexible and rigid. Flexible pipe is generally manufactured from proprietary materials. If it is UL listed and/or FM Global approved, it is generally acceptable. In addition, the joints and connections should be selected to provide the greatest strength, ease of installation, and corrosion resistance. Flexible, plastic coaxial piping systems are a double-walled piping system installed as a single pipe. For an illustration of a coaxial pipe, see Figure 7-14.

Rigid FRP piping with an epoxy interior lining has been widely used and accepted and is considered the piping material of choice. The primary pipe is assembled with socket-type fittings and epoxy cement. The outer (secondary containment) pipe is the same material as the primary pipe and is manufactured in two half sections with a longitudinal flange. It is assembled after the primary pipe is tested using cement placed on the adjacent flanges with nuts and bolts installed to hold the two half sections together until the cement dries. Drop tubes in tanks reduce production of vapors as well as product foaming. For a detail of a foot valve, refer to Figure 7-15.

Flexible pipe connectors are used to connect piping runs to sumps and manways to allow for settlement. In addition, because submersible pumps are screwed into a tank connection, the product discharge will not always face the direction of the piping run to the dispenser when tightened. Flexible connectors are necessary inside manways to connect the submersible pump discharge to the dispenser supply piping.

Gasket materials must be either Buna-N (nitrile butadiene) or NBR (acrylonitrile butadiene rubber).

Pipe Sizing

Pipe sizing is based on the flow rate of the product, the allowable friction loss of the fluid through the system, and fluid velocity. This is an iterative procedure done in conjunction with selecting the size of the product pump.

Before the pipe can be sized, the following procedure for sizing the dispensing system must be done:

1. Select the dispenser location, type, and ancillary devices.
2. Select the pipe material.
3. Lay out the piping system, including length, fittings, and elevations in the layout.
4. Select the storage tank size and location.
5. Select a suction or pressure product pump system.

Flow Rate

For ordinary applications, the typical discharge flow rate to a motor vehicle from an average dispenser is 8 to 10 gpm (0.50 to 0.63 L/s). High-rate dispensers with discharge rates of up to 45 gpm (2.84 L/s) are available for buses and trucks.

Simultaneous Use Factor

The number of dispensers likely to be used at once is usually determined by experience. Where this can't be determined by experience, the following rule of thumb may be used. For multiple dispensers up to four, normally use a 100 percent use factor. For more than four, use a 75 percent simultaneous use factor.

Velocity

For FRP piping, the recommended maximum velocity should be kept at or below 7.5 feet per second (fps) (2.3 m/s). This figure keeps the pressure rise from water hammer to a safe level of 150 percent of design pressure. This is necessary due to the quick closing of the dispenser valve. For steel pipe, a maximum velocity of 8 fps (2.44 m/s) has been found acceptable. Some coaxial piping systems can handle velocities of 20 fps (6.1 m/s) or lower.

Piping Friction Loss

Friction loss of product through piping is found by checking with the manufacturer of the submersible pump or dispenser. Using the established flow rate, the allowable friction loss can be selected based on pipe size and the selected product.

For preliminary sizing purposes only or if specific tables are not available, most products are close enough in viscosity to water that standard water charts can be used to obtain a friction loss figure that is sufficiently accurate. For FRP pipe, the friction loss should be decreased by 10 percent for a more accurate figure.

PUMP SIZING

The pump is sized using the total flow rate and the total head required. Then obtain the pump curves from the manufacturer and select the pump based on the calculated head and flow rate.

To find the flow rate, calculate the total gpm (L/s) from each section of the product line. This is done using the flow rate from the selected dispensers and the simultaneous use factor for the number of dispensers that may be used at the same time.

To find the total pump head required:

1. Calculate the height from the bottom of the storage tank to the high point of the dispenser hose, including the elevation of the high hose dispenser.
2. Find the friction loss of the product flow through the distribution piping up to the dispenser based on the flow rate calculated. This figure must include the equivalent length of run and other losses through fittings and all other connected devices. Most figures can be obtained from the manufacturer. For pressure loss through a submersible pump leak detector, dispenser assembly, and dispenser hose, refer to the manufacturer's information.
3. Obtain the recommended pressure required for proper operation of the selected dispenser. A typical figure used is in the range of 25 to 30 psi (172 to 207 kPa). This figure includes losses through the nozzle, hose, strainer, etc.

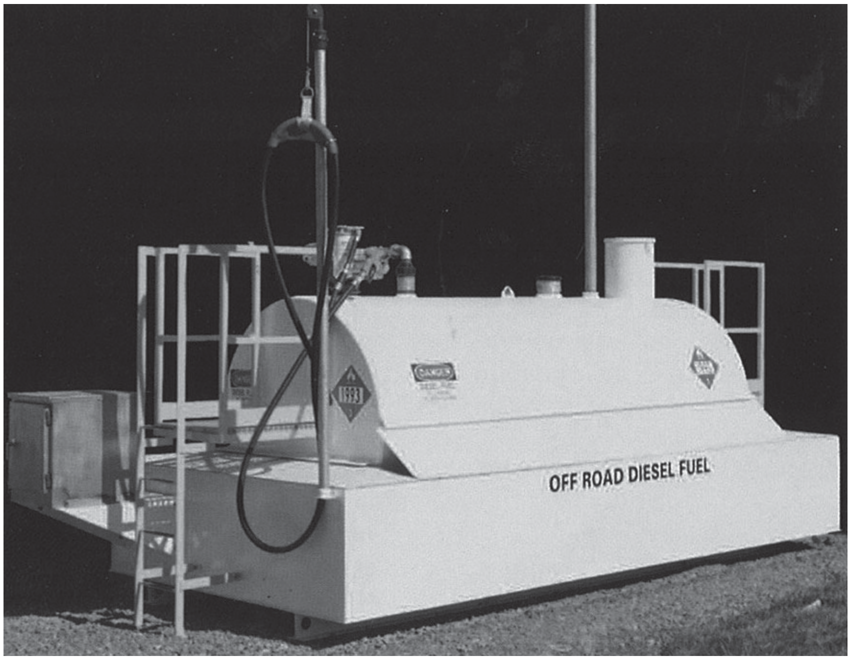


Figure 7-11 Aboveground Storage Tank

4. Add all of the above figures to calculate the total head required.

For a system head loss calculation sheet containing a checklist of all fittings and devices, refer to Figure 7-16. This checklist contains many items that may not be necessary for all installations.

TESTS

Testing of all piping and the UST at the time of installation is critical to ensure that no leakage of product can occur and to check the integrity of the pressure-bearing components. In addition, tests of the UST for deformation after installation and corrosive coating damage are also necessary. Testing must be performed in accordance with code and local jurisdictional authority requirements.

Testing of the Storage Tank

The UST must be pressure-tested before the tank is placed into the excavation and again after backfilling is complete. Certification must be obtained from the manufacturer that the inner and outer tank walls were leak-free prior to shipment. The certification must be based on a factory-performed tank tightness test. If a factory-installed hydrostatic interstitial monitoring system is used, a test before installation is not required since a visual check of the leak detection system will disclose any problem.

The pressure test prior to installation consists of applying 5-psig (34.5-kPa) air pressure in the tank for two hours with no lowering of pressure permitted. At this time, all tank openings should be sealed and a soapy water solution applied to all connections so

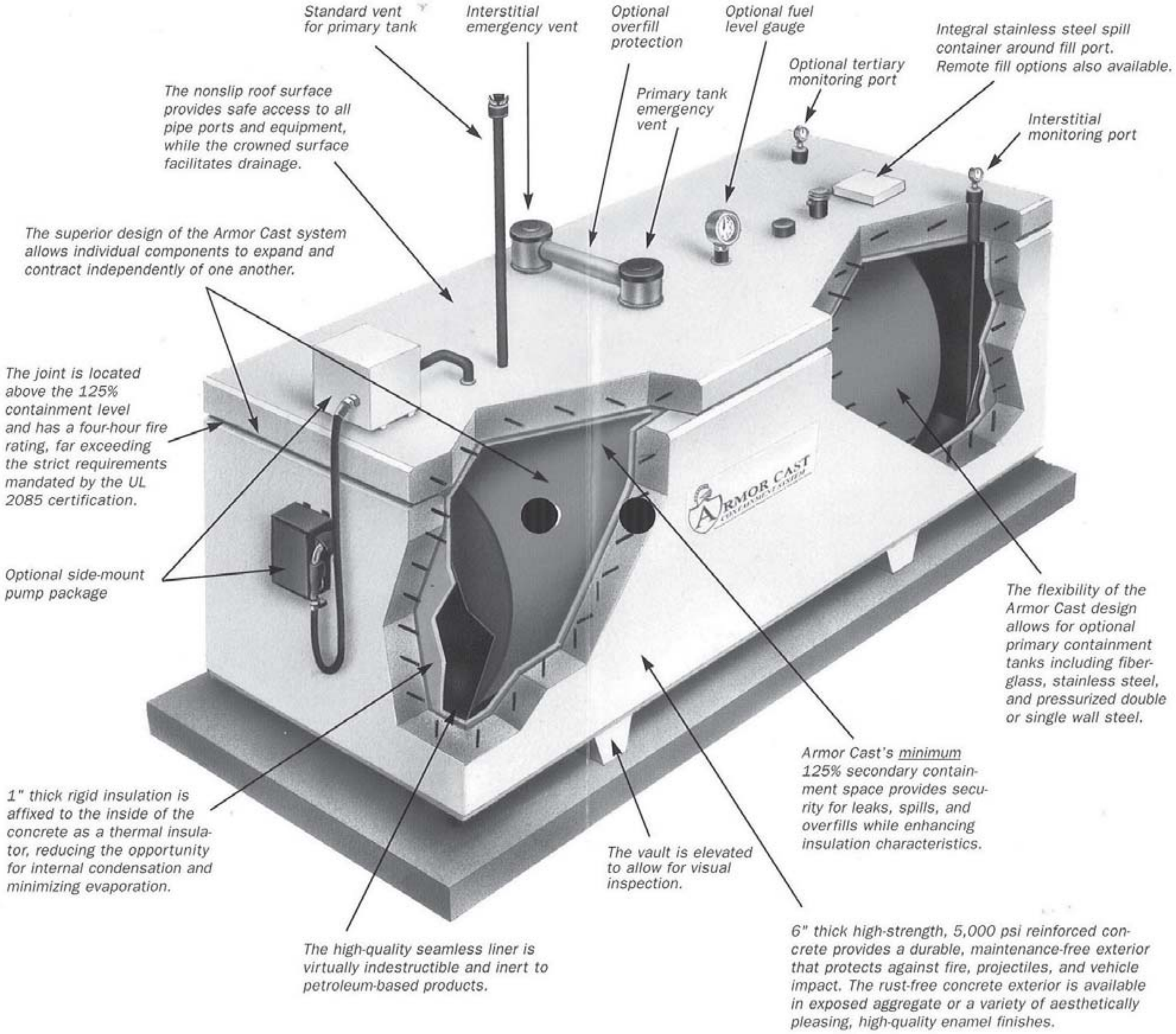


Figure 7-12 Aboveground Storage Tank Installation

any bubbles indicating leakage can be observed. If the tank has a coating for corrosion protection, this must be checked with an electronic device that discloses imperfections in the coating, called holidays, which must be repaired if found.

After installation, a hydrostatic test of the tank should be performed at a pressure of 5 psig (34.5 kPa) for a period of 30 minutes, with all piping isolated so only the tank is under pressure. (It is important to remove all traces of water prior to filling with product.)

Testing of the Piping Network

All piping containing product must be tested hydrostatically at a pressure of 100 psig (689.5 kPa) for a period of 30 minutes with no leakage allowed. Containment piping must be tested with air at 10 psig (68.9 kPa) for 30 minutes with no leakage permitted.

Vent and vapor recovery piping must be tested hydrostatically at a pressure of 30 psig (206.8 kPa) for 30 minutes with no leakage permitted.

Tightness Testing

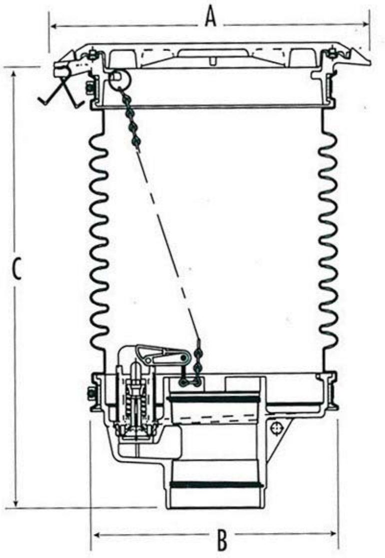
Tightness testing is a general term used to describe the testing and evaluating of existing tanks and piping systems that contain product. Tightness testing is required periodically, following a schedule obtained from the local authority. However, periodic tightness testing generally is not required for the following:

- Tanks and piping containing no. 5 and no. 6 fuel oil
- Tanks and piping with a capacity of 1,100 gallons (4,163.5 L) or less, unless leakage is occurring
- Tanks and piping that are corrosion resistant and have an approved leak-detection system
- Tanks and piping installed in conformance with requirements for new construction
- Tanks larger than 50,000 gallons (189,250 L) where it is technically impossible to perform a meaningful series of tests. In such cases, an alternative test or inspection approved by the local authority must be conducted.

All tests must conform to EPA and local requirements, and the technicians performing them must be trained and qualified by the test equipment manufacturer. The tightness test must detect a leak of 0.1 gph (0.38 L/h) from the system with a detection probability of 95 percent and a false alarm probability of 5 percent. Acceptable leakage amounts are variable and depend on values established by the local authority.

Many types of tests are capable of achieving this precision, and various manufacturers make equipment suited for performing these tests. The following should be considered prior to selecting the type of test:

- Vapor pockets
- Thermal expansion of product



OPW 1-2100E, 5-Gallon (Deep Bucket Model)

Figure 7-13 Fill Installation

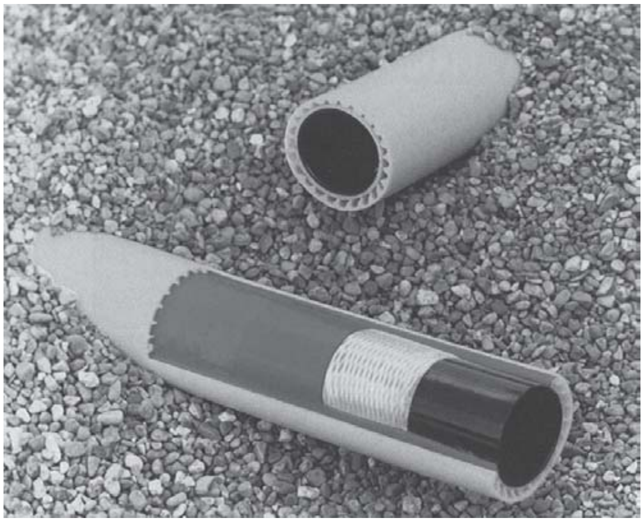


Figure 7-14 Coaxial Pipe

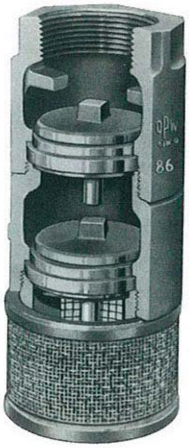


Figure 7-15 Foot Valve

Project ____________________ Specific gravity _______________ Temp. _______________

Liquid _______________ gpm (L/s) Range _________________ Viscosity _______________

Static Losses

Tank Diameter ____________ ft (m)

Bury Depth ____________ ft (m)

Height High Hose Reel ____________ ft (m)

Total Static Height ____________ ft (m)

A. Run of Pipe, Pipe Size (in diameter) ____________ in. (mm)

Measured Run ____________ ft (m)

Fittings — equivalent length (E.L.) ____________ ft (m)

Valves — equivalent length (E.L.) ____________ ft (m)

Reducers and Enlargements (E.L.) ____________ ft (m)

B. Total Equivalent Length ____________ ft (m)

C. Pipe Friction Loss ____________×friction loss/100 ft (30.5 m)

Total Friction Loss ____________ ft (m)

Equipment Loss (in feet head) Meter ____________ ft (m)

Dispenser ____________ ft (m)

Filter and Leak Detector ____________ ft (m)

Hose and Nozzle ____________ ft (m)

Strainer ____________ ft (m)

D. Total Equipment Losses ____________ ft (m)

E. Total Head Loss (A+C+D) ____________ ft (m)

Figure 7-16 System Head Loss Checklist

- Temperature and temperature stratification
- Groundwater level
- Evaporation
- Tank end deflection
- Pressure

SYSTEM INSTALLATION CONSIDERATIONS

Tank Removal and Abandonment

The standard life expectancy for fuel tanks installed today is approximately 30 years, so at some point these tanks will need to be removed or replaced. Every jurisdiction has its own regulations regarding how this is accomplished, so be sure to check with the local authority prior to tank removal. In general, tank removal consists of the following procedures.

- The tank must be emptied as much as possible. Ideally, this is accomplished by using as much product as possible prior to removal and then pumping the remaining product and sludge into labeled containers for proper disposal.
- Once as cleaned out as possible, the tank should be uncovered (if buried), and all manways, pipes, alarms, etc. should be removed.
- The tank then should be removed, and holes should be cut in the ends of the tank to allow quick venting of the tank as well as to facilitate additional sludge removal. Note that only non-sparking pneumatic tools should be used to prevent igniting any vapors present in the tank.
- Sludge and any other foreign materials shall be removed by shoveling and brushing. All major scale should be knocked loose and should be in a "brush clean" condition prior to removal from the site. Proper protective breathing apparatus and protective clothing should be used since the sludge is likely to contain lead and other toxic materials. Again, all sludge and scale from the tank interior should be drummed and legally disposed.

If the tank has been leaking or petroleum product is discovered outside the tank, contact the local authority for direction. At times, the local authority may require the installation of monitoring wells at the spill location. These monitoring wells consist of a slotted pipe that allows monitoring of ground water without excavation.

In most cases, it is advantageous to deal with the contamination issue once it is discovered rather than covering it up and dealing with it at a later date. Several techniques are available for dealing with contaminated soil. The most common method is to haul it to a landfill fitted with facilities to deal with the contamination. It may be cost-effective to deal with the contamination via on-site treatment systems or even by injecting bacteria that will digest the petroleum. In any case, it is important to isolate the contamination to prevent it from migrating further.

At times, it may be necessary to abandon the fuel tank, but this should be considered a last resort. Generally, this is allowed only if the tank removal will impact the structural integrity of a nearby structure. Again, coordinate all requirements for proper abandonment with the local authority.

Tank Installation

The installation of the tank is critical to the longevity and proper functioning of the system and to the prevention of leaks over time. The contractor or installer must be trained and certified by the specific tank manufacturer.

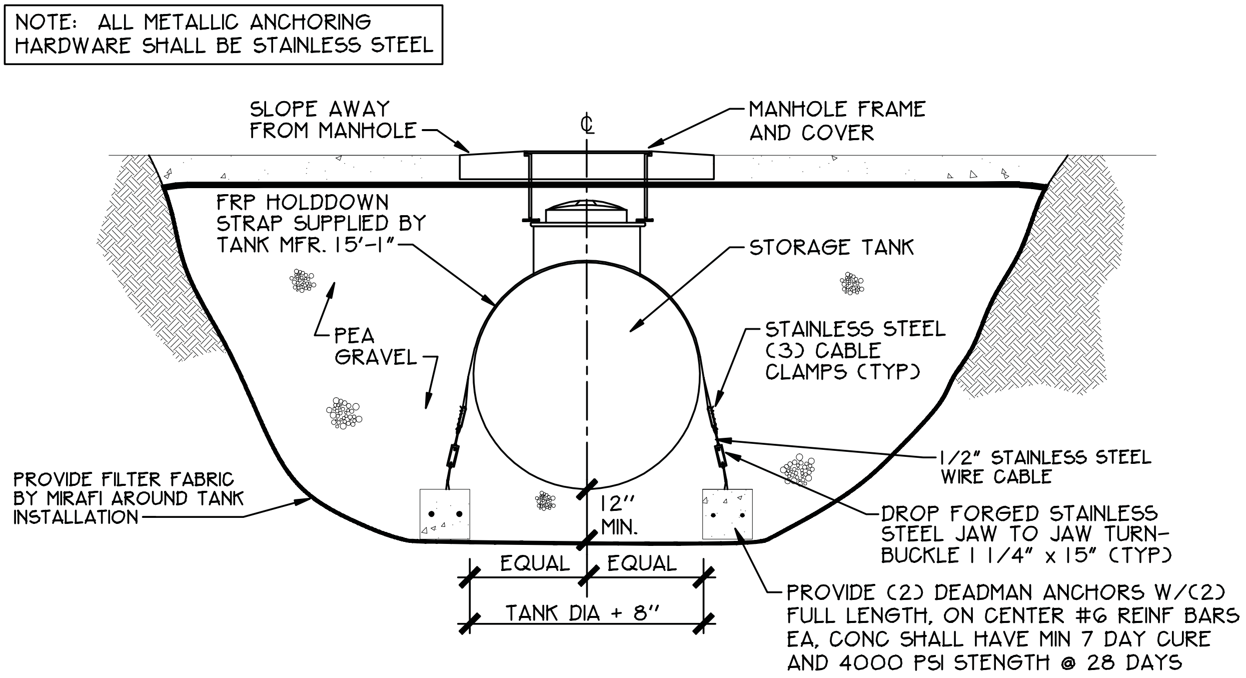


Figure 7-17 Deadman Installation

FRP-type UST tanks rely on the quality of the backfill for long-term support to resist distortion and resulting failure. Experience has shown that carefully compacted, washed pea gravel that is free from any organic matter and has no sharp edges is the best backfill material. FRP tanks must be installed in conformance with API Recommended Practice 1615: *Installation of Underground Petroleum Storage Systems*. If tank floating is a possibility, such as exists in areas subject to flooding or with a high water table, the tanks must be installed over a reinforced concrete ballast pad or deadman concrete anchors heavier than the buoyant force of the tank and anchored to the pad or anchors by means of hold-down straps (see Figure 7-17). The weight of the backfill over the pad, which also resists floating, should not be added but used instead as a safety factor. It is recommended that the calculated load on each hold-down strap have a safety factor of five.

Steel USTs are structurally stronger and do not depend as much as FRP tanks on backfill for support. The backfill must prevent all but very minor shifting or settling of the tank over time. Tanks must be installed in conformance with NFPA 30 and NFPA 31: *Standard for the Installation of Oil-Burning Equipment*. The requirements for a ballast pad and hold-down straps are the same as those for FRP tanks.

When steel tanks are used, they must be protected against corrosion by coating or cladding. Coatings must be tested for faults (called holidays) while the tank is on the truck and after its initial placement in the excavation. All defects found must be repaired in strict conformity to the manufacturer's recommendations.

Tanks should not be stored on the site prior to installation due to the possibility of damage. Arrangements should be made to deliver the tank on the day of installation.

ASTs should be placed on saddles on a level concrete pad of sufficient thickness to adequately support the tank and product. Bollards must be placed around the tank to protect it from vehicle damage.

The placement of the fuel tank must take into consideration its proximity to property lines, septic tanks, drywells, buildings, public ways, additional tanks, and other utilities.

Piping Installation

Pipe should be installed in a flat and level trench, far enough underground to prevent vehicular and frost damage. Initial backfill should be pea gravel, clean sand, or some other acceptable material. A generally accepted minimum depth from grade surface to the top of the pipe is 18 inches (450 mm) where there is no slab, 12 inches (300 mm) below asphalt slabs, and 6 inches (150 mm) under concrete slabs. It is also accepted practice where electrical conduit is installed in the same trench as piping to protect the conduit with a concrete encasement and to provide 4 inches (100 mm) minimum of separation.

Installation Checklist

Following is a typical installation checklist.

1. Is the installation in compliance with federal and local or municipal ordinances?

2. Have specifications and drawings been submitted to regulating bodies for approval?
3. Are all permits for construction compatible with the liquid to be stored?
4. Is the tank material's construction compatible with the liquid to be stored?
5. Will any surrounding structures create excessive loading on the tank?
6. Are clearances from adjacent buildings, property lines, roads, sidewalks, and surroundings in accordance with NFPA and insurance underwriter requirements?
7. Have groundwater tables, flood plains, and adjacent water bodies been investigated?
8. Does the piping system, as designed, create undesirable pressure or vacuum on the tank?
9. Have the chemical and physical properties of the soil been checked?
10. Has the depth of the tank installation been established with respect to traffic conditions over the tank?
11. What is the local seismic zone? Are other earth movements possible?
12. Are existing underground utilities or structures in the area?
13. Do the vent pipe locations pose hazards to buildings or personnel?
14. If a nonmetallic tank is installed, have the ballast pad weight and size been adjusted?
15. Has the frost-line depth in the area been checked for possible tank depth adjustment?
16. Regarding secondary containment, have the natural lay and slope of the land been considered?
17. Has the tank location been provided with restrictive fencing, lightning protection, maintenance lighting and power, and delivery truck access?
18. Can visual and audible alarms be observed or heard by operators?

REFERENCES

- API RP 1004: *Bottom Loading and Vapor Recovery for MC-306 Tank Motor Vehicles*. American Petroleum Institute.
- API Bulletin No. 1615: *Installation of Underground Gasoline Tanks and Piping at Service Stations*. American Petroleum Institute.
- API Bulletin No. 1611: *Service Station Tankage Guide*. American Petroleum Institute.
- Frankel, M. *Facility Piping Systems Handbook*. New York: McGraw-Hill.
- NFPA 30: *Flammable and Combustible Liquids Code*. National Fire Protection Association.
- NFPA 30A: *Code for Motor Fuel Dispensing Facilities and Repair Garages*. National Fire Protection Association.

RESOURCES

- American Petroleum Institute: api.org
- Environmental Protection Agency Office of Water: epa.gov/OW

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8

Steam and Condensate Piping

Put most simply, steam is used as a medium to transfer heat energy from a point of generation to a point of use where the heat energy can be extracted to do work. Steam is an efficient heat-transfer medium and has the advantage of flowing by pressure differential to the point of use. Thus, no pumps are necessary to move the heat-transfer medium as in a hot water system, which reduces initial equipment costs and associated maintenance expenses.

STEAM BASICS

Steam is produced when sufficient heat energy is added to change water from a liquid to a vapor. The heat energy inputs take two forms.

Sensible heat (also referred to as heat of saturated liquid) is the amount of heat energy required to raise 1 pound of water from a temperature of 32°F to the boiling point, or saturation temperature, for any given system pressure. This heat energy input is referred to as "sensible heat" because every British thermal unit (Btu) of heat energy added to the water can be sensed by a thermometer from the fact that the water temperature rises by 1°F. (1 Btu is the amount of energy required to raise the temperature of 1 pound of water by 1°F.) As an example (refer to Table 8-1, column 4), a steam system operating at 15.3 pounds per square inch gauge (psig) requires 218.82 Btu per pound of water of sensible heat energy input to raise the temperature of the water from 32°F to 250.33°F.

Latent heat content is the heat energy required to turn 1 pound of saturated water from a liquid to vapor steam. It is the heat energy available to be extracted from the steam to do work. When the latent heat content of a pound of steam has been extracted by any heat-transfer process, the steam will condense back to saturated liquid. The amount of latent heat energy cannot be determined with a thermometer because the temperature of saturated liquid and steam are identical for any given system pressure. Referring again to Table 8-1, column 5, at 15.3 psig the latent heat content is ~945 Btu per pound.

Specific Volume of Saturated Steam

The volume required per pound of steam at a given pressure (see Table 8-1, column 8) is of great importance when installing a steam-distribution system. The choice of the steam-generation pressure influences both the required distribution pipe size and the steam velocity in the system. Pipe size directly impacts initial system cost, while steam velocity raises issues of erosion and noise. Steam-distribution systems often are designed to generate the steam at a relatively high pressure, requiring smaller diameter, lower cost piping and reducing steam pressure prior to the point of use, thus increasing the available latent heat content.

Flash Steam

Condensed steam (condensate) is saturated liquid at the same temperature as the steam from which it was formed. If this condensate is discharged to an area of lower pressure, the excess sensible heat content of the condensate will cause a portion of the liquid to "flash" or re-evaporate to vapor steam. This is an energy-saving measure that reclaims the heating value of high-pressure condensate rather than letting it vent to atmosphere (to 0 psig) before being returned to the boiler.

Figure 8-1 provides information on flash steam formation for typical systems, while specific values of flash steam formation may be determined using the following equation:

Equation 8-1

$$\%\text{ of flash steam} = \frac{\text{SH}-\text{SL}}{\text{H}} \times 100$$

where:

SH = Sensible heat in the condensate at the higher pressure before discharge

SL = Sensible heat in the condensate at the lower pressure to which the discharge takes place

H = Latent heat in the steam at the lower pressure to which the condensate has been discharged

Table 8-1 Properties of Saturated Steam

	Col. 1 Gauge Pressure	Col. 2 Absolute Pressure (psia)	Col. 3 Steam Temp. (F°)	Col. 4 Heat of Sat. Liquid (Btu/lb)	Col. 5 Latent Heat (Btu/lb)	Col. 6 Total Heat of Steam (Btu/lb)	Col. 7 Specific Volume of Sat. Liquid (cu ft/lb)	Col. 8 Specific Volume of Sat. Steam (cu 11/lb)
Inches of Vacuum	29.743	0.08854	32.00	0.00	1075.8	1075.8	0.096022	3306.00
	29.515	0.2	53.14	21.21	1063.8	1085.0	0.016027	1526.00
	27.886	1.0	101.74	69.70	1036.3	1106.0	0.016136	333.60
	19.742	5.0	162.24	130.13	1001.0	1131.0	0.016407	73.52
	9.562	10.0	193.21	161.17	982.1	1143.3	0.016590	38.42
	7.536	11.0	197.75	165.73	979.3	1145.0	0.016620	35.14
	5.490	12.0	201.96	169.96	976.6	1146.6	0.016647	32.40
	3.454	13.0	205.88	173.91	974.2	1148.1	0.016674	30.06
	1.418	14.0	209.56	177.61	971.9	1149.5	0.016699	28.04
PSIG	0.0	14.696	212.00	180.07	970.3	1150.4	0.016715	26.80
	1.3	16.0	216.32	184.42	967.6	1152.0	0.016746	24.75
	2.3	17.0	219.44	187.56	965.5	1153.1	0.016768	23.39
	5.3	20.0	227.96	196.16	960.1	1156.3	0.016830	20.09
	10.3	25.0	240.07	208.42	952.1	1160.6	0.016922	16.30
	15.3	30.0	250.33	218.82	945.3	1164.1	0.017004	13.75
	20.3	35.0	259.28	227.91	939.2	1167.1	0.017078	11.90
	25.3	40.0	267.25	236.03	933.7	1169.7	0.017146	10.50
	30.3	45.0	274.44	243.36	928.6	1172.0	0.017209	9.40
	40.3	55.0	287.07	256.30	919.6	1175.9	0.017325	7.79
	50.3	65.0	297.97	267.50	911.6	1179.1	0.017429	6.66
	60.3	75.0	307.60	277.43	904.5	1181.9	0.017524	5.82
	70.3	85.0	316.25	286.39	897.8	1184.2	0.017613	5.17
	80.3	95.0	324.12	294.56	891.7	1186.2	0.017696	4.65
	90.3	105.0	331.36	302.10	886.0	1188.1	0.017775	4.23
	100.0	114.7	337.90	308.80	880.0	1188.8	0.017850	3.88
	110.3	125.0	344.33	315.68	875.4	1191.1	0.017922	3.59
	120.3	135.0	350.21	321.85	870.6	1192.4	0.017991	3.33
	125.3	140.0	353.02	324.82	868.2	1193.0	0.018024	3.22
	130.3	145.0	355.76	327.70	865.8	1193.5	0.018057	3.11
	140.3	155.0	360.50	333.24	861.3	1194.6	0.018121	2.92
	150.3	165.0	365.99	338.53	857.1	1195.6	0.018183	2.75
	160.3	175.0	370.75	343.57	852.8	1196.5	0.018244	2.60
	180.3	195.0	379.67	353.10	844.9	1198.0	0.018360	2.34
	200.3	215.0	387.89	361.91	837.4	1199.3	0.018470	2.13
	225.3	240.0	397.37	372.12	828.5	1200.6	0.018602	1.92
	250.3	265.0	406.11	381.60	820.1	1201.7	0.018728	1.74
		300.0	417.33	393.84	809.0	1202.8	0.018896	1.54
		400.0	444.59	424.00	780.5	1204.5	0.019340	1.16
		450.0	456.28	437.20	767.4	1204.6	0.019547	1.03
		500.0	467.01	449.40	755.0	1204.4	0.019748	0.93
		600.0	486.21	471.60	731.6	1203.2	0.02013	0.77
		900.0	531.98	526.60	668.8	1195.4	0.02123	0.50
		1200.0	567.22	571.70	611.7	1183.4	0.02232	0.36
		1500.0	596.23	611.60	556.3	1167.9	0.02346	0.28
		1700.0	613.15	636.30	519.6	1155.9	0.02428	0.24
		2000.0	635.82	671.70	463.4	1135.1	0.02565	0.19
		2500.0	668.13	730.60	360.5	1091.1	0.02860	0.13
		2700.0	679.55	756.20	312.1	1068.3	0.03027	0.11
		3206.2	705.40	902.70	0.0	902.7	0.05053	0.05

Source: Armstrong International, Inc.

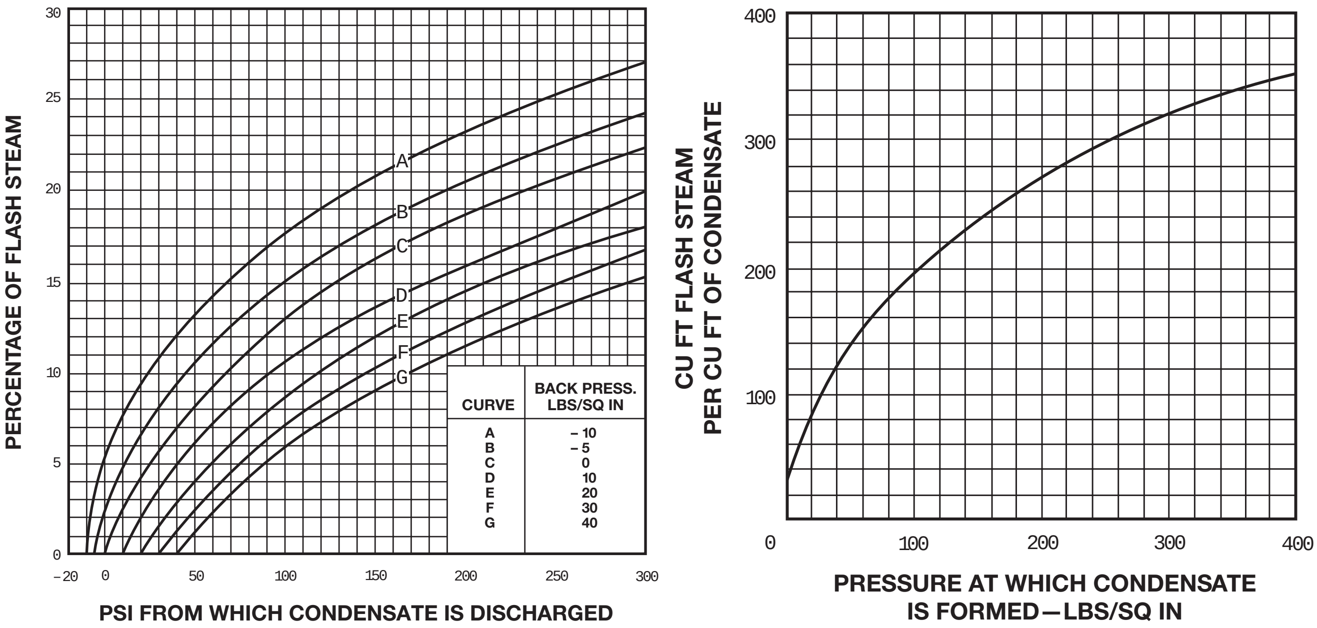


Figure 8-1 (a) Percentage of flash steam formed when discharging condensate to reduced pressure; (b) Volume of flash steam formed when 1 cubic foot of condensate is discharged to atmospheric pressure

Source: Armstrong International, Inc.

Example 8-1

The following example (courtesy of Armstrong International) illustrates the amount of recoverable heat energy in flash steam formation.

Condensate at steam temperature and 100-psig pressure has a heat content of 308.8 Btu per pound (see column 4 in Table 8-1). If this condensate is discharged to atmospheric pressure (0 psig), its heat content instantly drops to 180 Btu per pound. The surplus of 128.8 Btu re-evaporates or flashes a portion of the condensate. Thus,

$$\%\text{ of flash steam} = \frac{308.9 - 180}{970.3} \times 100 = 13.3\%$$

The ability to recover usable heat content in the form of flash steam can greatly increase overall steam system efficiency. Consider a heat exchanger operating on 50-psig steam and condensing 2,000 pounds per hour of condensate:

$$\%\text{ of flash steam} = \frac{267.5 - 180.07}{970.3} \times 100 = 9.01\%$$

Thus, flash steam produced = 0.0901 x 2,000, or 180 pounds per hour.

STEAM DISTRIBUTION PIPING

The purpose of any steam distribution system is to deliver clean, dry steam at the needed pressure to the eventual point of use. Two factors governing the design and sizing of steam distribution piping are steam velocity and the allowable pressure drop in the distribution system.

Steam Velocity

The velocity of the steam in a distribution system is a function of the mass rate of steam flow, steam pressure, and pipe size.

The steam velocity can be determined by the following:

Equation 8-2

$$V = \frac{2.4Q \times V_s}{A}$$

where:

V = Velocity, feet per minute (fpm)
Q = Flow of steam, pounds per hour
V_s = Specific volume of steam at system pressure
A = Internal area of pipe, square inches

Steam velocities of 6,000 to 8,000 feet per minute are common in process steam systems. In heating systems where noise from flowing steam is an issue, velocities are typically 4,000 to 6,000 fpm.

Pressure Drop

One function of the steam distribution system is to deliver the steam at the needed pressure. Friction losses in the piping, as well as flow through elbows, fittings, strainers, and valves, contribute to pressure drop between the boiler and the point of use. While steam velocity is a function of the mass flow rate, pressure drop is a function of the square of the mass flow rate. Table 8-2 provides an example of the relationship of mass flow rate, velocity, and pressure drop in a 2-inch steam line at 100 psig.

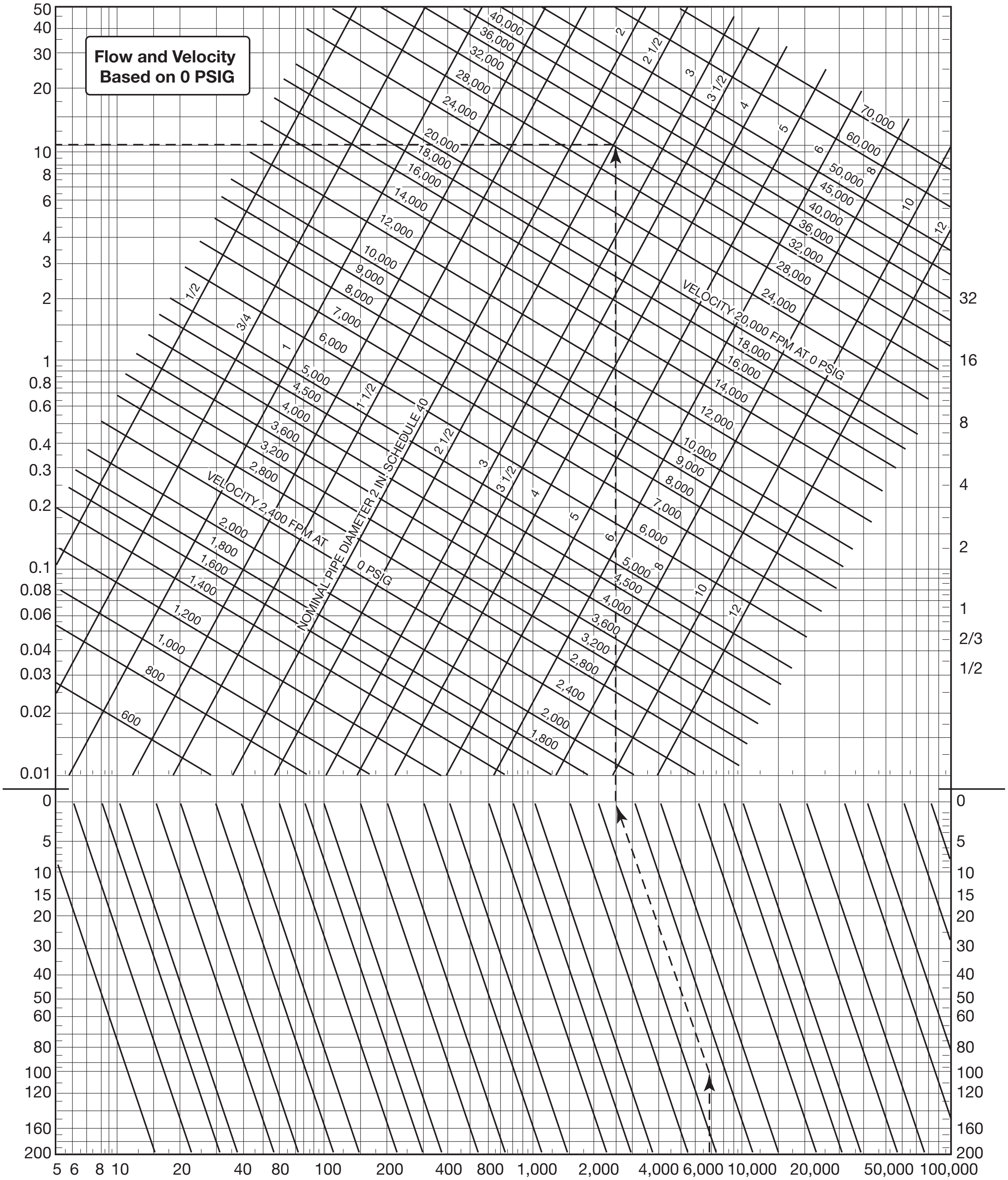


Figure 8-2 Flow Rate and Velocity of Steam in Schedule 40 Pipe at Saturation Pressure of 0 psig

Source: ASHRAE Handbook

Table 8-2 Relationship of Mass Flow Rate, Velocity, and Pressure Drop in a 2-inch Steam Line at 100 psig

Mass Flow (lb/hour)	Velocity (fpm)	Pressure Drop
1,000	2,780	0.7 psi/100 ft
2,000	5,560	2.7 psi/100 ft
3,000	8,340	6.0 psi/100 ft

It is commonly accepted that the total pressure drop in a steam system should not exceed 20 percent of the steam supply pressure at the boiler.

One other factor to note in sizing steam distribution piping is the possibility of future expansion of the steam system. Generous sizing of the original distribution system can save costly retrofits in the future.

Figures 8-2 and 8-3 provide guidance for properly sizing steam distribution lines to take into account both steam velocity and pressure drop. The following example (reprinted with permission from the *ASHRAE Handbook*) illustrates the use of the charts.

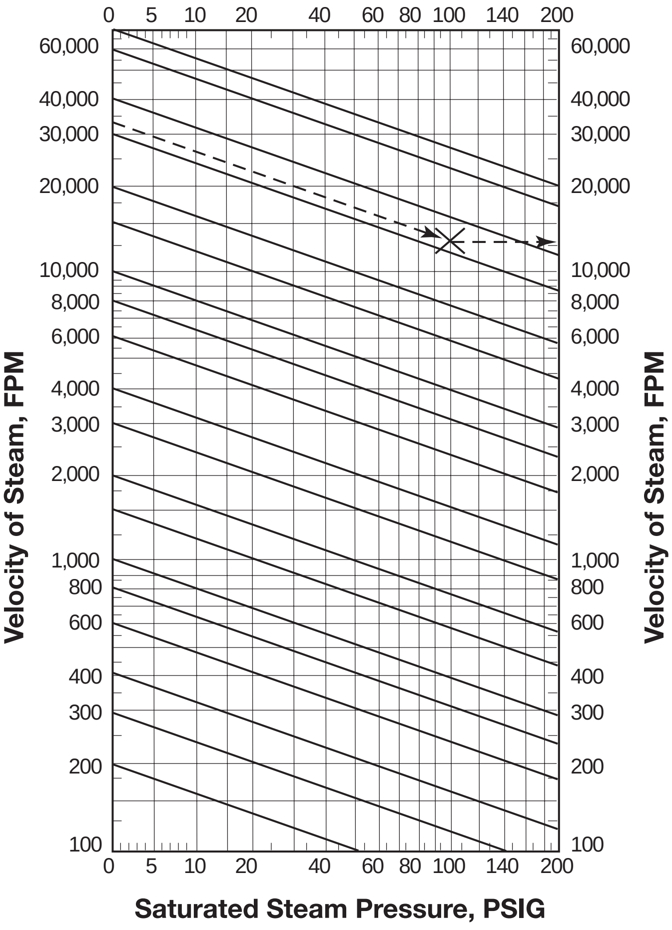


Figure 8-3 Velocity Multiplier Chart for Figure 8-2

Source: ASHRAE Handbook

Example 8-2

Given a flow rate of 6,700 pounds per hour, an initial steam pressure of 100 psig, and a pressure drop of 11 psi per 100 feet, find the size of Schedule 40 pipe required and the velocity of steam in the pipe.

The following steps are illustrated by the broken line on Figure 8-2 and Figure 8-3.

1. Enter Figure 8-2 at a flow rate of 6,700 pounds per hour, and move vertically to the horizontal line at 100 psig.
2. Follow the inclined multiplier line (upward and to the left) to the horizontal 0-psig line. The equivalent mass flow at 0 psig is about 2,500 pounds per hour.
3. Follow the 2,500-pounds-per-hour line vertically until it intersects the horizontal line at 11 psi per 100 feet of pressure drop. The nominal pipe size is 2.5 inches. The equivalent steam velocity at 0 psig is about 32,700 fpm.
4. To find the steam velocity at 100 psig, locate the value of 32,700 fpm on the ordinate of the velocity multiplier chart (Figure 8-3) at 0 psig.
5. Move along the inclined multiplier line (downward and to the right) until it intersects the vertical 100-psig pressure line. The velocity as read from the right (or left) scale is about 13,000 fpm.

Note: Steps 1 through 5 would be rearranged or reversed if different data were given.

Erosion in Steam Distribution Systems

It is important to note that high steam velocity, especially with the presence of entrained droplets of condensate, will erode piping and fittings. This is most apparent at elbows, valves, and reducing fittings where flow direction or flow volume changes cause impingement on the piping.

CONDENSATE REMOVAL

Condensate is formed in steam systems when the latent heat of the steam is given up. This heat transfer can be intentional, such as in a space heater, radiator, or steam jacketed kettle, or unintentional (and unavoidable) due to radiation heat loss from piping and equipment.

In either case, it is imperative that the condensate, as well as any air or other noncondensable gases, be removed from the steam system as quickly as possible. Condensate and noncondensable gases contribute to a loss of heat transfer efficiency, corrosion of piping and equipment, and an increased probability of dangerous water hammer.

The problems resulting from poor condensate drainage are as follows.

- A loss of heat-transfer performance will result unless condensate is drained from the steam heating unit. Since heat transfer in a steam system is based on the large amount of latent heat that becomes available as the steam condenses, if the heating unit is flooded, only the sensible heat from the condensate will become available as it cools. Table 8-1 shows that the sensible heat is only a small fraction of the latent heat available in a pound of steam at any given pressure. The latent heat is transferred at constant steam temperature as the steam condenses.
- Water hammer in an undrained or improperly drained steam main can be caused by the impact of a rapidly moving slug of water. Unless the condensate is removed from low points in the steam mains, it gradually accumulates until the high-velocity steam forms ripples. As condensate builds up, it decreases the area available for steam flow, leading to even higher steam velocities to the point where water is entrained by the steam in the form of a wave. The slug of water accelerated by the steam can reach velocities in excess of 100 miles per hour before it hits some obstruction, such as an elbow or other fitting. The rapid change in speed can cause a loud noise or even severe damage to the system.
- Corrosion occurs in units that are not properly drained. Several corrosion processes have been defined: generalized corrosion, which removes metal more or less uniformly from the surface; oxygen pitting, which concentrates on small areas, rapidly creating holes; and condensate grooving, which etches away the metal along the path followed by condensate, which has become acidic (carbonic acid) due to dissolved carbon dioxide.
- Corrosion is accelerated by the presence of carbon dioxide, which can form in the boiler as chemical components like carbonates and bicarbonates decompose. Oxygen introduced by vacuum breakers or from makeup feed water also increases the corrosion rate.
- Fouling or scaling on heat-transfer surfaces also is increased by inadequate condensate drainage and venting.

STEAM TRAPS

Properly installed steam traps can minimize these problems by draining the condensate and venting noncondensable gases from steam piping and heat exchangers. A steam trap is an automatic valve that is open in the presence of condensate and noncondensable gases and closed in the presence of live steam. The main difference between trap types is the method of actuation. All steam traps must:

- Vent air and other gases from the mains and heating units
- Prevent the flow of steam into the condensate piping
- Allow condensate to drain into the condensate piping

Many steam trap designs have been developed, but the most commonly used traps fall into one of the following categories:

- Thermostatic: The trap opens and closes by sensing the difference in temperature between steam and the condensate, which has been allowed to subcool to below steam temperature. Some examples of this type of trap include thermostatic bellows and bimetallic traps. Figure 8-4 shows a typical thermostatic bellows trap.

Figure 8-4 Thermostatic Bellows Trap

- Mechanical: These include inverted bucket and float and thermostatic (F&T) traps. These traps operate on the difference in density between steam and condensate, opening when a mixture of condensate and steam lifts the bucket (or condensate alone lifts the float) and closing when the condensate is discharged and live steam enters the trap. Figure 8-5 shows a typical inverted bucket trap.
- Thermodynamic disc: This trap senses differences in flow velocity or pressure caused by relatively high-velocity steam compared to lower-velocity condensate. A typical thermodynamic disc trap is shown in Figure 8-6.

Each trap design gives the trap its own set of characteristics. Because of the variety of trap designs, one of the key decisions in condensate drainage design is

Figure 8-5 Inverted Bucket Trap

the choice of the right type of trap. Often this choice is easy; for example, low-pressure heating system radiators are almost always equipped with thermostatic traps because the characteristics of that type of trap match the condensate drainage and air-venting requirements of low-pressure heating equipment. Sometimes, either of two different types of trap could be applied equally well to a given condensate drainage situation because the trap characteristics meet the drainage and venting requirements. For example, a high-pressure steam main could be equipped with either an inverted bucket trap or a thermodynamic disc trap. In some cases, a given kind of trap simply would not be able to do the job. For instance, since a thermodynamic trap requires a significant pressure drop between the steam-condensing device and the condensate pipe, installing such a trap in a low-pressure heating system would not have a great enough pressure differential to operate.

Figure 8-6 Thermodynamic Disc Trap

PROPER CONDENSATE DRAINAGE FROM SYSTEM PIPING

Properly drained mains and care taken in starting up a cold system not only prevent water hammer damage but also improve the quality of the steam and reduce the maintenance required on pressure-reducing valves, temperature controls, and other components.

Startup Loads

When bringing a steam distribution system up to operating pressure and temperature from a cold state, large amounts of latent heat are given up to the piping and fittings. This heat loss causes condensate formation on a scale much greater than that encountered in normal system operation. Table 8-3 gives values for warming-up loads for various sizes of pipe to different saturation temperatures.

Take as an example 300 feet of 10-inch line being brought up to 125-psi system pressure or ~353°F, assuming a warm-up time of one hour. The warming-up load of the line would be 450 pounds per hour of condensate. When at the operating pressure/temperature, this same line only loses latent heat through radiation and creates only 88 pounds per hour of condensate in still air at 70°F with 90 percent efficient insulation, or a factor of more than 5:1.

A liberal steam trap load safety factor and oversized steam traps do not always provide an efficient and safe steam main drain installation. The following points should also be considered by the designer:

- The method of heat up to be employed
- Providing suitable reservoirs, or drip legs, for the condensate
- Ensuring adequate pressure differential across the steam trap
- Selecting and sizing the steam trap
- Proper trap installation

Heat-up Method

The type and size of the steam trap used to drain steam mains depend on the method used to bring the system up to normal operating pressure and temperature. The two methods of system heat up commonly used are the supervised and the automatic heat up.

In the supervised heat-up method, manual drain valves are installed at all drainage points in the steam main system. The valves are fully opened to the condensate return or to drain before steam is admitted to the system. After most of the heat-up condensate has been discharged, the drain valves are closed, allowing the steam traps to drain the normal operating

Table 8-3 The Warming-up Load from 70°F, Schedule 40 Pipe

Steam Pressure, psig		2	15	30	60	125	180	250
Pipe Size (in)	wt of Pipe Per ft (lbs)	Pounds of Water Per Lineal Foot						
1	1.69	.030	.037	.043	.051	.063	.071	.079
1¼	2.27	.040	.050	.057	.068	.085	.095	.106
1½	2.72	.048	.059	.069	.082	.101	.114	.127
2	3.65	.065	.080	.092	.110	.136	.153	.171
2½	5.79	.104	.126	.146	.174	.215	.262	.271
3	7.57	.133	.165	.190	.227	.282	.316	.354
3½	9.11	.162	.198	.229	.273	.339	.381	.426
4	10.79	.190	.234	.271	.323	.400	.451	.505
5	14.62	.258	.352	.406	.439	.544	.612	.684
6	18.97	.335	.413	.476	.569	.705	.795	.882
8	28.55	.504	.620	.720	.860	1.060	1.190	1.340
10	40.48	.714	.880	1.020	1.210	1.500	1.690	1.890
12	53.60	.945	1.170	1.350	1.610	2.000	2.240	2.510
14	63.00	1.110	1.370	1.580	1.890	2.340	2.640	2.940
16	83.00	1.460	1.810	2.080	2.490	3.080	3.470	3.880
18	105.00	1.850	2.280	2.630	3.150	3.900	4.400	4.900
20	123.00	2.170	2.680	3.080	3.690	4.570	5.150	5.750
24	171.00	3.020	3.720	4.290	5.130	6.350	7.150	8.000

load. Therefore, the steam traps are sized to handle only the condensate formed due to radiation losses at the system's operating pressure. This heat-up method generally is used for large installations with steam mains of appreciable size and length and where the heat up generally occurs only once a year, such as in large systems where the system pressure is maintained at a constant level after the startup and is not shut down except in emergencies.

In the automatic heat-up method, the steam boiler brings the system up to full steam pressure and temperature without supervision or manual drainage. This method relies on the traps to drain the warm-up load of condensate automatically as soon as it forms. This heat-up method generally is used in small installations that are shut down and started up at regular intervals, as occurs in heating systems or dry-cleaning plants where the boiler is usually shut down at night and started up again the following morning. To avoid system shock, steam system warm up also can be done with a ¾-foot line with a ½-inch valve to gradually warm up the main for a fixed amount of time before opening the main control valve.

Drip Legs

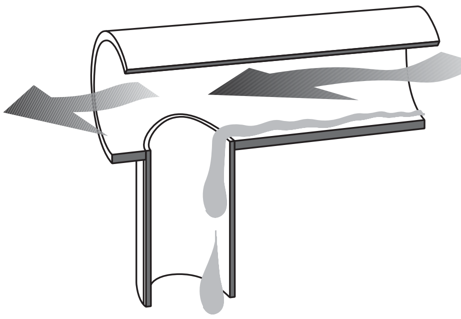
A reservoir, or drip leg, must be provided for the steam trap to be effective, since a steam trap can discharge only the condensate that is brought into it. Drip legs should be provided at all low points in the system and wherever the condensate can collect, such as at the ends of mains, at the bottoms of risers, and ahead of expansion joints, separators, pressure-reducing valves, and temperature regulators.

For long horizontal runs of steam mains and where there are no low drainage points, the drip legs should be provided at intervals of approximately 300 feet, but never more than 500 feet.

Figure 8-7 provides guidelines for drip leg sizing. A properly sized drip leg will capture condensate. An inadequately sized drip leg can actually cause a vertical "piccolo" effect where pressure drop pulls condensate out of the trap. The diameter of the drip leg should be the same as that of the steam main up to 4 inches in diameter and half the steam main diameter (but not less than 4 inches) on larger lines.

Adequate Pressure Differential Across the Trap

The trap cannot discharge condensate unless a pressure differential exists across it—that is, unless there



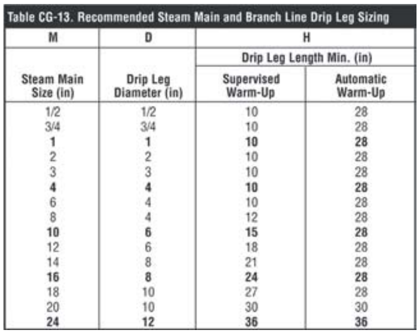


Table CG-13. Recommended Steam Main and Branch Line Drip Leg Sizing

M	D	H	
		Drip Leg Length Min. (in)	
Steam Main Size (in)	Drip Leg Diameter (in)	Supervised Warm-Up	Automatic Warm-Up
1/2	1/2	10	28
3/4	3/4	10	28
1	**1**	**10**	**28**
2	2	10	28
3	3	10	28
4	**4**	**10**	**28**
6	4	10	28
8	4	12	28
10	**6**	**15**	**28**
12	6	18	28
14	8	21	28
16	**8**	**24**	**28**
18	10	27	28
20	10	30	30
24	**12**	**36**	**36**

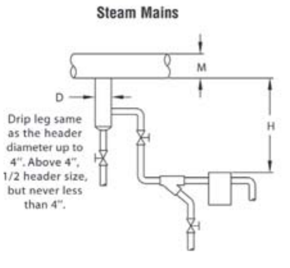


Figure CG-30.
Trap draining drip leg on main.

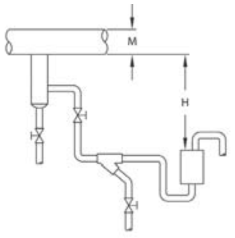


Figure CG-31.
Trap draining drip leg at riser. Distance H in inches 28 = psi static head for forcing water through the trap.

Figure 8-7 Guidelines for Drip Leg Sizing is a higher pressure at the inlet than there is in the condensate line. The drip leg should be of sufficient length to provide a hydrostatic head at the trap inlet so the condensate can be discharged during warm up, before a positive steam pressure develops in the steam main.

For mechanical traps, the minimum differential plus the maximum allowable differential (the trap operating pressure rating) must be considered. In draining devices such as heat exchangers that are controlled by temperature-regulating valves that could possibly operate in a vacuum at part load, install a vacuum breaker to ensure that pressure upstream of the trap cannot fall below atmospheric pressure and that adequate hydrostatic head is available.

Table 8-4 Condensation in Insulated Pipes Carrying Saturated Steam in Quiet Air at 70°F (insulation assumed to be 75% efficient)

Pressure, psi		15	30	60	125	180	250	450	600	800
Pipe Size (in)	sq ft Per Lineal ft	Pounds of Condensate Per Hour Per Lineal Foot								
1	.344	.05	.06	.07	.10	.12	.14	.186	.221	.289
1¼	.434	.06	.07	.09	.12	.14	.17	.231	.273	.359
1½	.497	.07	.08	.10	.14	.16	.19	.261	.310	.406
2	.622	.08	.10	.13	.17	.20	.23	.320	.379	.498
2½	.753	.10	.12	.15	.20	.24	.28	.384	.454	.596
3	.916	.12	.14	.18	.24	.28	.33	.460	.546	.714
3½	1.047	.13	.16	.20	.27	.32	.38	.520	.617	.807
4	1.178	.15	.18	.22	.30	.36	.43	.578	.686	.897
5	1.456	.18	.22	.27	.37	.44	.51	.698	.826	1.078
6	1.735	.20	.25	.32	.44	.51	.59	.809	.959	1.253
8	2.260	.27	.32	.41	.55	.66	.76	1.051	1.244	1.628
10	2.810	.32	.39	.51	.68	.80	.94	1.301	1.542	2.019
12	3.340	.38	.46	.58	.80	.92	1.11	1.539	1.821	2.393
14	3.670	.42	.51	.65	.87	1.03	1.21	1.688	1.999	2.624
16	4.200	.47	.57	.74	.99	1.19	1.38	1.927	2.281	2.997
18	4.710	.53	.64	.85	1.11	1.31	1.53	2.151	2.550	3.351
20	5.250	.58	.71	.91	1.23	1.45	1.70	2.387	2.830	3.725
24	6.280	.68	.84	1.09	1.45	1.71	2.03	2.833	3.364	4.434

Running Loads

As noted earlier, condensate formation is significantly lower after the system has come up to temperature, since it is due only to radiation heat loss from the system through the insulation. Table 8-4 provides condensate loads for various pressures and line sizes.

Piping Layout

Since the condensate in the steam line flows to the drip leg by gravity, it is important that the piping be pitched to properly direct that flow. Figure 8-8 provides guidelines for proper pipe pitch.

Trap Installation

The following recommendations should be observed.

- The steam trap should be installed as close as possible to the drip leg.
- The need to lift condensate to the return system requires special consideration. If the equipment being drained is under modulating pressure, as in a temperature-controlled heat exchanger, the inlet pressure to the trap could fall below that needed to lift the condensate. As a rule of thumb, the trap needs approximately 1 psig at the inlet for every 2 feet of lift to the return (0.43 psig per 1 foot, more precisely). When sufficient lift pressure cannot be guaranteed, the condensate should be drained to a reservoir/pump system and pumped to the return. A check valve should be piped in the trap outlet line if condensate is being lifted to the return.
- Pipe connections to and from the steam trap should be at least equal to the pipe size of the trap connection, and full-size isolation valves should be installed on each side of the trap to allow service.

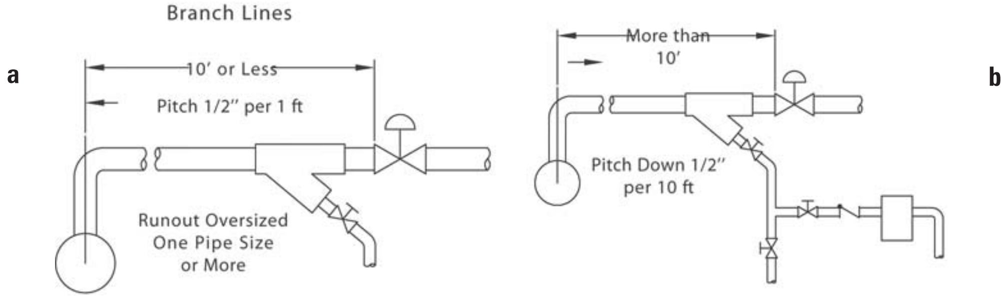


Figure 8-8 (a) Piping for runout less than 10 feet: No trap required unless pitch back to supply header is less than ½ inch per foot; (b) Piping for runout greater than 10 feet: Drip leg and trap required ahead of control valve. Strainer ahead of control valve can serve as drip leg if blowdown connection runs to an inverted bucket trap. This will also minimize the strainer cleaning problem. Trap should be equipped with an internal check valve or a swing check installed ahead of the trap.

Table 8-5 Constants for Determining the Btu Output of a Unit Heater Under Conditions Other than Standard (Standard = 2 pounds of steam pressure at 60°F entering air temperature. To apply, multiply the standard Btu capacity rating of the heater by the indicated constant.)

Steam Pressure, lbs/in^2	Latent Heat of Steam	Entering Air Temperature, °F											
		-10	0	10	20	30	40	50	60	70	80	90	100
2	966.3	–	–	–	–	–	1.155	1.078	1.000	0.926	0.853	0.782	0.713
5	960.7	1.640	1.550	1.456	1.370	1.289	1.206	1.127	1.050	0.974	0.901	0.829	0.760
10	952.4	1.730	1.639	1.545	1.460	1.375	1.290	1.211	1.131	1.056	0.982	0.908	0.838
15	945.5	1.799	1.708	1.614	1.525	1.441	1.335	1.275	1.194	1.117	1.043	0.970	0.897
20	939.3	1.861	1.769	1.675	1.584	1.498	1.416	1.333	1.251	1.174	1.097	1.024	0.952
30	928.5	1.966	1.871	1.775	1.684	1.597	1.509	1.429	1.346	1.266	1.190	1.115	1.042
40	919.3	2.058	1.959	1.862	1.771	1.683	1.596	1.511	1.430	1.349	1.270	1.194	1.119
50	911.2	2.134	2.035	1.936	1.845	1.755	1.666	1.582	1.498	1.416	1.338	1.262	1.187
60	903.9	2.196	2.094	1.997	1.902	1.811	1.725	1.640	1.555	1.472	1.393	1.314	1.239
70	897.3	2.256	2.157	2.057	1.961	1.872	1.782	1.696	1.610	1.527	1.447	1.368	1.293
75	893.8	2.283	2.183	2.085	1.990	1.896	1.808	1.721	1.635	1.552	1.472	1.392	1.316
80	891.1	2.312	2.211	2.112	2.015	1.925	1.836	1.748	1.660	1.577	1.497	1.418	1.342
90	885.4	2.361	2.258	2.159	2.063	1.968	1.880	1.792	1.705	1.621	1.541	1.461	1.383
100	880.0	2.409	2.307	2.204	2.108	2.015	1.927	1.836	1.749	1.663	1.581	1.502	1.424

- A strainer equipped with a blowdown valve should be installed before the steam trap, and a test valve should be installed downstream of the trap. (Some traps now available combine isolation valves, strainers, and test valves in a single package.)
- All low points of the steam main and wherever condensate can collect, such as before pressure-reducing valves and temperature regulators, should be drained.

FLASHING FLOW AND HIGH-PRESSURE CONDENSATE PIPING

Flash tanks play an important role in condensate drainage. They get their name from the sudden evaporation, or flashing, that occurs when condensate at high pressure is suddenly released to low pressure. The production of flash steam also is influenced by other components in the system. For example, thermostatic steam traps open only after the condensate has subcooled to below the saturation temperature for the given pressure. In sizing condensate returns for high-pressure systems, this flash steam must be considered, since it provides more friction loss than would be the case if the flashing did not occur and the pipe was carrying only liquid. Flash steam lines typically are sized for the pressure at which the main is operating. Low-pressure steam requires a larger pipe size than high-pressure steam.

To size condensate pipes to carry flashing condensate, determine the percentage of flash steam using Figure 8-1, and then multiply the total high-pressure condensate flow by the flash steam percentage to determine the flash steam flow rate. This procedure will oversize the condensate pipe to accommodate the flash steam without generating excess return line pressures.

TRAPPING APPLICATIONS

Two common applications for steam in industrial and commercial environments are space-heating equipment and shell and tube heat exchangers.

Trapping Space-heating Equipment

Space-heating equipment is found in most industries. The type and size of trap to be used depend on the application requirements.

Two standard methods for sizing traps for this equipment are available. For constant steam pressure for inverted bucket traps and F&T traps, use a 3:1 safety factor at operating pressure differentials. For modulating steam pressure for F&T traps and inverted bucket traps with thermic buckets, the safety factors are as follows:

- 0–15-psig steam: 2:1 safety factor at 0.5-psi pressure differential
- 16–30-psig steam: 2:1 at 2-psi pressure differential
- More than 30-psig steam: 3:1 at one-half of the maximum pressure differential across the trap

For inverted bucket traps without thermic buckets with more than 30-psig steam pressure only, use a 3:1

safety factor at one-half of the maximum pressure differential across the trap.

Trap Selection for Unit Heaters and Air-handling Units

Three methods can be used to determine the amount of condensate to be handled, based on the operating conditions.

Btu Method

The standard rating for unit heaters and other air coils is Btu output with 2-psig steam pressure in the heater and an incoming air temperature of 60°F. To convert from standard to actual rating, use the conversion factors in Table 8-5, and then multiply the condensate load by the safety factor.

Cubic Feet per Minute and Air Temperature Rise Method

If only the cubic feet per minute (cfm) capacity of the fan and the air temperature rise are known, find the actual Btu output using Equation 8-3:

Equation 8-3

Btu/hr = cfm x 1.08 × temperature rise in °F

The following example from Armstrong International illustrates this equation.

Example 8-3

What size trap will drain a 3,500-cfm heater that produces an 80°F temperature rise? The steam pressure is constant at 60 psig.

Using Equation 8-3:

- 3,500 x 1.08 x 80 = 302,400 Btuh

Now divide 302,400 Btuh by 904.5 Btu (from Table 8-1) to obtain 334 pounds per hour and then multiply by the recommended safety factor of 3. The application needs a trap with a 1,002-pounds-per-hour capacity.

Derive the 1.08 factor in Equation 8-3 as follows:

- 1 cfm x 60 = 60 (cubic feet per hour) cfh
- 60 cfh x .075 pounds of air per cubic foot = 4.5 pounds of air per hour
- 4.5 x 0.24 Btu/lb-°F (specific heat of air) = 1.08 Btu/hr°F-cfm

Condensate Method

The condensate method can be used if the Btu output has been determined. First, divide the Btu output by the latent heat of steam at the steam pressure used. (See Column 2 of Table 8-5 or Table 8-1.) This will give the actual weight of steam condensed. For a close approximation, a rule of thumb is to divide the Btu output by 1,000. Then, multiply the actual weight of steam condensing by the safety factor to get the continuous trap discharge capacity required.

Trapping Shell and Tube Heat Exchangers

In shell and tube heat exchangers (see Figure 8-9), numerous tubes are installed in a housing or shell with confined free area. This ensures positive contact with the tubes by any fluid flowing in the shell. In the most common applications such as water heaters, the steam is in the shell, and the liquid is in the tubes.

The safety factors for constant steam pressure for inverted bucket traps and F&T traps is 2:1 at operating pressure differentials. The safety factors for modulating steam pressure for F&T traps and inverted bucket traps are:

- 0–15-psig steam: 2:1 at 0.5-psi pressure differential
- 16–30-psig steam: 2:1 at 2-psi pressure differential
- More than 30-psig steam: 3:1 at one-half of the maximum pressure differential across the trap

Trap Selection for Shell and Tube Heat Exchangers

To determine the condensate load on shell and tube heaters, use the following formula when the actual rating is known.

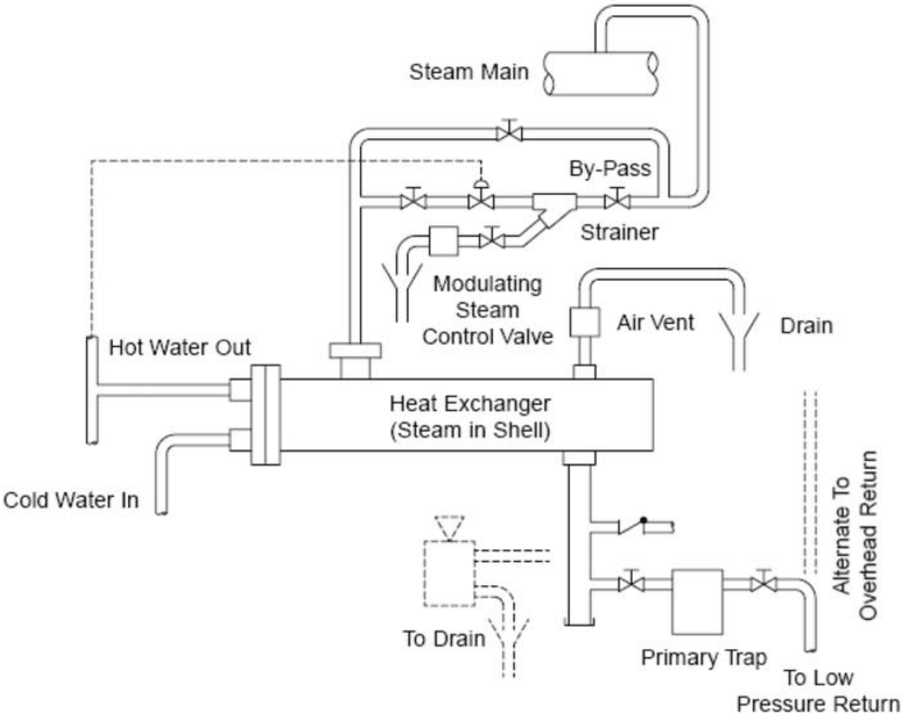


Figure 8-9 Shell and Tube Heat Exchanger

Table 8-6 Specific Gravity and Specific Heats of Various Substances

Substance	Liquid (L) or Solid (S)	Specific Gravity at 60–70°F	Specific Heat at 60°F, Btu/lb-°F
Acetic acid, 100%	L	1.05	0.48
Acetic acid, 10%	L	1.01	0.96
Acetone, 100%	L	0.78	0.514
Alcohol, ethyl, 95%	L	0.81	0.60
Alcohol, methyl, 90%	L	0.82	0.65
Aluminum	S	2.64	0.23
Ammonia, 100%	L	0.61	1.10
Ammonia, 26%	L	0.90	1.00
Aroclor	L	1.44	0.28
Asbestos board	S	0.88	0.19
Asphalt	L	1.00	0.42
Asphalt, solid	S	1.1–.5	0.22–0.4
Benzene	L	0.84	0.41
Brickwork and masonry	S	1.6–2.0	0.22
Brine, calcium chloride, 25%	L	1.23	0.689
Brine, sodium chloride, 25%	L	1.19	0.786
Clay, dry	S	1.9–2.4	0.224
Coal	S	1.2–1.8	0.26–0.37
Coal tars	S	1.20	0.35@40
Coke, solid	S	1.0–1.4	0.265
Copper	S	8.82	0.10
Cork	S	0.25	0.48
Cotton, cloth	S	1.50	0.32
Cottonseed oil	L	0.95	0.47
Dowtherm A	L	0.99	0.63
Dowtherm C	L	1.10	0.35–0.65
Ethylene glycol	L	1.11	0.58
Fatty acid, palmitic	L	0.85	0.653
Fatty acid, stearic	L	0.84	0.550
Fish, fresh, average	S	–	0.75–0.92
Fruit, fresh, average	S	–	0.80–0.88
Gasoline	L	0.73	0.53
Glass, Pyrex	S	2.25	0.20
Glass, wool	S	0.072	0.157
Glue, 2 parts water/1 part dry glue	L	1.09	0.89
Glycerol, 100% (glycerin)	L	1.26	0.58
Honey	L	–	0.34
Hydrochloric acid, 31.5% (muriatic)	L	1.15	0.60
Hydrochloric acid, 10% (muriatic)	L	1.05	0.75
Ice	S	0.90	0.50
Ice cream	S	–	0.70
Lard	S	0.92	0.64
Lead	S	11.34	0.031
Leather	S	0.86–1.02	0.36
Linseed oil	L	0.93	0.44
Magnesia, 85%	S	0.208	0.27
Maple syrup	L	–	0.48
Meat, fresh, average	S	–	0.78
Milk	L	1.03	0.9–0.93
Nickel	S	8.90	0.11
Nitric acid, 95%	L	1.50	0.50
Nitric acid, 60%	L	1.37	0.64
Nitric acid, 10%	L	1.05	0.90
No. 1 fuel oil (kerosene)	L	0.81	0.47
No. 2 fuel oil	L	0.86	0.44
No. 3 fuel oil	L	0.88	0.43
No. 4 fuel oil	L	0.90	0.42
No. 5 fuel oil	L	0.93	0.41
No. 6 fuel oil	L	0.95	0.40
API mid-continent crude	L	0.085	0.44
API gas oil	L	0.88	0.42
Paper	S	1.7–1.15	0.45
Paraffin	S	0.86–0.91	0.62
Paraffin, melted	L	0.90	0.69
Phenol (carbolic acid)	L	1.07	0.56
Phosphoric acid, 20%	L	1.11	0.85
Phosphoric acid, 10%	L	1.05	0.93
Phthalic anhydride	L	1.53	0.232
Rubber, vulcanized	S	1.10	0.415
SAE, SW (#8 machine lube oil)	L	0.88	–
SAE, 20 (#20 machine lube oil)	L	0.89	–
SAE, 30 (#30 machine lube oil)	L	0.89	–
Sand	S	1.4–1.76	0.19
Sea water	L	1.03	0.94
Silk	S	1.25–1.35	0.33
Sodium hydroxide, 50% (caustic acid)	L	1.53	0.78
Sodium hydroxide, 30%	L	1.33	0.84
Soybean oil	L	0.92	0.24–0.33

Steel, mild @ 70	S	7.90	0.11
Steel, stainless, 300 series	S	8.04	0.12
Sucrose, 60% sugar syrup	L	1.29	0.74
Sucrose, 40% sugar syrup	L	1.18	0.66
Sugar, cane and beet	S	1.66	0.30
Sulfur	S	2.00	0.203
Sulfuric acid, 100% (fuming)	L	–	0.27
Sulfuric acid, 98%	L	1.84	0.35
Sulfuric acid, 60%	L	1.50	0.52
Sulfuric acid, 20%	L	1.14	0.84
Titanium (commercial)	S	4.50	0.13
Toluene	L	0.86	0.42
Trichloroethylene	L	1.62	0.215
Tetrachloride carbon	L	1.58	0.21
Turpentine, spirits oil	L	0.86	0.42
Vegetables, fresh, average	S	–	0.73–0.94
Water	L	1.00	1.00
Wines, table, dessert, average	L	1.03	0.90
Woods, vary from	S	0.35–0.9	0.90
Wool	S	1.32	0.325
Zinc	S	7.05	0.095

Equation 8-4

$$Q = \frac{L \times \Delta T \times 500 \times sg}{H}$$

where:
Q = Condensate load, pounds per hour
L = Liquid flow, gallons per minute (gpm)
ΔT = Temperature rise, °F
C = Specific heat of liquid, Btu/lb-°F (Table 8-6)
500 = 60 minutes per hour x 8.33 pounds per gallon
sg = Specific gravity of liquid (Table 8-6)
H = Latent heat of steam, Btu per pound (Table 8-1)

Example 8-4

Assume a water flow rate of 50 gpm with an entering temperature of 40°F and an exiting temperature of 140°F. The steam pressure is 15 psig. Determine the condensate load.

Using Equation 8-4:

$$Q = \frac{50\text{ gpm} \times 100°\text{F} \times 1\text{ Btu/lb-°F} \times 500 \times 1.0\text{ sg}}{945\text{ Btu/lb}}$$

Thus, Q = 2,645 pounds per hour.

TECHNICAL RESOURCES

All reputable steam equipment manufacturers have technical manuals and other literature available to aid in the proper design, sizing, installation, and maintenance of steam systems and equipment. The ASHRAE Handbooks also provide valuable information on these issues.

REFERENCES

- *Fundamentals Handbook*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE).
- *Solution Source for Steam, Air, and Hot Water Systems*, Armstrong International Inc.
- *Publication No. 200,* Hydronics Institute.

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9

Compressed Air Systems

Air is the natural atmosphere surrounding Earth and is a major source of power possessing many advantages for industrial and commercial applications. It is nonflammable, economical, easily transmitted, and adaptable. Compressed air has thousands of applications. It is used for hand tools, air hammers, paving breakers, rock drills, positive-displacement pumps, paint chippers, vibrators, and more. It also is employed to actuate linear movement through a piston and cylinder or a diaphragm for air-actuated valves, doors, dampers, brakes, etc. Atomizing, spraying, and moving hard-to-pump fluids are other applications. Compressed air can be bubbled to measure fluid levels, agitate liquids, and inhibit ice formation in bodies of water. Another use of compressed air is for instrumentation. Air circuits solve the most complex problems in automatic control, starting and stopping, and modulation of valves, machines, and processes. Some applications would be almost impossible with any power medium other than compressed air.

This chapter discusses compressed air for industrial and commercial applications. For medical compressed air used in healthcare facilities, refer to Chapter 2: "Plumbing Design for Healthcare Facilities." For purified compressed air used in laboratories, refer to Chapter 12: "Laboratory Gases."

For the purposes of this chapter, a compressed gas is any gas at a pressure higher than atmospheric.

CODES AND STANDARDS

The building codes and standards impacting the design and installation of compressed air systems have been put in place to protect the safety and health of operating personnel and building occupants. However, no mandated code requirements have been written specifically about compressed gases. Industry standards and guidelines are published by the Compressed Gas Association (CGA) and National Fire Protection Association (NFPA). These requirements are usually specific to the type of facility, application, and end user.

FUNDAMENTALS

Air is a fluid. The two types of fluids are liquids and gases. Gases have a weaker cohesive force holding their molecules together than liquids and will conform to the shape of their container. Ambient air is a mixture of gases, the main components of which are oxygen and nitrogen, along with many other gases in minor concentrations. For the composition of dry air, refer to Table 9-1.

The actual volume of an atom of gas in relation to the total volume of a gas molecule is quite small; thus, gases are mostly empty space. Pressure is produced when the molecules of a gas in an enclosed space rapidly strike the enclosing surfaces. If the gas is confined to smaller and smaller spaces, the molecules strike the container walls more and more frequently, producing greater pressure.

Because free air is less dense at higher elevations, a correction factor (see Table 9-2) must be used to determine the equivalent volume of air at high elevations. Temperature is also a consideration. Because a volume of free air at a high temperature exerts a higher pressure than the same volume of air at a lower temperature, a correction factor (see Table 9-3) must be used to determine the equivalent volume of air at different temperatures.

The most commonly used compression process in industrial compressed air production is the polytropic process, which allows variations in pressure,

Table 9-2 Elevation Correction Factor

Altitude, ft (meters)	Correction Factor
0 (0)	1.00
1,600 (480)	1.05
3,300 (990)	1.11
5,000 (1,500)	1.17
6,600 (1,980)	1.24
8,200 (2,460)	1.31
9,900 (2,970)	1.39

Table 9-1 General Composition of Dry Air

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

temperature, and volume to occur during the compression cycle.

UNITS OF MEASURE

Pressure

Pressure measurements are made using force acting upon an area. In the United States, pressure is commonly measured using inch-pound (IP) units of measurement and expressed as pounds per square inch (psi). Another common unit of measurement for low-pressure systems is inches of water column (in. wc). In International System (SI) units, pressure is commonly measured in kilopascals (kPa).

The two basic reference points for measuring pressure are standard atmospheric pressure and a perfect vacuum. When pressure is measured using standard atmospheric pressure as the point of reference, the measurement is called gauge pressure, expressed as pounds per square inch gauge (psig) (kPa). If the reference pressure level is a perfect vacuum, the term used is absolute pressure, expressed as pounds per square inch absolute (psia) (kPa absolute). A graphical representation of the relationship between gauge and absolute pressure is shown in Figure 9-1. A perfect vacuum has a value of 0 psia (0 kPa) and 0 inch of mercury (Hg).

Local barometric pressure, which is the prevailing pressure at any specific location, is variable and should not be confused with standard atmosphere, which is the theoretical barometric pressure at sea level (14.7 psia or 0 psig and 29.92 inches Hg [101.4 kPa and 760 mm Hg]).

Flow Rate

The most common IP unit of measure for flow rate is cubic feet per minute (cfm). If the flow rate is low, it commonly is expressed in cubic feet per hour (cfh). The SI units used for flow rate are cubic meters per minute (m^3/min), liters per minute (L/min), and liters per second (L/s).

Flow rate must reference a standard, which in the United States is 14.7 psia, standard atmospheric temperature (60°F [15.6°C]), and 0 percent humidity. This is called "standard air" and is referenced as standard cubic feet per minute (scfm) or actual cubic feet per minute (acfm) (nL/min or aL/min). Some manufacturers use nm^3/min, which means normal cubic meters per minute, or nL/min, which means normal liters per minute (the SI equivalent of standard air). It is mandatory that all flow rate criteria for the selection of equipment be in the same units.

WATER VAPOR IN AIR

Air contains varying amounts of water vapor, depending on its temperature and pressure. When a given volume of free air is compressed under conditions used in facilities, an increase in temperature occurs, resulting in an increased ability of the air to retain moisture. With each 20°F (5.6°C) increase in temperature, the ability of air to accept water vapor doubles. Because of the high temperature of the air during the compression cycle, water is not precipitated during compression inside the compressor; rather, it is precipitated after the cycle has been completed.

The quantity of moisture carried during the process varies widely with the ambient temperature. The amount of moisture in completely saturated air is referred to as 100 percent humidity. Relative humidity is the amount of water vapor actually present compared to that of saturated air. It is not the preferred manner to express moisture. The

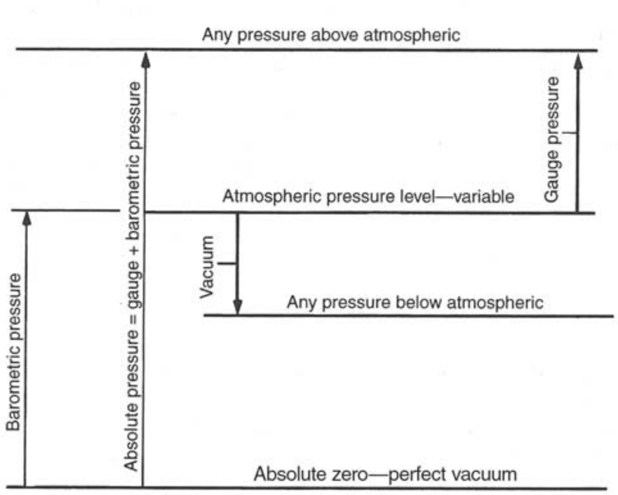
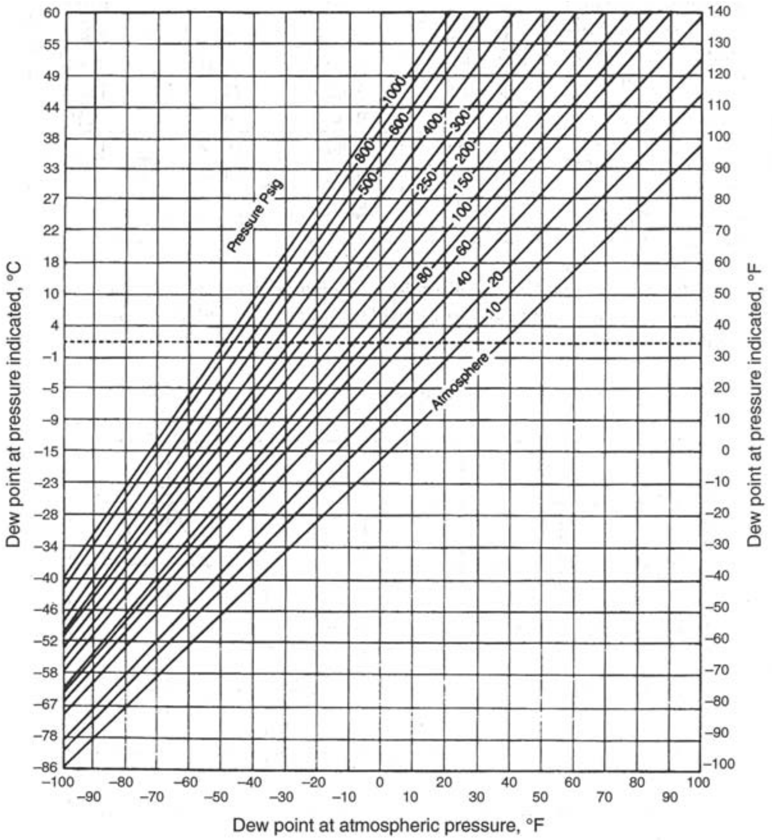


Figure 9-1 Relationship Between Gauge and Absolute Pressure

Table 9-3 Temperature Correction Factor

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



Note: Multiply pressure in PSIG by 6.9 to obtain KPa

Figure 9-2 Dewpoint Conversion Chart

Source: Hankison Corp.

preferred method is to use the dewpoint, which is the temperature at which moisture will condense on a surface and does not depend on temperature. A chart comparing the dewpoints at various pressures is shown in Figure 9-2.

CONTAMINANTS

The four general classes of contamination in air are liquids (oil and water), vapor (oil, water, and hydrocarbons), gas, and particulates. Knowing the various pollutants in the air is helpful when the engineer has to decide what equipment is required to effectively reduce or remove them. The required level of protection from the various contaminants depends on the purpose for the air. The performance criteria for each system, along with the identity and quantity of pollutants, must be determined prior to the selection of equipment.

Liquids

Water enters a system with the intake air, passes through the compressor as a vapor, and condenses afterward into liquid droplets. When water settles on or within pipes, corrosion begins, ultimately ruining machinery and tools, causing product contamination and rejection. Water also allows microorganisms to grow.

Most liquid oil contamination originates at the intake location or in an oil-lubricated compressor. As the droplets are swept through the system at velocities approaching 4,000 feet per minute (fpm) (1,200 m/min), they gradually erode obstructions in their path by repeated collisions. At high temperatures, oils break down to form acids. In the presence of particulates, oil forms sludge. Oil also can act like water droplets and cause erosion.

Liquid chemicals react with water and corrode surfaces. There is no safe level of liquids in the airstream. They should be removed as completely as practical.

Vapor

Water vapor is the most common contaminant to enter the system. Oil, water, and chemical vapors enter the system in the same manner as liquids and contribute to the corrosion of surfaces in contact with the air. Oil vapor also reacts with oxygen to form varnish buildup on surfaces.

The level of acceptable water vapor varies with the end-use requirements. A dewpoint of -30°F (-34°C) is required to minimize corrosion in pipelines. For critical applications, a dewpoint of -100°F (-86°C) may be required. Oil vapor remaining in the air should be removed as much as practical. Chemical concentrations should be reduced to zero where practical.

Gas

Gases such as carbon dioxide, sulfur dioxide, and nitrogen compounds react with heat and water to form acids. Gases in any quantity that are potentially harmful to the system or process requirements should be reduced to zero or to a point that will cause no harm, depending on practical considerations. Condensable hydrocarbons should be removed as completely as practical.

Particulates

Particulates enter the system from the air intake, originate in the compressor due to mechanical action, or are released from some air-drying systems. These particles erode piping and valves or cause product contamination. However, the most harmful effect is that they clog orifices or passages of (for example) tools at the end-use points. These particulates include metal fines, carbon and Teflon particles, pollen, dust, rust, and scale.

Particulate contamination must be reduced to a level low enough to minimize end-use machine or tool clogging, cause product rejection, or contaminate a process. These values must be established by the engineer and client and will vary widely. The general range of particle size in a typical system is between 0.01 and 10 micrometers (μm) in diameter.

USE FACTOR

The use factor represents how many of the tools connected to the system will be in use simultaneously and their air usage. Experience indicates that it is almost impossible to accurately determine a use factor for commercial and industrial applications. Therefore, sufficient receiver capacity or large compressor capacity to allow for possible variances must be provided. The selection of the use factor shall be verified with the end user.

SYSTEM COMPONENTS

Air Compressor

The purpose of an air compressor is to concentrate free air, decreasing its volume and thereby increasing its pressure. The two general categories of air compressors are positive displacement and dynamic.

The positive-displacement compressor is essentially a constant-volume, variable-pressure machine capable of operating over a wide range of discharge pressures at a relatively constant capacity. Positive-displacement compressors can be further categorized as reciprocating or rotary machines. Typical reciprocating compressors include piston and diaphragm types. Rotary compressors include such types as sliding vane, liquid ring (or liquid piston), and screw. The most widely used types of dynamic compressors include the centrifugal and the axial flow.

Dynamic compressor characteristics are opposite those of the positive-displacement compressor. This machine operates over a relatively wide range of capacities at a relatively constant discharge pressure.

Reciprocating Compressor

A reciprocating compressor uses positive displacement, which is accomplished by a piston moving in a cylinder similar to an internal combustion engine. When compression occurs on only one stroke, it is called a single-acting cylinder, and when compression occurs on both strokes, it is called a double-acting compressor. The cylinders can be horizontal, vertical, or angled, and they can be sealed and lubricated with oil when traces of oil in the discharge air are not problematic. Oil-free machines are also available, but they cost more than those requiring oil.

Cooling is accomplished by air or water. Water cooling is generally more effective than air cooling and consumes less power, but the initial and

Figure 9-3 Typical Aftercooler and Moisture Separator

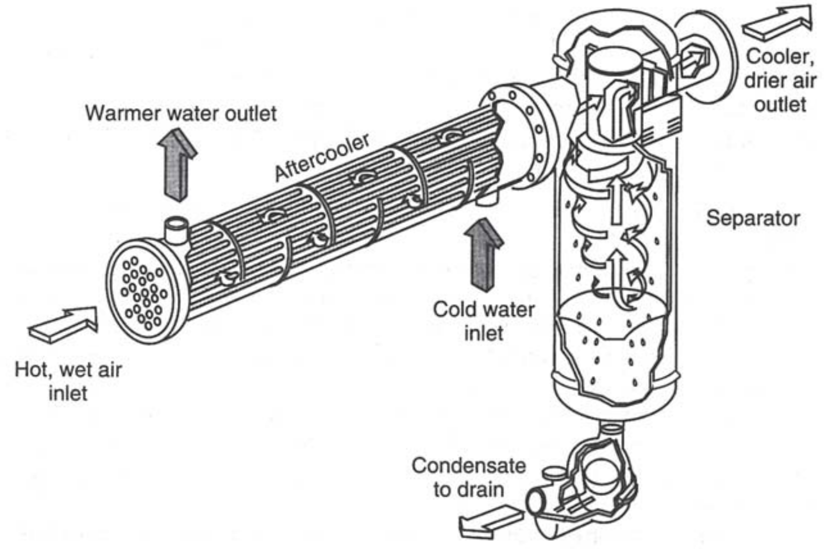


Table 9-4 Standard ASME Receiver Dimensions

Diameter, in.	Length, ft	Volume, ft3
13	4	4.5
14	6	11
24	6	19
30	7	34
36	8	57
42	10	96
48	12	151
54	14	223
60	16	314
66	18	428

Notes: 1 in. = 25.4 mm; 1 ft = 0.003 m3; 1 ft = 0.3 m

Table 9-5 Selection of Supply Hose Size

	Air Inlet Port NPT, in.			
	8	¼	a	½
Supply Hose Size ID, in.	¼	a	½	¾

Table 9-6 Inlet Air Filter Characteristics

Filter Type	Filtration Efficiency, %	Particle Size, μm	Maximum Drop When Clean, wc	Comments (see key)
Dry	100 99 98	10 5 3	3–8	(1)
Viscous impingement (oil wetted)	100 95 85	20 10	¼–2	(2) (3)
Oil bath	98 90	10 3	6–10 = nominal 2 = low drop	(2) (3) (4)
Dry with silencer	100 99 98	10 5 3	5(5) 7(6)	

(1) Recommended for nonlubricated compressors and for rotary vane compressors in a high-dust environment
(2) Not recommended for dusty areas or for nonlubricated compressors
(3) Performance requires that oil is suitable for both warm and cold weather operation
(4) Recommended for rotary vane compressors in normal service
(5) Full flow capacity up to 1,600 scfm
(6) Full flow capacity from 1,600 to 6,500 scfm

operating costs are higher. A two-stage compressor consumes less power than a single-stage unit for the equivalent output.

Sliding Vane Compressor

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

These are compact units, well suited for direct connection to a relatively high-speed motor. Their efficiency is usually less than that of an equivalent piston unit. They are best applied in situations where small, low-capacity compressors, generally in the range of 100 cfm and 75 psi (2,832 L/min and 517.1 kPa), are required.

Liquid Ring Compressor

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

This type of compressor also can handle wet, corrosive, or explosive gases. Various liquids, which are compatible with specific gases to be compressed, can be used.

This unit is very well suited for hospital and laboratory use. A practical limitation of 100 psi (689.5 kPa) exists, and they consume more power than piston units of a similar rating.

Straight Lobe Compressor

Straight lobe (often referred to as rotary lobe) compressors function in a manner similar to that of gear pumps. A pair of identical rotors, each with lobes shaped like the figure 8 in cross section, are mounted inside a casing. As they rotate, air is trapped between the impeller lobes and pump casing and carried around without compression. This air is then discharged, using the existing pressure in the system to increase pressure. These units are available oil free and generally are recommended for pressures up to 200 psig (1,379 kPa) and 150 scfm (4,285 nL/min).

Rotary Screw Compressor

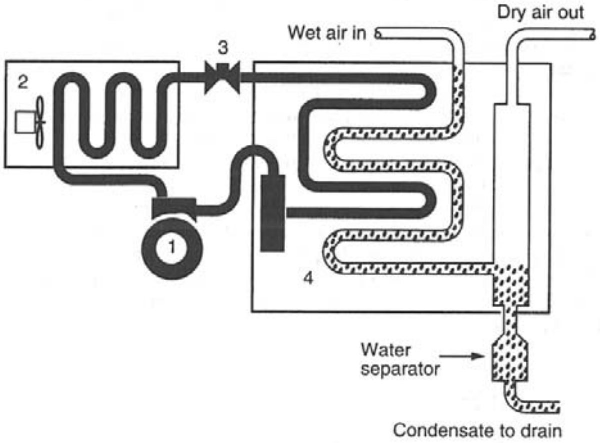
Rotary screw compressors use a pair of close-clearance, helical-lobe rotors turning in unison. As air enters the inlet, the rotation of the rotors causes the cavity in which air is trapped to become smaller and smaller, increasing pressure. The air reaches the end of the screw at high pressure and flows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

The majority of rotary screw compressors in use today are of the oil-flooded type, but designs that produce oil-free air are available. These compressors produce pulse-free air and are generally available for pressures from 150 to 300 psi (1,034 to 2,068 kPa) and 300 scfm (8,496 nL/min).

Centrifugal Compressor

Centrifugal compressors are dynamic machines that utilize impellers to add kinetic energy to the airstream by centrifugal action. The velocity of the air is increased as it passes through each impeller. A diffuser section decelerates the high-velocity air, converting the kinetic energy into potential energy. The volute

Figure 9-4 Refrigerated Air Dryer with Four Major Components: (1) Refrigeration Compressor A hermetically sealed motor-driven compressor operates continuously and generates a high-pressure refrigerant gas. (2) Hot Gas Condenser The high-pressure refrigerant gas enters an air-cooled condenser where it is partially cooled by a continuously running fan. (3) Automatic Expansion Valve The high-pressure liquid enters an automatic expansion valve where it thermodynamically changes to a subcooled low-pressure liquid. (4) Heat Exchanger A system of coils produces dry air. Source: Arrow Pneumatics



further increases the pressure and directs the air into the discharge piping.

Centrifugal compressors typically produce large volumes of air at relatively low pressures. Higher pressures can be attained by adding stages with intercooling between the stages. The centrifugal compressor takes up less floor space but requires more power than a reciprocating unit of equal output. Its inherently oil-free air delivery is a major advantage in many applications.

Piping

The most often used pipe material is ASTM B88 copper tube for water use. When considering other materials, the engineer should take into account the pressure rating of the pipe and joints, the temperature rating of the pipe, and the joining method. If all elements are equal, the least expensive piping shall be selected.

The allowable pressure ratings for the various piping materials is based on wall thickness values at ambient temperatures calculated from equations appearing in ASME B31.3: *Process Piping Design*. The pipe pressure rating is selected to resist the highest system design pressure, which is usually in the range of 50–55 psi (344.7–379.2 kPa). Higher pressures for special uses are well within the limits of piping with flared and brazed joints. Type L copper tubing is used for pressures up to 200 psi (1,379 kPa), and type K is used for pressures up to 300 psi (2,068.4 kPa).

Joints

The most often used joint for copper tubing at low pressures is the soldered joint, with those at 100 psig (689.5 kPa) and above being brazed. The flared joint is popular because it can be made using only a saw and some wrenches. When copper tubing is used with flared joints, the pipe shall not have embossed identification stamped into the pipe because doing so causes leaks at the joint. There is no designation for patented flared joints, but they are acceptable for all applications as long as the allowable joint pressure ratings are not exceeded.

Experience has shown that reaming the ends of pipe or tubing to obtain a smooth interior has left pieces of shaved metal in the pipe. If this is a cause for concern, reaming methods and tools are available to eliminate this problem.

For systems with operating pressures up to 200 psi (1,379 kPa) and piping 4 inches (101.6 mm) and smaller, consider 304 or 316 stainless steel and/or copper tubing with press-fit joining.

Valves

Valves are an often-overlooked component of a compressed air system, but the valve type and material are important to efficiency and operating life. The valves used should have been designed for compressed air service. Be careful to examine valve specifications for airway ports or openings smaller than the nominal size indicated or expected.

The most often used shutoff valves are ball valves. Three-piece valves also are desirable because the body can be separated from the end connections when being installed and serviced. For exact control and modulating purposes, needle valves are used because of the precise level of control permitted.

In addition to the end use, the engineer should take the following design considerations into account when selecting valves.

- The most important valve feature is minimum flow restriction (pressure drop) when the valve is fully open. Ball, gate, and plug valves have the lowest pressure drop, and it is extremely rare to use these types for flow restriction.
- The pressure rating should be suitable for the maximum pressure possible.
- The valve body and seat materials must be compatible with the expected trace gases and contaminants.
- The valve must be capable of positive shutoff.
- Leakage through the valve stem should be prevented.

Flow Meters

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

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

Compressed Air Receivers

The primary purpose of a receiver is to store air. Secondary purposes are to equalize pressure variations (pulsations) from the compressor and to collect residual condensate. Determination of the need for a receiver is always based on the type of pressure regulation the system uses. If the compressor runs 100 percent of the time and has constant pressure and blowoff, an air receiver is not required.

For most applications, the system pressure is regulated by starting and stopping the compressor, with a receiver used to store air and prevent the compressor from cycling too often. The generally accepted practice for reciprocating compressors is to limit starts to about 10 per hour (less is better) and the running time to 70 percent. Centrifugal, screw, and sliding vane compressors are best run 100 percent of the time, but the starts still should be limited to about 10 starts per hour.

Receivers should be ASME stamped for unfired pressure vessels. Manufacturers offer standard receiver sizes measured in gallons (liters) of water capacity (see Table 9-4). Receivers should be selected based on system demand and compressor size, using the starts per hour and running time best suited for the project. The design engineer must keep in mind that a compressor operates to satisfy the pressure switch rather than the use of air and that the receiver is an integral part of the system that must function with respect to load conditions, amount of storage, and pressure differential. Often the manufacturer offers a standard size receiver for specific compressor models, but a commonly used formula to estimate the size of the receiver is as follows:

Table 9-7 Recommended Air Inlet Pipe Size

Maximum scfm Free Air Capacity	Minimum Size, in.
50	2½
110	3
210	4
400	5
800	6

Note: 1 cfm = 0.03 m^3/min
Source: James Church

Table 9-8 Equivalent Pressure Loss Through Valves and Fittings, ft of pipe

Nominal Pipe Size, in.	Actual ID, in.	Gate Valve	Long Radius, All or on Run of Standard Tee	Standard Ell or on Run of Tee Reduced in Size 50 Percent	Angle Valve	Close Return Bend	Tee Through Side Outlet	Globe Valve
½	0.622	0.36	0.62	1.55	8.65	3.47	3.10	17.3
¾	0.824	0.48	0.82	2.06	11.4	4.60	4.12	22.9
1	1.049	0.61	1.05	2.62	14.6	5.82	5.24	29.1
1¼	1.380	0.81	1.38	3.45	19.1	7.66	6.90	38.3
1½	1.610	0.94	1.61	4.02	22.4	8.95	8.04	44.7
2	2.067	1.21	2.07	5.17	28.7	11.5	10.3	57.4
2½	2.469	1.44	2.47	6.16	34.3	13.7	12.3	68.5
3	3.068	1.79	3.07	6.16	42.6	17.1	15.3	85.2
4	4.026	2.35	4.03	7.67	56.0	22.4	20.2	112.0
5	5.047	2.94	5.05	10.1	70.0	28.0	25.2	140.0
6	6.065	3.54	6.07	15.2	84.1	33.8	30.4	168.0
8	7.981	4.65	7.96	20.0	111.0	44.6	40.0	222.0
10	10.020	5.85	10.00	25.0	139.0	55.7	50.0	278.0
12	11.940	6.96	11.00	29.8	166.0	66.3	59.6	332.0

Notes: 1 ft = 0.3 m; 1 in. = 25.4 mm

Equation 9-1

$$T = \frac{V \times (P_1 - P_2)}{C + P_a}$$

where:

T = Time the receiver takes to go from the upper to the lower pressure limit, minutes
V = Volume of the tank, cubic feet (m^3)
P_1 = Maximum tank pressure, psia (kPa)
P_2 = Minimum tank absolute pressure, psia (nL/min)
C = Free air needed, scfm (nL/min)
P_a = Atmospheric pressure, psia (kPa)

While it is common practice to locate a receiver near the compressor, the designer should consider locating the receiver at the largest air consumers. Installation of a receiver at a remote point on the piping system allows the system to handle surges and possibly can eliminate the need for an additional compressor.

Piping connections should be made in such a way that the incoming air is forced to circulate and mix with the air already inside the tank before being discharged. A common piping scheme used in large manufacturing facilities is to provide a loop header around the plant. This scheme provides flexibility for future connections and reduced pressure drops to remote locations. Oversizing the header one pipe size also provides storage capacity and may eliminate the need for a remote receiver.

An automatic drain valve is required so the receiver can discharge wastewater to an adjacent floor drain through an air gap.

Aftercoolers

An aftercooler is used to lower the temperature of the compressed air immediately after the compression process. Air leaving the compressor is very hot, and it is desirable to reduce the temperature of discharged air to the range of 70–110°F (21.1–43°C). A primary reason the temperature is lowered is to remove moisture that would otherwise condense elsewhere in the system as the air cools to ambient conditions. Therefore, it is considered good practice to install the cooling unit as close to the compressor discharge as practical. An aftercooler is also useful to precondition air where additional conditioning is necessary.

The three general types of aftercoolers are water cooled, air cooled, and refrigerant. Air-cooled is the most often used type of aftercooler.

Since large amounts of water typically are removed from the air in an aftercooler, a moisture separator is usually provided. The separator could be either an integral part of the aftercooler or a separate unit. Additional factors to be considered when selecting an aftercooler are pressure drop through the unit, space and clearance requirements, operation costs, and maintenance.

Separators

A separator is a type of filter used to remove large quantities of liquid water or oil from the airstream. Often, oil and water form an emulsion inside the compressor and are discharged together.

Since suspended liquids are present after air leaves the aftercooler or compressor, the compressor discharge is the most common location for a separator. The general design of these units should allow for the removal of between 90 and 99 percent, by weight, of liquids. An aftercooler and separator are illustrated in Figure 9-3.

Compressed Air Dryers

Air dryers are used to remove additional water vapor from the airstream after the separator has removed large volumes of water consisting of large droplets. The general categories of dryer, defined by the method of drying, are high pressurization of the compressed air, refrigerated, absorption, desiccant (adsorption), and heat of compression.

High Pressurization

High pressurization reduces the quantity of water vapor by compressing air to pressures greater than those required for actual use. An increase in pressure decreases the ability of air to hold moisture. Since pressurization requires large amounts of energy, this process is rarely used.

Refrigerated Dryer

The most common type of dryer uses a refrigerant and is called a refrigerated dryer. It lowers the temperature of the airstream through a heat exchanger to produce a lower dewpoint. Lowering the dewpoint reduces the capability of the air to retain moisture. Moisture then condenses out of the air onto the coils of the dryer, and a moisture separator removes the condensate.

The cooling medium in the coil could be water, brine, or a refrigerant. A refrigerated dryer requires operation within a small range of pressure and airflow rates to be effective. In general, a minimum of 20 percent of rated airflow is required to achieve the specified moisture removal.

The greatest limitation of these dryers is that they cannot practically produce a pressure dewpoint lower than 35°F (1.7°C). Otherwise, the condensed moisture would freeze on the coils. The advantages are that they have a low operating cost and do not introduce impurities into the airstream. A refrigerated air dryer is illustrated in Figure 9-4.

Absorption

Absorption dryers use either a solid or a liquid medium and operate on the principle that when the airstream containing water vapor passes through or over a deliquescent material, the water causes the medium to change state (or dissolve). The solvent is then drained away; thus, the water is removed, and the amount of material available for absorption is reduced. Solid absorbers are much more common than liquid ones.

The advantage of this type of dryer is that it requires no outside power source or connection to any other system. A disadvantage is that impurities may be introduced into the airstream.

Desiccant Dryers

Desiccant dryers use a porous, nonconsumable material that causes water vapor to condense as a very thin film on the material's surface, a process called adsorption. This material is called a desiccant. No chemical interaction occurs, and the adsorption process is reversible. Desiccant dryers are capable of producing pressure dewpoints as low as -100°F (-73.3°C).

Desiccant materials include silica gel, activated alumina, and aluminosilicate (molecular sieve). Each material also has applications for the removal of specific impurities other than water. Desiccant materials age when in use over a period of years, which may affect their capacity. In addition, care must be taken to avoid contamination of the materials, particularly by oils.

The method of regeneration is the primary way to distinguish between types of desiccant dryers. One type is the duplex-bed pressure swing (heatless) dryer, which uses approximately 15 percent of the hot air directly discharged from the compressor before it goes into the aftercooler to dry one bed while the other is operating. Additional compressor capacity is necessary to provide this extra air. The other type is the heat-activated dryer, which uses internal or external heaters.

A typical desiccant air dryer is illustrated in Figure 9-5.

Heat of Compression

Another type, the heat of compression dryer, accomplishes continuous regeneration of the desiccant material by using a portion of the hot air directly discharged from the compressor before it goes into the aftercooler. The difference between this and the pressure swing dryer is that for continuous duty, the pressure swing regenerates one whole bed at a time, requiring a second bed to dry the airstream. The continuous dryer has only one bed that rotates and regenerates a portion of the desiccant material on a continuous basis, leaving the remainder of the bed to dry the air. The air used to regenerate the desiccant is then returned into the main airstream. No regeneration air is lost, and no electric heaters are used. This dryer could be cooled by a fan (air cooled) or water cooled. Units that are cooled with air at 95°F (35°C) often give a pressure dewpoint of -15°F (-26.1°C).

Dryer Selection

The most important requirement in the selection process is to determine the lowest required pressure dewpoint for the intended application. The economics of initial and operating costs, which vary from one unit to another, are another determining factor. Space conditions and maintenance availability also should be considered.

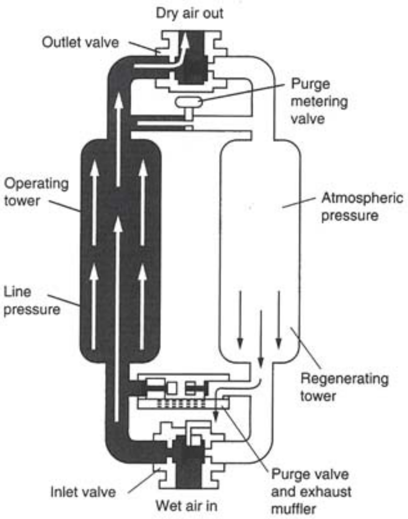


Figure 9-5 Absorption (Dessicant) Dryer

Source: Van Air Systems

Regulators

A regulator is used to reduce a variable high inlet pressure to a constant lower outlet pressure. Regulators are available in two types: single and double stage. The single stage is less costly and less accurate. This type should be chosen if maintenance of an exact pressure is not a major factor in system operation. The double stage is more costly and more accurate, and it is able to achieve a constant outlet pressure within a narrow operating range. When selecting a regulator for specific accuracy requirements, obtain the accuracy envelope diagrams from the manufacturer to check the device parameters using actual anticipated system design pressures and flow rates.

The single-stage regulator reduces pressure in one step. Typical differences in outlet pressure could vary as much as 7 psig (49 kPa) from low to high flow rates. The double-stage regulator reduces the pressure in two steps. Typical differences in outlet pressure could vary as much as 3 psig (21 kPa) from low to high flow rates.

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

The following design considerations should be taken into account when selecting a regulator.

Table 9-9 General Air Requirements for Tools

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

Notes: 1 psi = 6.9 kPa; 1 cfm = 0.03 m^3/min

- The regulator should have a positive gas vent.
- The regulator must be rated for the highest possible working pressure.
- The delivery pressure range must be adequate.
- The operating temperature must be compatible with the environment in which the regulator is located.
- The pressure range of the gauges must be compatible with the pressures expected. As an ideal, the working pressure should be half the maximum outlet gauge reading.

Filters and Purifiers

Filters and purifiers are necessary to reduce or eliminate unwanted contaminants and particulates other than water in the airstream. The most common purifiers are those used to remove water vapor, hydrocarbons, and particulates. They are also used to eliminate other unwanted trace elements if desired by the user.

The most often used filter removes particulates 0.2 μm and larger, and a number of materials are used for filters. To remove hydrogen, palladium filters are used. Ceramic, fiberglass, sintered metal, and other adsorbent material are used to remove oil, moisture, and other trace contaminants. Another type of filter material is the molecular sieve, which is a synthetically produced crystalline metal powder that has been activated for adsorption by removing the water of hydration. This material is manufactured with precise and uniform size and dimensions, which determines what can be filtered. Sieves are available as powder, pellets, beads, and mesh.

Pressure drop through the filter medium is a critical factor in the selection of the material used. For large installations, pressure gauges on each side of the filter are used to monitor their effectiveness. Usually, a 5-psig (35-kPa) drop means that replacement is required.

Relief Valves

Relief valves are used to protect a system from overpressure. A relief valve must be provided between the regulator and the first shutoff valve in the system, at the first point in the system that could be subject to full cylinder pressure if the regulator should fail. The discharge should be independently piped outdoors, and the discharge pipe should be a minimum of ¾ inch in diameter. No valve should be located between the relief valve and the regulator, and no connection from any source to a relief discharge may be made from any other system. The relief valve release point should be set to 50 percent more than working pressure.

When two-stage regulators are used, a preset first-stage (or interstage) relief valve is sometimes required to protect the second stage from overpres-

Table 9-10 High-Pressure Compressed Air Friction Loss Table

cfm	Pressure Loss Through Schedule 40 Steel Pipe, feet											
	½-in. diameter			¾-in. diameter			1-in. diameter			1¼-in. diameter		
	at 125 psi	at 175 psi	at 250 psi	at 125 psi	at 175 psi	at 250 psi	at 125 psi	at 175 psi	at 250 psi	at 125 psi	at 175 psi	at 250 psi
6	.102	.075	.054	.023								
8	.181	.133	.096	.041	.030							
10	.283	.208	.149	.064	.047	.034	.017					
15	.636	.469	.336	.144	.106	.076	.038	.028				
20	1.131	.833	.597	.255	.188	.135	.067	.050	.036	.016		
25	1.768	1.302	.933	.399	.294	.211	.105	.078	.056	.025	.019	
30	2.546	1.875	1.344	.574	.423	.303	.152	.112	.080	.037	.027	
35	3.465	2.552	1.829	.782	.576	.413	.206	.152	.109	.050	.037	.026
40	4.526	3.333	2.388	1.021	.752	.539	.270	.199	.142	.065	.048	.034
45	5.728	4.218	3.023	1.292	.952	.682	.341	.251	.180	.083	.061	.044
50	7.071	5.208	3.732	1.596	1.175	.842	.421	.310	.222	.102	.075	.054
60	10.183	7.499	5.374	2.298	1.692	1.213	.607	.447	.320	.147	.108	.078
70	13.860	10.207	7.315	3.128	2.303	1.651	.826	.608	.436	.200	.147	.105
80		13.331	9.554	4.085	3.008	2.156	1.079	.794	.569	.261	.192	.138
90		16.872	12.092	5.170	3.807	2.729	1.365	1.005	.721	.330	.243	.174
100		20.830	14.928	6.383	4.700	3.369	1.685	1.241	.890	.408	.300	.215
125			23.325	9.973	7.344	5.263	2.633	1.939	1.390	.637	.469	.336
150				14.361	10.576	7.579	3.792	2.793	2.001	.918	.676	.494
175					14.395	10.316	5.162	3.801	2.724	1.249	.920	.659
200					18.801	13.474	6.742	4.965	3.558	1.632	1.202	.861
225						17.053	8.533	6.284	4.503	2.065	1.521	1.090
250						21.054	10.534	7.757	5.559	2.550	1.878	1.346
275						25.475	12.746	9.387	6.727	3.085	2.272	1.628
300						30.317	15.169	11.171	8.006	3.671	2.704	1.938
325								13.110	9.396	4.309	3.173	2.274
350								15.205	10.867	4.997	3.680	2.637
375								17.454	12.509	5.736	4.224	3.027
400								19.859	14.232	6.527	4.806	3.445
425								22.419	16.067	7.368	5.426	3.889
450									18.013	8.260	6.083	4.360

Notes: 1 ft = 0.3 m; 1 in. = 25.4 mm; 1 psi = 6.9 kPa

sure. Additionally, it is good practice to install an adjustable relief valve on the second stage to protect the system and instruments from damage due to excessive pressure. For outdoor installations involving inert gases, the relief valves can exhaust directly to atmosphere. For indoor installations, or any installation involving toxic or flammable gases, the relief valve exhaust should be captured and vented to a safe location.

Hose and Fittings

Most tools use flexible hose to connect to the piping system, and the hose used is usually larger than the air inlet port on the tool it serves. Table 9-5 indicates generally accepted practice for the selection of supply hose based on the size of the inlet port. When the length of the hose extends more than 20 feet (6 m), one size larger should be used to allow for the additional friction loss. It is good practice to limit the friction loss within the hose to approximately 5 psig (35 kPa).

(Refer to Table 9-11 for pressure loss through various sizes and lengths of hose.)

Alarms

Alarms are necessary to alert users of immediate or potential trouble, and they can be visible and/or audible. The typical alarms are high system pressure, low system pressure, and reserve in use. In some installations, a normal light is also requested. If a single cylinder is the sole source of supply, an alarm might be installed when the pressure in the tank reaches 400 psig (2,800 kPa). Other alarms could be provided to indicate high pressure loss at filters, low gas temperature, purifiers at limit of capacity, and flow limit valve operation.

These alarms typically are installed in an alarm panel. The panel could be mounted in a constantly occupied location such as a maintenance shop or receptionist area or in the area of use itself, depending on the availability and level of maintenance.

Various devices must be placed in the system for these alarms to function, such as pressure switches, transducers, and auxiliary contacts in a manifold assembly to transmit the alarm signal to the alarm panel.

Vibration Isolation

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

Compressor Inlet Piping

Since air compressor performance depends on inlet conditions, the inlet piping system deserves special care and should be held to the minimum requirements. The air intake should provide a supply of air to the compressor that is as clean, cool, and dry as possible. Depending on location, an inlet filter may be required. Table 9-6 provides the characteristics of inlet air filters. The velocity of the inlet air should be limited to about 1,000 fpm (300 m/min) The proposed location should be studied for the presence of any type of airborne contamination and positioned to avoid the probability of contaminated intake. For recommended intake piping sizes, refer to Table 9-7.

PIPE LAYOUT DESIGN AND SIZING

On the piping layout, the following information must be available:

- A list of all air-consuming devices and their locations
- Minimum and maximum pressure requirements for each device
- Actual volume of air used by each device
- Suggested duty cycle and diversity factor for equipment
- Special individual air purification requirements
- An allowance for future expansion

Recommended Pipe and System Sizing

Following is a recommended system sizing procedure. (Note: The sizing procedure discussed below is not intended for compressed air for laboratories.)

1. Locate the mechanical room and lay out the locations of compressors and ancillary equipment.
2. Establish a general layout of the system from the storage area to the farthest outlet or use point. Measure the actual distance along the run of pipe to the most remote outlet. Next, add a fitting allowance. For ease of calculations, the addition of 30 percent to the actual measured run will give a conservative approximation of the entire system. Adding the measured length to the fitting allowance will result in the equivalent run of pipe. If a precise calculation is desired, refer to Table 9-8 for the equivalent loss of pressure, in feet, through valves and fittings.
3. Obtain specific purity requirements from the end user and choose all of the filters, purifiers, and accessories necessary for system purity. This will establish a combined allowable pressure drop through each of them and the assembly as a whole.
4. Establish the actual pressure required at the farthest outlet.
5. Calculate the allowable total system friction loss.
    a. It is accepted practice for general use to have a minimum system pressure loss of 10 percent in the pipe. For high-pressure systems serving specific equipment or tools, start with the high end of the range for the actual pressure required. Thus, for a 125-psig (860-kPa) system, a figure of ±12 psig (85 kPa) friction loss will be allowed. This figure is variable. To that figure add the pressure required to overcome the drop through the ancillary purifier equipment and other accessories as required.
    b. Divide the total equivalent run of pipe (in hundreds of feet) by the allowable friction loss to calculate the allowable friction loss per 100 feet of pipe. This calculation is necessary to allow the use of the sizing chart provided in this chapter. If other methods are used to indicate friction loss in the piping system, calculate the loss in that specific method.

6. Calculate the connected flow rate for the piping to be sized. In the absence of data from the end user, Table 9-9 provides preliminary data on air usage and pressure. For general use other than the equipment listed, a figure of 1 scfm (30 nL/min) for each outlet is used unless information from the end user indicates otherwise. Calculate the scfm (nL/min) of gas through each branch, from the farthest outlet back to the source (or main). For specific equipment, use the flow rate recommended by the manufacturer.
7. Calculate the expected flow rate for all points using the appropriate diversity factor for all parts of the system. For specific equipment, the duty factor must be determined from the end user. The diversity (simultaneous use) factor, which determines the maximum number of outlets in use at any one time, has a major influence on the sizing of the piping system. Consulting with the end user to determine the diversity factor is strongly suggested. Starting from the most remote point on the branch and then proceeding to the main, calculate the actual flow rate using the appropriate diversity factor.
8. With the above information available, the piping system can be sized using the charts for system pressure. Table 9-10 provides a sizing chart for pressure losses through piping for air at various high pressures. Since many tools are connected to piping through hose, Table 9-11 provides friction losses through various size hoses. Enter the appropriate table with the actual flow rate and the allowable friction loss. Find the flow rate, and then read across to find a friction loss figure that is equal to or less than the allowable friction loss. Read up the column to find the size. In some cases, the diversity factor for the next highest range of outlets may result in a smaller-size pipe than the range previously calculated. If this occurs, do not reduce the size of the pipe; keep the larger size previously determined.

FLUSHING AND TESTING THE DISTRIBUTION SYSTEM

After the system is completely installed and before it is placed in service, the piping system must be flushed to remove all loose debris and then tested. An accepted flushing method is to allow a volume of two to five times the expected flow through each respective part of the system. This is done by connecting air under pressure to the piping system and then opening and closing all outlets and valves, starting from the closest and working to the most remote.

Testing is done by pressurizing the system to the test pressure with air. The system test pressure for low-pressure systems is 150 percent more than the working pressure. For systems with a working pressure up to 200 psig, the entire piping system is tested to 300 psig for one hour, with no leakage permitted. If a working pressure higher than 200 psig is required, the system is tested at 150 percent of the system pressure. This pressure testing should be done in increments of 100 psig, starting with 100 psig. This is done to avoid damage due to a catastrophic failure. Leaks are repaired after each increment. After final testing, it is recommended that the piping be left pressurized at the system working pressure.

GLOSSARY

Absolute pressure The arithmetic sum of gauge and atmospheric/barometric pressures. It must be used in all calculations involving the basic gas laws.

Absolute temperature The temperature of a body referred to as absolute zero, at which point the volume of an ideal gas theoretically becomes zero. On the Fahrenheit scale, this is -459.67°F; on the Celsius scale, it is -273.15°C. Engineering values of -460°F and -273°C are typically used.

Aftercooling The cooling of air in a heat exchanger following the completion of compression to reduce the temperature and to liquefy condensable vapors

Altitude The elevation of a compressor above sea level

Barometric pressure The absolute atmospheric pressure existing at the surface of Earth. It is the weight of a unit column of air above the point of measurement. It varies with altitude and, at any given location, with moisture content and weather.

Capacity The quantity of air actually delivered when operating between the specified inlet and discharge pressures. For ejectors, capacity is measured in pounds per hour. For all other compressor types, capacity is a volume measured at the conditions of pressure, temperature, gas composition, and moisture content existing at the compressor inlet flange.

Compressed air Ambient air stored and distributed at a pressure greater than atmospheric pressure (14.7 psia, 101 kPa)

Compressibility The property of air or of an air mixture that causes it to differ in volume from that of a perfect gas when each is under the same pressure and temperature conditions. Occasionally it is called deviation. It must be experimentally determined.

Compression efficiency The ratio of the theoretical work requirement (using a stated process) to the actual work required to be done on the air for compression and delivery. Expressed as a percentage, compression efficiency accounts for leakage and fluid friction losses and thermodynamic variations from the theoretical process.

Compression ratio The ratio of the absolute discharge to the absolute intake pressure. It usually

Table 9-11 Friction Loss for Hose, psi

Free Air Flow, scfm	6 ft, 1/8 in.	8 ft, 5/32 in.	8 ft, ¼ in.	8 ft, 5/16 in.	8 ft, 3/8 in.	12.5 ft, ½ in.	25 ft, ½ in.	50 ft, ½ in.	25 ft, ¾ in.	50 ft, ¾ in.	8 ft, 5/32 in. 25 ft, ½ in.	8 ft, ¼ in. 50 ft, ½ in.	12.5 ft, ½ in. 25 ft, ¾ in.	12.5 ft, ½ in. 50 ft, ¾ in.
2	3.5	1.2									1.3			
3	7.3	2.7									2.8			
4	12.5	4.4									4.6			
5		6.7									6.9			
6	9.3	9.3									9.7	1.2		
7		12.4	1.3								12.9	1.6		
8			1.6									2.1		
10			2.5									3.2		
12			3.5	1.3								4.5		
15			5.3	2.0				1.1				6.9		
20			9.0	3.4	1.4		1.0	1.9				11.8		
25			13.8	5.1	2.2		1.5	3.0					1.3	1.5
30				7.3	3.1	1.1	2.1	4.2					1.8	2.1
35				9.8	4.1	1.5	2.9	5.6					2.5	2.8
40				12.5	5.3	2.0	3.7	7.1		1.0			3.2	3.7
45					6.6	2.5	4.6	8.9		1.2			4.0	4.6
50					8.1	3.0	5.6	10.9		1.5			4.9	5.6
55					9.7	3.6	6.7	13.0		1.8			5.9	6.8
60					11.5	4.3	7.9		1.1	2.1			7.0	8.0
70						5.7	10.6		1.4	2.8			9.4	10.7
80						7.3	13.6		1.9	3.6			12.1	13.9
90						9.2			2.3	4.5				
100						11.2			2.8	5.5				
120									4.0	7.7				
140									5.4	10.3				
160									6.9	13.3				
180									8.7					
200									10.6					
220									12.7					

Note: Based on 95-psig air pressure at hose inlet, includes normal couplings (quick-connect coupling will increase pressure losses materially). Hose is assumed to be smooth. Air is clean and dry. If an airline lubricator is upstream from the hose, pressure loss will be considerably higher. Pressure loss varies inversely as the absolute pressure (approximately). Probably accuracy is believed to be ±10 percent. Use on-half of indicated value for air at 50 psig.

applies to a single stage of compression, but may be applied to a complete multistage compressor as well.

Critical pressure The saturation pressure at the critical temperature. It is the highest vapor pressure that a liquid can exert. When calculated for a mixture, it is called the pseudo (pretend) critical condition.

Critical temperature The highest temperature at which a gas can be liquefied.

Dead-end pressure The suction pressure attained by an ejector or positive-displacement vacuum pump at zero capacity with the suction absolutely blanked off.

Degrees Kelvin (°K) An absolute temperature scale

Degree Rankine (°R) An absolute temperature scale

Density The weight of a given volume of gas, usually expressed in pounds per cubic feet at standard pressure and temperature conditions (air = 0.09 pound/cubic foot [1.3 kilograms/cubic meter])

Design (built-in) compression ratio In a rotary compressor, the compression ratio that has been attained when the fixed discharge port is uncovered. A helical-lobe compressor (and most other rotary units) can have an operating ratio somewhat higher or lower than the design ratio with little change in efficiency.

Dewpoint The temperature at which the vapor in a space (at a given pressure) will start to condense (form dew). The dewpoint of a gas mixture is the temperature at which the highest boiling point constituent will start to condense.

Discharge pressure The total pressure (static plus velocity) at the discharge flange of the compressor. Velocity pressure usually is considered only with dynamic compressors.

Discharge temperature The temperature existing at the discharge flange of the compressor

Displacement The net volume swept by the moving parts in a unit of time, usually one minute (applies only to positive displacement compressors)

Dry bulb temperature The ambient gas temperature

Dry gas Any gas or gas mixture that contains no water vapor and/or in which all of the constituents are substantially above their respective saturated vapor pressures at the existing temperature (see wet gas). Note: In commercial compressor work, a gas may be considered dry (even though it contains water vapor) if its dewpoint is low at the inlet condition (-50° to -60°F).

Dry unit One in which there is no liquid injection and/or liquid circulation for evaporative cooling or sealing (see evaporative cooling)

Energy The capacity of a substance, either latent or apparent, to exert a force through a distance, that is, to do work

External energy The energy represented by the product of pressure and volume. It may be regarded as the energy a substance possesses by virtue of the space it occupies.

Internal energy The energy a substance possesses because of the motion and configuration of its atoms, molecules, and subatomic particles.

Kinetic energy The energy a substance possesses by virtue of its motion or velocity. It enters into dynamic and ejector compressor calculations, but seldom into positive-displacement problems.

Potential energy The energy a substance possesses because of its elevation above Earth (or above some other chosen datum plane)

Enthalpy (heat content) The sum of the internal and external energies

Entrainment ratios Used with ejectors to convert the weight of gas and/or water vapor handled to or from equivalent air. They are based on extensive tests.

Table 9-12 Factors for the Sizing of Any Gas, Based on Specific Gravity

Specific Gravity	Factor
.05	4.50
.10	3.16
.15	2.58
.20	2.20
.25	2.00
.30	1.79
.35	1.68
.40	1.57
.45	1.49
.50	1.41
.55	1.33
.60	1.28
.65	1.23
.70	1.19
.75	1.15
.80	1.12
.85	1.07
.90	1.05
.95	1.02
1.00	1.00
1.10	.95
1.20	.91
1.30	.87
1.40	.85
1.50	.81
1.60	.78
1.70	.76
1.80	.74
1.90	.72
2.00	.70
2.10	.69
2.20	.67
2.30	.65
2.40	.63
2.50	.62
2.60	.61
2.70	.60
3.00	.56
4.50	.25

Note: Multiply factor by scfm in Table 9-7. Calculate adjusted scfm. Use adjusted scfm to obtain friction loss.

Entropy A measure of the unavailability of energy in a substance

Equivalent air An ejector term—the calculated pounds per hour of air at 70°F and 14.696 psia and containing normal atmospheric moisture that is equivalent to, but not necessarily equal to, the weight rate of the gas handled by the ejector at suction conditions. Entrainment ratios are involved.

Evaporative cooling Takes place when a liquid (usually water) is injected into the gas stream before or during compression. As compression takes place, the gas temperature rises and some or all of the liquid is evaporated—the latent heat of liquid vaporization being removed from the gas—thus lowering its temperature.

Fixed compression ratio The design (built-in) compression ratio for a rotary unit having this feature

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

Gauge pressure Pressure as determined by most instruments and gauges. Barometric pressure must be allowed for to obtain the true or absolute pressure.

Heat Energy transferred because of a temperature difference. No transfer of mass occurs.

Horsepower A unit of work equal to 33,000 foot-pounds per minute

Brake horsepower The total power input required including gas horsepower plus all friction losses

Gas horsepower The actual work required to compress and deliver a given gas quantity, including all thermodynamic, leakage, and fluid friction losses. It does not include mechanical losses.

Indicated horsepower That obtained by indicator card analysis of compression or expansion in a cylinder of a reciprocating compressor. It is the same as gas horsepower.

Peak horsepower The maximum power required by a given compressor when operating at a constant discharge pressure with variable intake pressure or constant intake pressure with variable discharge pressure.

Theoretical horsepower The work theoretically required to compress and deliver a given gas quantity in accordance with a specified product

Humidity In normal usage, the moisture (water vapor) in the atmosphere

Relative humidity The ratio of the actual partial vapor pressure in an air and vapor mixture to the saturated vapor pressure at the existing dry-bulb mixture temperature, usually expressed in percent

Specific humidity The ratio of the weight of water vapor in an air and vapor mixture to the weight of dry air, usually expressed as pounds of vapor per pound of dry air

Inlet pressure The total pressure (static plus velocity) at the inlet flange of the compressor. Velocity pressure is usually considered only with dynamic compressors.

Inlet temperature The temperature at the inlet flange of the compressor. Note: In a multistage compressor, the various stages may have differing inlet temperatures.

Intercooling The cooling of gas between stages of compression to reduce the temperature, reduce the volume to be compressed in the succeeding stage, liquefy condensable vapors, and save power

Maximum discharge pressure As applied to ejectors, the maximum absolute static recovery pressure against which the ejector will operate with stability

Mechanical efficiency The ratio, expressed in percent, of the indicated horsepower to the actual shaft horsepower (or steam indicated horsepower in an integral steam-driven unit)

Normal air The term used for average atmospheric air at sea level in a temperate zone where it contains some moisture. It is defined as being at 14.696 psia, 68°F, 36 percent relative humidity, and weighing 0.075 pound per cubic feet. The k-value is 1.395.

Piston displacement For a reciprocating compressor cylinder, the net volume displaced by the piston at rated machine speed, generally expressed in cubic feet per minute (cfm). For single-acting cylinders, it is the displacement of the compressing end only. For double-acting cylinders, it is the total of both ends. For multistage compressors, the displacement of the first stage only is commonly stated as that of the entire machine.

Precooler A heat exchanger located immediately preceding an ejector to condense and remove a portion of the vapor in the mixture and thus reduce the total pounds per hour to be handled

Psychrometry A measurement of the properties of air and water vapor mixtures in the atmosphere

Pumping The reversal of flow within a dynamic compressor that takes place when the capacity being handled is reduced to a point where insufficient pressure is being generated to maintain flow

Ratio of specific heats The ratio of the specific heat at constant pressure to the specific heat constant volume. It may vary considerably with pressure and temperature.

Recovery pressure That pressure of either motive fluid or discharge at which an ejector requires stable operation following a period of unstable operation due to having previously reached the breaking pressure.

Reduced pressure The ratio of the actual absolute gas pressure to the absolute critical pressure.

Reduced temperature The ratio in absolute units of the actual gas temperature to the critical temperature.

Saturation When a vapor is at the dewpoint or saturation temperature corresponding to its partial pressure. A gas is never saturated with a vapor. The space occupied jointly by the gas and vapor may be saturated, however.

Degree of saturation The ratio of the weight of a vapor existing in a given space to the weight that would be present if the space were saturated at the space temperature

Saturated air and vapor mixture A mixture in which the space occupied by the mixture is saturated with water vapor at the mixture temperature

Saturated vapor pressure The pressure existing at a given temperature in a closed vessel containing a liquid and the vapor from that liquid after equilibrium conditions have been reached. It depends only on temperature and must be determined experimentally.

Saturation pressure Another term for saturated vapor pressure

Saturation temperature The temperature corresponding to a given saturated vapor pressure for a given vapor

Slip The internal leakage within a rotary compressor. It represents gas at least partially compressed but not delivered. It is experimentally determined and expressed in cfm to be deducted from the displacement to obtain capacity.

Slip rpm The speed required of a rotary compressor to maintain a given discharge pressure, supplying leakage only (zero actual output). It is an experience factor.

Specific gravity The ratio of the density of a given gas to the density of dry air, both measured at the same specified conditions of temperature and pressure, usually 14.696 psia and 60°F. It should also take into account any compressibility deviation from a perfect gas.

Specific heat (heat capacity) The rate of change in enthalpy with temperature. It is commonly measured at constant pressure or at constant volume. The values are different and are known as cp and cv respectively.

Specific volume The volume of a given weight of gas, usually expressed as cubic feet per pound at standard pressure and temperature conditions

Standard air Dry air with a relative humidity of 0 percent, a temperature of 60°F (15.6°C), and a pressure of 14.7 psig (101.4 kPa). For the chemical industry, standard air is 68°F (20°C) at a relative humidity of 0 percent, and a pressure of 14.7 psig (101.4 kPa). Some manufacturers use a relative humidity of 36 percent, a temperature of 68°F (20°C), and a pressure of 14.2 psig (100 kPa) for performance test ratings. It is imperative that the conditions under which a compressor rating is calculated are obtained from the owner and manufacturer.

Actual cubic feet per minute (acfm) (actual liters per minute [aL/min]) A volume measurement of standard air after it has been compressed. The term "acfm (aL/min)" is not to be used unless the pressure is stated.

Standard cubic feet per minute (scfm) (normal liters per minute [nL/min]) A volume measurement of air at standard conditions. Outside the United States, standard is commonly referred to as normal, hence nL/min and nL/s.

Standard pressure and temperature (SPT) 14.696 psia and 60°F unless specifically stated otherwise

State A gas's condition at an instant of time as described or measured by its properties

Suction pressure The absolute static pressure prevailing at the suction of the ejector

Superheated air and vapor mixture A mixture in which the space occupied by the mixture is above the saturation temperature at the mixture temperature

Temperature The property of a substance that gauges the potential or driving force for the flow of heat

Thermal compressor An ejector used to compress waste or exhaust steam or any other gas through a moderate range of compression above atmospheric pressure

Vapor pressure The pressure exerted by a vapor confined within a given space. The vapor may be the sole occupant, or the space or may be associated with other gases.

Wet bulb temperature Used in psychrometry, the temperature recorded by a thermometer whose bulb has been covered with a wetted wick and whirled on a sling psychrometer. Taken with the dry bulb, it permits the determination of the relative humidity of the atmosphere.

Wet gas Any gas or gas mixture in which one or more of the constituents is at its saturated vapor pressure. The constituent at saturation pressure may or may not be water vapor.

Wet helical-lobe unit A device that handles a small constant flow of liquid with the gas, utilizes evaporative (injection) cooling, or circulates a liquid for sealing and/or cooling. The last may or may not be evaporative cooling.

Work Energy in transition, defined in units of force times distance. Work cannot be done unless there is movement.

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10

Solar Energy

OUR SUN

- Diameter: 864,000 miles (1,390,473 km)
- Mass: 438 trillion, trillion, billion pounds (1.99 trillion, trillion, billion kg)
- Surface temperature: 5,800°K (9,980°F)
- Core temperature: 15,600,000°K (28,079,540°F)
- Energy output: 386 billion, billion mega watts per second
- Distance from Earth: 93,000,000 miles (149,668,992 km)
- Power level at Earth: 1.4 kilowatts per square meter or 440 British thermal units (Btu) per square foot

The Sun hits Earth with enough energy every minute to meet the needs of the world's population for an entire year.Earth is populated with more than 6.5 billion people, and the population is growing at a rapid rate, even though the rate of increase actually has been declining since the 1980s. It is estimated that the global population will reach 9 billion people around 2045. Beyond the increase in the population itself are higher rates of increase in industry to support this population and the nations that are emerging into the industrial age. One of the downsides to this industrial growth is its insatiable appetite for energy. Fossil resources are finite, while appetites for consumption are not.

The biggest leap in energy consumption will come from emerging economies such as China and India, where populations are expected to grow by 25 percent over the next two decades and economic output and standards of living also will rise dramatically. Energy demand in China and India alone is expected to double by 2025, but the issue isn't limited to developing countries.

Canada is the No. 1 country for use of energy per capita. The United States is in second place per capita and uses a tremendous amount of energy. The United States is home to 4 percent of the world's population but consumes 25 percent of the world's energy. As the more developed countries continue to prosper, it is only natural that their energy needs will continue to grow accordingly.

A POSSIBLE SOLUTION

To reduce dependence on fossil fuels, the use of renewable energy sources must increase. Some progress is being made. For instance, solar panels are now compulsory on all new and renovated buildings in Spain as part of the country's efforts to update its building codes and to meet the growing demand for energy.

The sun bombards Earth with an enormous amount of energy continuously. If this energy source is tapped, it could provide "free" energy.

WHAT IS SOLAR ENERGY?

The Earth bathes in a variety of energy wavelengths and particles from the sun, but for the purposes of this chapter, solar energy is a renewable, environmentally friendly resource in the form of heat and light. Solar energy is available everywhere on Earth, at least part of the time, and this energy is provided free of charge. It just needs to be harvested and used to provide heat, lighting, mechanical power, and electricity.

Various methods of harnessing the sun's abundant and clean energy are available. Energy from the sun, for these purposes, can be categorized in two ways:

- Thermal energy (heat)
- Light energy (photovoltaics)

Solar thermal technologies use the sun's heat energy to heat substances (such as transfer fluids or panels) for applications such as space heating, pool heating, and domestic water heating. Many products are on the market that utilize thermal energy. Often the products used for this application are called solar thermal collectors and can be mounted on the roof of a building or in some other sunny location. The sun's heat also can be used to produce electricity on a large utility-scale by converting the sun's heat energy into mechanical energy.

Light energy can be converted directly into electrical current through photovoltaic devices. Photovoltaics (PV) is a technology often confused with solar thermal and is in fact what many people mean when they refer to "solar energy." Photovoltaics (photo = light, voltaics = electricity) is a semiconductor-based technology (similar to the microchip) that converts light energy directly into an electric current that can be used either immediately or stored, such as in a battery or capacitor, for later use. PV panels and modules are very versatile and can be mounted in a variety of sizes and applications (e.g., on a roof or awning of a building, on roadside emergency phones, or as very large arrays consisting of multiple panels and modules). Currently they are being integrated into building materials, such as PV roofing material, which replaces conventional roofing shingles.

How much energy is needed to heat water?

- 1 kilowatt will raise 4.1 gallons of water 100 degrees in one hour (4.1 gph at 100°ΔT).
- 1 watt is approximately 3.41 Btuh.
- 1 kilowatt is 3,412 Btuh.
- 1,000 Btuh is approximately 293 watts.
- 1 Btu will heat 1 pound of water 1°F.

How Can Solar Help?

Research shows that an average household with an electric water heater spends about 25 percent of its home energy costs on heating water. Solar water heaters offer the largest potential savings, with solar water heater owners saving as much as 50 percent to 85 percent annually on their utility bills over the cost of electric water heating. A simple payback of four to eight years can be expected on a well-designed and properly installed solar water heater. (Simple payback is the length of time required to recover the investment through reduced or avoided energy costs.)

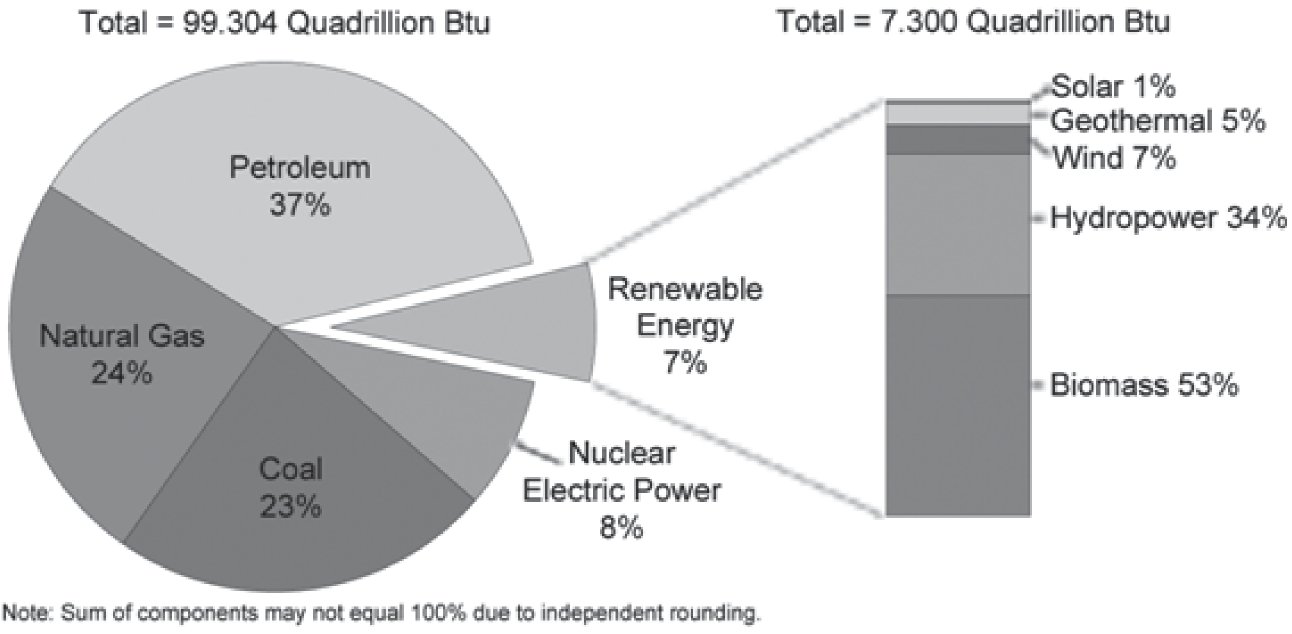
The United States spends more than $13 billion a year on energy for home water heating. That is the equivalent of 11.4 barrels of oil per household—more than the amount of oil (in the form of gasoline) burned by a medium-size automobile driven 12,000 miles. See Figure 10-1 for a breakdown of how the use of solar energy compares to other energy sources.

Solar water heaters do not pollute. Specifying a solar water heater system prevents carbon dioxide, nitrogen oxides, sulfur dioxide, and the other air pollution and wastes created when the utility generates power or fuel is burned to heat the domestic water. When a solar water heater replaces an electric water heater, the electricity displaced over 20 years represents more than 50 tons of avoided carbon dioxide emissions alone.

Environmental Impact: What Is Being Saved?

Consider a family of four with a hot water demand of 60 usages per day. They install a solar collector system with two collectors and an 80-gallon storage tank and an expected minimum system lifetime of 20 years. The solar energy supplied is 11,010,000 Btu per year, so the energy supplied in 20 years is 220,200,000 Btu. The emissions reduction in 20 years is:

- 16.5 tons of carbon dioxide
- 3330 lbs of nitrous oxides
- 1950 lbs of carbon monoxide



Note: Sum of components may not equal 100% due to independent rounding.

Figure 10-1 The Role of Renewable Energy in the U.S. Energy Supply

Source: U.S. Energy Information Administration

Does It Work for Commercial Applications?

Solar is being used by more businesses every day in applications ranging from heating water to providing a reliable and clean power source. A business can save 40 to 80 percent on electric or fuel bills by replacing a conventional water heater with a solar water-heating system. Solar energy also provides other benefits to business such as "power security," enabling a business to continue operating even when outside utility power is disrupted.

Concentrating solar power plants generate electricity by using the heat from solar thermal collectors to heat a fluid that produces steam used to power the generator.

Why Use Solar?

A solar energy system can be used to help earn two LEED credits:

- SS Credit 7.1: Heat Island, Non-roof, one credit
- E&A Credit 2: Renewable Resources, one to seven credits

Solar energy also reduces reliance on natural gas or electricity for water heating with a sustainable source of "free" energy and reduces pollution emissions.

Tax Credits

Tax credits are constantly changing and evolving. Be sure to check for the current local, state, and federal incentives. Many sources for this information are available, including:

- On-site Renewables Tax Incentives: energytaxincentives.org/business/renewables.php
- Database of State Incentives for Renewables and Efficiency: dsireusa.org
- Guide to Federal Tax Incentives for Solar Energy: seia.org (member login required)

DEFINITIONS

The following terms are frequently employed in solar energy technology and related applications.

Absorber area The total heat transfer area from which the absorbed solar radiation heats the transfer fluid or the absorber media if both transfer fluid and solid surfaces jointly perform the absorbing function, in square feet (m^2)

Absorber (plate) The part of the solar collector that receives the incident solar radiation energy and transforms it into thermal energy. In some cases, the heat transfer fluid itself could be the absorber.

Absorptance The ratio of the absorbed flux to the total incident flux, measured in terms of percent

Angle of incidence The angle between the line of direct solar irradiation and the perpendicular to the aperture plane, in degrees

Angle of reflection The angle between the reflected rays' propagation direction and the perpendicular to the surface at the point of reflection, in degrees

Angle of refraction The angle between the refracted rays' propagation direction and the perpendicular to the interface at the point of refraction, in degrees

Area, aperture The maximum projected area of a solar collector through which un-concentrated solar radiant energy is admitted, in square feet (m^2)

Area, gross collector The maximum projected area of a solar collector module including any integral mounting devices, in square feet (m^2)

Auxiliary energy subsystem A configuration of equipment and components, utilizing conventional energy sources, to supplement the output of the solar system

Collector A device used to absorb the sun's energy

Collector, concentrating A collector that uses reflectors, lenses, or other optical devices to concentrate the radiant solar energy passing through the aperture onto an absorber of which the surface area is smaller than the aperture area. Parabolic trough-shaped reflectors concentrate sunlight onto an absorber or receiver to provide hot water and steam, usually for industrial and commercial applications.

Collector, flat plate A non-concentrating collector in which the absorbing surface is essentially planar and usually with approximately the same area as the aperture. Small tubes run through the box and carry fluid—either water or another fluid such as an antifreeze solution. The tubes attach to a black absorber plate. As heat builds up in the collector, the fluid passing through the tubes is heated. The hot transfer liquid goes to a storage tank, and water is heated as it passes through a tube inside the storage tank full of hot fluid. This is the most common type of collector for solar water heating.

Collector, evacuated tube (vacuum tube) A collector consisting of rows of parallel transparent glass tubes, each containing an absorber and covered with a selective coating. Sunlight enters the tube, strikes the absorber, and heats the liquid flowing through the absorber. These collectors are manufactured with a vacuum between the tubes, which helps them achieve extremely high temperatures (170–350°F). Their high efficiency makes them a good choice for commercial uses.

Collector, transpired A south-facing exterior wall covered by a dark sheet-metal collector. The collector heats outside air, which is then drawn into the building's ventilation system through perforations in the collector. They have been used for preheating ventilation air and crop drying. They are inexpensive to make, and commercially have achieved efficiencies of more than 70 percent.

Collector, trickle A flat-plate collector over which non-pressurized liquids flow

Collector efficiency The ratio of the energy collected (or absorbed) to the total solar energy incident on the collector, expressed in percent

Collector subsystem That portion or assembly of the solar system used for absorbing incident solar radiation, converting it to thermal energy and transferring this thermal energy to a heat-transfer fluid. The collector subsystem includes the solar collectors, related piping or ducts, and regulating devices.

Collector tilt The angle above the horizontal plane at which a solar collector is mounted, in degrees

Concentrating ratio The ratio of the aperture area to the absorber of a solar collector

Concentrator A reflector, lens, or other optical device in concentration solar collectors used to focus the incident solar energy on the reduced absorber area

Conduction A heat-transfer process by which heat flows from a region of higher temperature to a region of lower temperature within a solid, liquid, or gaseous medium by molecular contact or between different media having a direct physical contact

Convection A heat-transfer process in which heat is transferred from one region to another by motion of a fluid

Convection, forced A convection transfer process caused by mechanical devices, such as fans and injectors

Convection, free A convection transfer process caused by density differential within a fluid, without involvement of any mechanical devices

Cooling system The complete assembly of subsystems required to convert solar energy into other forms of energy for space cooling purposes

Cover, collector The transparent material placed over the aperture or absorber area of a solar collector to provide protection from the environment and reduce thermal losses from radiation or convection

Distribution subsystem The portion of a solar system from the storage subsystem to the point of ultimate use, including the related piping or ducts and regulating devices

Emittance The fraction of heat radiated by the solar collector, measured in percent of the absorbed energy by the panel

Emissivity The ratio of the radiation emitted by a surface to the radiation emitted by a black body at the same temperature

Energy transport subsystem The portion of a solar system that contains the heat-transfer media and transports the energy throughout the solar system, including related piping and regulating devices

Heat exchanger A device designed for transferring heat between two physically separated fluids

Heat pump A device designed to simultaneously or alternately use the heat extracted at a low temperature and the heat rejected at a high temperature for cooling and heating purposes

Heat-transfer medium A fluid used in the transport of thermal energy

Heating and cooling system The complete assembly of subsystems required to convert solar energy into thermal energy and utilize this energy, in combination with auxiliary energy (if necessary), for combined heating and cooling purposes

Heating system The complete assembly of subsystems required to convert solar energy into thermal energy and utilize this energy, in combination with auxiliary energy (if necessary), for heating purposes

Hot water system The complete assembly of subsystems required to convert solar energy into thermal energy and utilize this energy, in combination with auxiliary energy (if necessary), for service water heating

Infrared radiation Radiation with wavelengths greater than 70 millionths centimeter (7,000 Angstrom units) but less than radio waves, about 5.5 centimeters

Irradiation (insolation), instantaneous The quantity of solar radiation incident on a unit surface area in a unit of time, in Btuh per square foot (W/m^2)

Insolation The solar radiation striking the surface of Earth or another planet. Also the rate of delivery of solar radiation per unit of horizontal surface (see irradiation).

Performance factor efficiency The ratio of the useful output capacity of a system to the input required to obtain it

Radiant emittance (exitance) The quotient of the radiant flux leaving an element of the surface containing the point by the area of that element

Radiant flux Power emitted, transferred, or received in the form of electromagnetic waves or photons

Radiant intensity The quotient of the radiant flux emitted by a source (or by an element of a source in an infinitesimal cone containing the given direction) by the solid angle of the cone

Radiation The heat-transfer process by which heat flows from a body at a higher temperature to a body at a lower temperature, when the bodies are separated in space or when a vacuum exists between them (emission or transfer of energy in the form of electromagnetic waves or photons)

Selective surface A coating applied to a solar collector, or its absorber area, having a high absorptance and a low emittance

Solar absorptance The fraction of the solar irradiance that is absorbed

Table 10-1 Solar Cost Comparison, Method A

Solar Collector (Flat Plate)			**Cost**	**Total Cost**
Total kilowatts	Watts per square foot	Square feet	Cost per watt	
200	63	3,200	1	$200,000
PV Panel			**Cost**	**Total Cost**
Total kilowatts	Watts per square foot	Square feet	Cost per watt	
200	16	12,500	10	$2,000,000
PV Roof Material			**Cost**	**Total Cost**
Total kilowatts	Watts per square foot	Square feet	Cost per watt	
200	4	50,000	10	$2,000,000

Table 10-2 Solar Cost Comparison, Method B

Solar Collector (Flat Plate)			**Cost**	**Total Cost**
Square feet	Watts per square foot	Total kilowatts	Cost per watt	
3,200	63	200	1	$200,000
PV Panel			**Cost**	**Total Cost**
Square feet	Watts per square foot	Total kilowatts	Cost per watt	
12,500	16	200	10	$2,000,000
PV Roof Material			Cost	Total Cost
Square feet	Watts per square foot	Total kilowatts	Cost per watt	
50,000	4	200	10	$2,000,000

Solar constant The solar radiation intensity that is incident on a surface normal to the sun's rays, outside the Earth's atmosphere, at a distance from the sun equal to the mean distance between the Earth and the sun. The accepted valued of the solar constant is equal to 428.8 Btuh per square foot (1,353 W/m^2).

Solar degradation The process by which exposure to sunlight deteriorates the properties of materials

Solar energy The photon (electromagnetic) energy originating from the sun

Solar system Equipment and components arranged in a manner to collect, convey, store, and convert solar energy

Solar system, air A solar system that uses air as the primary heat-transfer fluid

Solar system, active A solar system in which the incident solar radiation is absorbed by the solar collectors, transferred to an independent thermal storage unit, and distributed to the point of ultimate use by means of mechanical devices powered by conventional fuels (i.e., pumps and fans)

Solar system, closed A solar system that has a completely enclosed collector subsystem circulating the heat-transfer fluid under pressure above atmospheric and shut off from the atmosphere, except for an expansion tank

Solar system, liquid A solar system that uses liquid as the primary heat-transfer fluid

Solar system, open A solar system that exchanges heat directly with the end-use application

Solar system, passive A solar system in which solar energy utilization becomes the prime objective of engineering and architectural design. The flow of heat is achieved by natural convention, conduction, and radiation

Solar system, thermosyphon A passive solar system in which fluids circulate due to their temperature differentials, rather than under the influence of pumps or fans

Storage device (thermal) The containers, including all contents of such containers, used for storing thermal energy. Heat-transfer fluid, heat exchangers, flow-control devices, valves, baffles, etc. that are integral with the thermal storage container are regarded as parts of the storage device.

Storage medium (thermal) The material in the thermal storage device, independent of the containing structure, in which the major portion of the energy is stored

Storage subsystem The assembly of components necessary for storing energy so it can be used when required, including all related regulating devices used in connection thereof

Subsystem A major, separable, and functional assembly or portion of a system

Thermosyphon The natural circulation of a fluid caused by temperature differentials within the fluid system

Transfer fluid, heat The medium that flows through a solar collector and carries the absorbed energy away from the collector

Transmittance The ratio of flux transmitted through a material to the incident flux

Ultraviolet radiation Radiation with wavelengths from 180 to 400 μm (Angstrom units)

Watt An energy per second unit (1 watt = 1 joule per second)

SOME QUICK ESTIMATING CALCULATIONS

Following are some estimates that can be used in calculations:

- One direct hour of sunlight = 1 kilowatt-hour per square meter
- 1 kilowatt-hour = 3,412 Btu
- 1 gallon of #2 fuel oil = 150,000 Btu
- 1 square meter = 10.6 square feet
- One 4x8 collector (approximately) = 3 square meters
- One 4x8 collector (approximately) = 12–15 kilowatt-hours per day

QUICK COST COMPARISONS

Tables 10-1 and 10-2 illustrate two simple spreadsheets used to estimate costs for different solar systems. Many variables and other project-specific items are not taken into account within these calculations, so the actual cost of a system will be higher. This is only to provide a general idea of the magnitude of the differences among the systems.

A plethora of information is available via the Internet, books, and magazines to assist in the design of solar systems. Some of this information can be found within this chapter; however, a more complete understanding will come only through further research.

SYSTEM SIZING RULES OF THUMB

Approximately 440 Btuh per square foot of energy generated by the sun could potentially reach the Earth (see Figure 10-2). Of that potential energy, 30 to 60 percent is lost in the journey through the atmosphere, and 170 to 315 Btuh per square foot eventually reaches the surface.

For example, Chicago receives 1,260 to 1,575 Btu per square foot per day of energy from the sun. For optimum output, panels should be installed at a 45-degree angle and face south. The optimum output from a panel is roughly 220 Btuh per square foot. The amount of energy disbursed by the sun fluctuates with sunspot activity and solar storms, but the maximum available energy from a collector is generally considered to be 220 Btuh per square foot.

SOLAR IRRADIATION COLLECTION METHODS

The solar collector is the main component of the active solar irradiation collection subsystem (see Figure 10-3). It is the device that absorbs the incoming solar energy, converts it to heat, and transfers this heat to a fluid (liquid or air) flowing through the solar collector. To absorb or collect this energy, several different panel or collector styles are available, which can be classified into three general categories:

- Flat-plate solar collectors: Non-concentrating collectors in which the absorbing surface is essentially planar and is approximately equal to the gross collector area
- Concentrating solar collectors: Collectors that use mirrors, lenses, reflectors, or other optical devices to concentrate the radiant solar energy passing through the collector's aperture onto an absorber of which the absorber area is smaller than the aperture area
- Vacuum tube solar collectors: Collectors that use sealed vacuum tubes, which operate via a self-contained vapor reaction to heat a condenser at the end of the tube and transmit heat through a small, integral heat exchanger through a manifold through which the fluid (water and/or glycol) circulates

Flat-plate Solar Collectors

A typical flat-plate solar collector unit consists of the following basic elements:

- One or more collector covers (glazing), transparent to the incoming incident solar radiation and opaque to the infrared radiation from the absorber plate. These are intended to protect the absorber

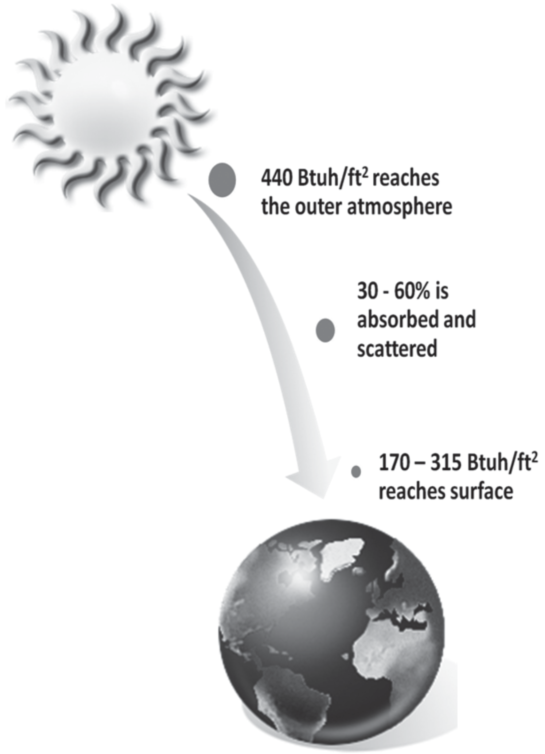


Figure 10-2 Amount of Sun's Energy that Reaches the Earth

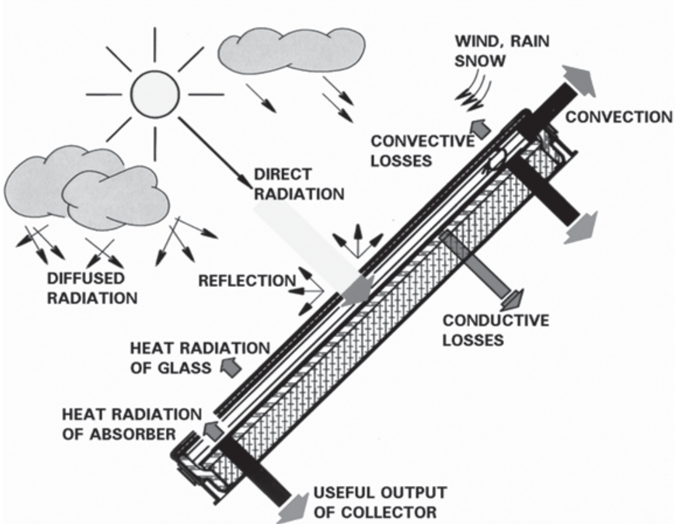


Figure 10-3 How Solar Energy Is Collected

plate from the environment and to act as a shield to reduce radiative and convective heat losses from the absorbing surface. Glass and plastic typically are the materials utilized for collector covers.

- An absorber plate (surface), usually incorporating channels (conduits) containing the heat-transfer fluid, used to absorb the sun's incident radiation and to transfer the energy (heat) to the fluid medium in the channels. Metals and plastics have been used in the construction of absorber plates, which are sometimes coated with a selective surface finish having high-absorptivity and low-emissivity factors. Extreme care should be exercised when selecting a metal for the construction of the absorber plates. Each material has its own characteristics, which may induce galvanic corrosion. Also, it should be noted that the thermal conductivities of plastics are less than those of metals. Therefore, plastic materials should be limited to low-temperature applications (e.g., swimming pool heating).
- Thermal insulation, placed behind the absorber plate and channel assembly and surrounding the perimeter of the solar collector module, used to reduce heat losses and increase radiation on the absorber plates and channel assembly
- A backplate, which is placed behind the insulation and acts as a reflector surface, used to reduce heat losses and increase radiation on the absorber plates and channel assembly. Aluminum and foil reflectors are the materials generally used in the construction of backplates.
- Headers (manifolds), which are used to convey the absorbed energy. To ensure steady flow conditions, the headers should have a cross-sectional area larger than the area served by the channels. Metals and plastics are the materials commonly utilized in the construction of the headers.
- A frame, including angle-fixing and mounting devices, etc., enclosing the complete solar collector module

Many configurations of flat-plate solar collectors are available. For example, the absorber plate/channel assembly could be of fin design or corrugated sheets, with channels above, channels below, or channels as integral parts with the absorber plate. Also, flat-plate modules used in swimming pool heating applications (low temperature/high water volume) do not normally require a covers, backplate, or insulation by design. The absorber plate, channel assembly, and headers are the only elements necessary.

The amount of incident solar energy (radiation) collected is governed by the following criteria:

- Transmittance of the collectors covers, which should exceed 90 percent of the solar spectrum
- Absorptivity factor of the absorber plate to the incident solar radiation, which should exceed 95 percent
- Emissivity factor of the absorber plate in the infrared spectrum
- Thermal resistance between the absorber plate and the heat-transfer medium
- Reduction of the conductive, convective, and radiative heat (thermal) losses from the panel, which depends on the operating temperature of the panel, usually ranging from 90–210˚F (32.2–98.8˚C) or higher

The most widely used measure of the performance of flat-plate collectors is thermal efficiency (q), which is defined as the ratio of delivered heat to the incident solar radiation. However, it should be noted that the thermal efficiency of a flat-plate solar collector is not a sufficiently descriptive index to select a unit module. The most important properties of a flat-plate solar collector are the collector operating temperature, type of collector surface, and type and number of collector covers.

The steps for determining the thermal efficiency of a flat-plate solar collector, including the necessary data, are as follows:

- To calculate the incident beam component of insolation normal to the collector (Ib,coll) and the diffuse component of insolation (Ih,d), obtain the insolation on a horizontal surface (Ih), cloud cover (CC), solar altitude angle (a), collector tilt angle (E), and latitude (L).
- To calculate the absorbed radiation (Icoll), obtain the number of collector covers (n).
- To calculate the delivered energy to working fluid (qa), obtain the wind speed (v) in knots (m/s), collector temperature (Tcoll) in ˚R, and collector physical properties.

The following equations should be used in calculating the thermal efficiency:

Equation 10-1

$$^{I}b,coll = {}^{I}h,b(\cos i)/\sin a$$

Equation 10-2

$$^{I}h,d = 0.78 + (1.07)\ a + (6.17)\ CC$$

Equation 10-3

$$^{I}coll = {}^{I}b,coll(l - Pbn)\ {}^{\alpha}s,b + {}^{I}h,d\ (l - Pd)\ {}^{\alpha}s,d$$

Equation 10-4

$$qa = {}^{I}coll - L_t$$

Equation 10-5

$$\eta\ = q/({}^{I}b,coll + {}^{I}h,d)$$

where:

^{I}b,coll = Incident beam component of insolation normal to the collector surface, Btuh per square foot (W/m^2)

^{I}h,b = Horizontal beam component of insolation, Btuh per square foot (W/m^2)

i = Angle of incidence, degrees

a = Solar altitude angle, degrees

^{I}h,d = Diffuse component of insolation, Btuh per square foot (W/m^2)

CC = Cloud cover, tenths (1/10) of sky covered

^{I}coll = Absorbed radiation, Btuh per square foot (W/m^2)

Pbn = Reflectance from several covered sources

$^{\alpha}$s,b = Absorptance (beam)

Pd = Diffuse reflectance

$^{\alpha}$s,d = Absorptance (diffuse)

qa = Energy delivered to working fluid, Btuh per square foot (W/m^2)

L_t = Thermal losses of collectors, Btuh per square foot (W/m^2)

η = Thermal efficiency, percent

Concentrating Collectors

The advantages of using concentrating collectors in solar systems have long been recognized. Several thermal processes require much higher temperatures than those that can be reached by flat-plate solar collectors; therefore, concentrators must be employed. However, although many concentrating solar systems have successfully operated over the years, the economics have played a very important role. The flat-plate solar collectors that do not require sun-tracking devices have taken predominance because of their lower manufacturing and installation costs.

Some of the advantages of concentrating collectors over flat-plate collectors are as follows:

- The reflecting surfaces require less material and are structurally simpler than flat-plate units.
- The absorber area is significantly smaller than that of a flat-plate unit. Therefore, the radiation intensity is much greater.
- The working fluid can attain higher temperatures.
- Little or no antifreeze solution is required.
- Some of the disadvantages are:
- The concentrating collectors only collect on the direct component of the radiation.
- Maintenance and operating costs are higher.
- Reflecting surfaces may deteriorate.
- The diffuse component of radiation plays a very small role in the heating of the fluid.

Among the concentrating collector systems, particular notice should be paid to the following.

Stationary Reflector Tracking Absorber

The stationary reflector tracking absorber (SRTA) system was developed by W. Gene Steward (Environmental Consulting Services in Boulder, Colorado) and J. L. Russel (General Atomics in San Diego, California). The Steward SRTA is a compound curvature collector, whereas the Russel SRTA is a single curvature collector. Both SRTA systems are for electric power generation (photovoltaic application). This collector system is based on optical principles showing that, regardless of the position of the sun, a fixed mirror can focus most of the incoming solar radiation on a line parallel to the rays of the sun.

The size of the SRTA absorber is based on the width of the solar image and the maximum absorber length necessary to capture all reflected rays.

A theoretical average geometric concentration factor (F_c) is defined as the ratio of the projected surface area of a concentrator (A_p) to the area of the sun's image (A_i) on the collecting surface. The temporal average for a day is obtained from the following relation:

Equation 10-6

$$\bar{F}_c = \frac{A_p}{A_i} = \frac{I}{\theta_1} \int_{o}^{\theta_1} \bar{F}_c di$$

where:

θ = Incidence angle i at mirror sunrise

The value of the concentration factor obtained from Equation 10-6 does not take into account surface irregularities in the reflecting mirror. In actual practice, the absorber may be five or six times greater than the theoretical value to compensate for surface irregularities in the reflecting mirror and to absorb some diffuse radiation on cloudy or hazy days.

When comparing a flat-plate collector system and a SRTA system, it is imperative that a complete system analysis be performed. One does not pay for the surface area, but rather for the amount of heat or useful energy delivered per unit surface area. A cost comparison between a flat-plate collector and a SRTA system can be made on the following:

Equation 10-7

$$\left(\frac{Afp}{\eta fp}\right) \text{(cost per ft}^2\text{ of flat-plate collector)}$$

Equation 10-8

$$\frac{\pi d_a^2}{\eta_{SRTA}} \times \frac{\text{cost per ft}^2\text{ of mirror surface}}{\text{frontal area per mirror area}}$$

where:

Afp = Surface area of flat-plate collector, square feet (m^2)

ηfp = Diameter of flat-plate collector, percent

d_a = Diameter of aperture area of SRTA collector, feet (m)

η_{SRTA} = Efficiency of stationary reflector tracking absorber collector, percent

The cost of the SRTA absorber is prorated on a mirror surface area basis. For complete cost comparisons, the cost of the entire solar system for each design should be considered.

Compound Parabolic Concentrator

The compound parabolic concentrator (CPC) system was developed by Roland Winston (Argonne National Laboratories in Argonne, Illinois). The CPC is a non-tracking solar collector consisting of two sections of a parabola of second degree, symmetrically located about the mid-plane of a collector. The two sections form a single curvature solar concentrator with an angular acceptance of 2 (θ_{max}). The acceptance depends on the ratio of aperture area (W_c) to the absorber area (W_a) and is expressed by the relation:

Equation 10-9

$$\theta_{max} = \sin^{-1}\left(\frac{W_a}{W_c}\right)$$

where

θ_{max}= Maximum acceptance

W_a= Absorber area, square feet (m^2)

W_c= Aperture area, square feet (m^2)

The concentration ratio (CR) of the CPC system can be determined by the expression:

Equation 10-10

$$CR = \frac{W_e}{W_a}$$

This collector system should be oriented in an east-west direction and tilted toward the south at an angle (E) from the horizontal plane. When the angle (y) is less than A_{max}, the CPC collector accepts both direct and diffuse components of sunlight. When the angle is greater than A_{max}, the CPC collector accepts only diffuse sunlight over the portion of the aperture area equal to the absorber area. Beam insolation incident on a CPC collector outside the acceptance angle does not reach the absorber area, but is reflected from the side walls back through the aperture.

The theoretical depth of the CPC collector (d_{coll}) depends on the concentration ratio and is defined by the expression:

Equation 10-11

$$d_{coll} = W_a\left[\frac{(CR+1)}{2}\right][(CR-1)^{1/2}]$$

In actual practice, it has been found advantageous to use a value of d_{coll} that is one-third smaller than that calculated from Equation 10-11.

SYSTEM SIZING AND CALCULATIONS

Several computer simulation design programs are currently available for sizing solar-assisted service water- and space-heating systems. In this chapter, the f-chart method developed by the University of Wisconsin is used for sizing such systems. The f, expressed in terms of percent, is the fraction of the heating load supplied by solar energy or the percentage of the total heating load furnished by the solar system. These design charts are calculated utilizing double-glazed, selective-surface collector panels. Other types of solar collectors (e.g., single-glazed selective surface; double-glazed non-selective surface; single-glazed non-selective surface) could be used. However, the data for developing the charts must be varied accordingly.

The following data is required when employing the f-chart method in the sizing procedures: number of degree days, ambient temperature, building heat loss (if space heating is being considered), hot water demand, collector orientation, and design parameters of the system.

Solar-assisted Service Water Heating

Solar-assisted service water-heating systems generally provide maximum savings when the system is designed to deliver 45 to 70 percent of the load (f = 45 to 70 percent). To determine the amount of energy required to heat the service water, the following information is needed:

- Hot water supply temperature
- Cold water supply temperature
- Daily hot water demand

To meet the requirements set forth in the Federal Housing Administration's Minimum Property Standards, the hot water supply temperature must be 140°F (60°C) minimum. This also helps reduce waterborne pathogens such as Legionella. Depending on the season and geographical location, the cold water supply temperature may vary from 40°F to 70°F (4.4°C to 21.1°C), although it is possible to have lower or higher temperatures. This should always be considered when calculating water heating or cooling applications.

Although many system types, applications, and design techniques may be considered for various service water-heating requirements, a few basic guidelines should be followed in all cases.

- Systems should be designed to be as simple and as feasible as possible for each specific application.
- Match system design to load patterns and magnitude, and avoid misuse of design rules of thumb.
- Consider system efficiency, as well as collector efficiency.
- All phases of a system's control cycle should be examined for potential operational and energy waste problems.
- Plan for component expansion, movement, and service during system design.

Sizing Procedure for Service Water Heating

The following steps should be followed when sizing a solar-assisted service water-heating system.

1. Determine the daily hot water demand.
2. Determine the hot water supply temperature. Generally, this temperature can be taken as 140°F (60°C).
3. Determine the cold water supply temperature. This temperature typically ranges from 40°F to 70°F (4.4°C to 21.1°C), depending on the season and geographical location. In the absence of such data, assume this temperature to be 45°F (7.2°C) as a year-round average.
4. Determine the closest weather station location and prepare an f-chart. A sample f-chart is illustrated in Figure 10-4. Data on degree days and percent f at the collection point may be obtained from the ASHRAE Handbook of Fundamentals and the Solar Decision Handbook.
5. Determine the percent f to be delivered by the solar system.
6. Using the f-chart, determine the size of the collector array (in square feet [m2]) required to provide the desired percent f. The following calculations will provide approximate values, as indicated.
    - To determine the flow rate of the heat-transfer fluid in the collector loop, multiply the collector area by 0.039 (0.027 in SI units).
    - To determine the maximum heat transfer to the heat exchanger, multiply the collector area by 225 (709.6 in SI units).
    - To determine the size of the preheater tank, multiply the collector area by 2 (81.4 in SI units).
7. Determine the pump head in the collector loop.
8. Determine the pump head in the storage loop.
9. Determine the volume of heat-transfer fluid required.
10. To determine the size of the expansion tank needed, multiply the volume of the heat-transfer fluid by 10 percent.

Figures 10-5 and 10-6 illustrate typical installations of solar-assisted service water-heating systems.

Example 10-1

- Location: Memphis, Tennessee
- Family of four, standard kitchen and bathroom

Step 1: Determine the daily hot water demand, approximated as 15 gallons per person per day (56.8 L per person per day). For four persons, the daily hot water demand would be 60 gallons (227.2 L).

Step 2: Determine the hot water supply temperature. To meet FHA requirements, this temperature should be 140°F (60°C).

Step 3: Determine the cold water supply temperature. This temperature can be assumed to be 45°F (7.2°C).

Step 4: Develop an f-chart. See Figure 10-7.

If 60 percent of the load is to be supplied by the solar system, approximately 35 square feet (3.3 m^2) of collector area is required. The flow rate of the heat-transfer fluid in the collector loop would be 35 $ft^2 \times 0.039 = 1.4$ gpm (3.3 $m^2 \times 0.027 = 0.09$ L/s). The maximum heat transfer to the heat exchanger would be 35 $ft^2 \times 225 = 7{,}875$ Btuh (3.3 $m^2 \times 709.6 = 2{,}341.7$ W).

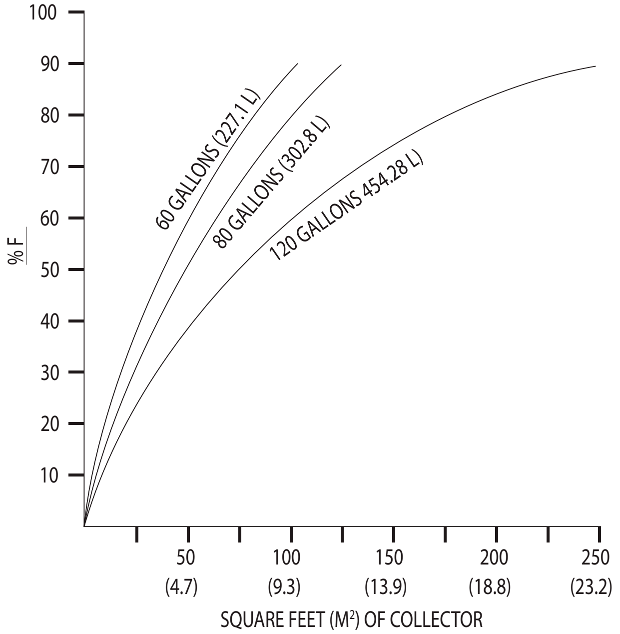


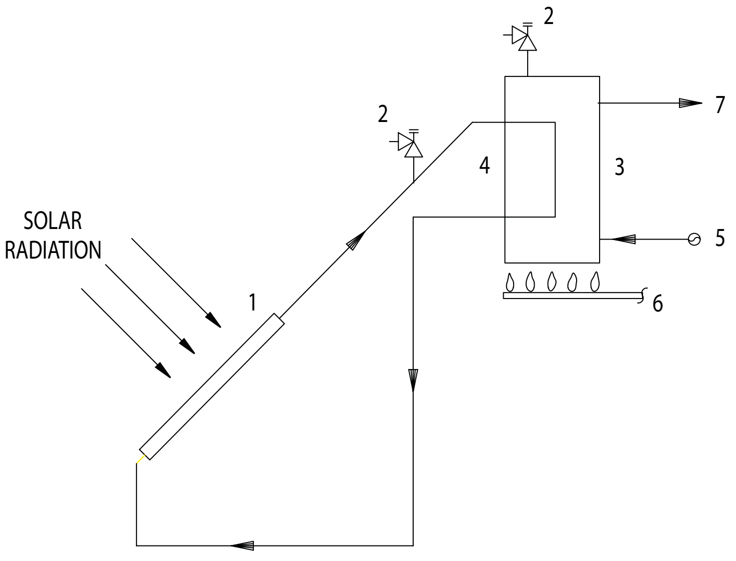
Figure 10-4 Sample f-chart, Service Water Heating Application

Sizing Procedure for Service Water and Space Heating

The following steps should be followed when sizing a combined solar-assisted service water- and space-heating system.

1. Calculate the building heat loss. ASHRAE-recommended methods should be used.
2. Determine the building's design temperature. This temperature is the lowest outside air temperature, in °F (°C), at which the building must be heated to 65°F (18.3°C).
3. Calculate the building's design load. This load is the product of the building's heat loss and the building's design temperature.
4. Determine the daily hot water demand, hot water supply temperature, and cold water supply temperature. Follow steps 1, 2, and 3 given for service water-heating systems.
5. Determine the closest weather station and prepare an f-chart.
6. Determine the percent f to be delivered by the solar system.
7. Determine the size of the collector array, in square feet (m2), required to provide the desired percent f using the chart.
8. Determine the flow rate of the heat-transfer fluid in the collector loop, maximum heat-transfer fluid in the collector loop, maximum heat transfer to the heat exchanger, and the size of the storage tank. Use step 6 of the service water-heating procedure.
9. Determine the pump head in the collector loop and storage loop.
10. Determine the pump head for the entire heat-delivery loop (preheater, to and from storage tank, etc.).
11. Determine the fan coil size. The output of the fan coil should be equal to or greater than the building's design load.
12. Select a heat pump with an output equal to or greater than the building's design load.
13. Select an auxiliary heater with an output equal to or greater than the building's design load.

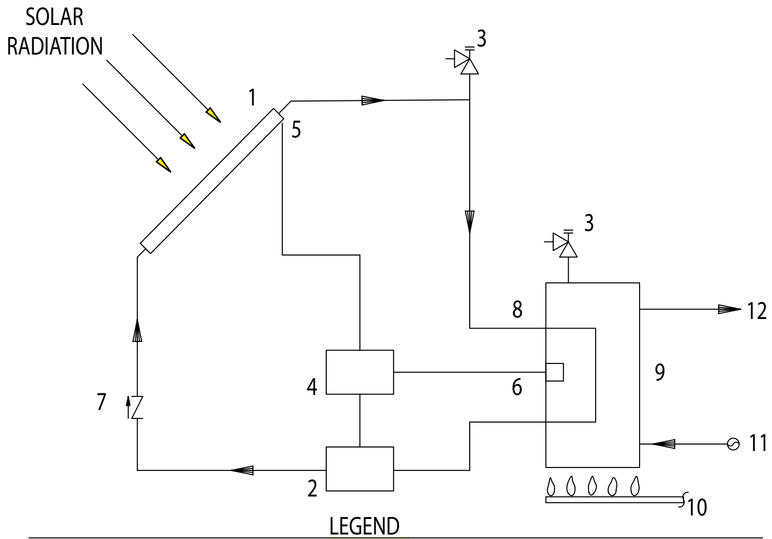
Figure 10-8 provides illustrations of combined systems.



LEGEND

1. SOLAR COLLECTORS
2. TEMPERATURE/PRESSURE RELIEF VALVE
3. STORAGE TANK
4. HEAT EXCHANGER
5. WATER SUPPLY
6. AUXILLARY HEAT SOURCE
7. TO BUILDING

Figure 10-5 Thermosyphon System, Service Water Heating Application, Indirect



LEGEND

1. SOLAR COLLECTORS
2. CIRCULATING PUMP
3. TEMPERATURE/PRESSURE RELIEF VALVE
4. PUMP CONTROLLER
5. SENSOR: COLLECTOR TEMPERATURE
6. SENSOR: TANK TEMPERATURE
7. CHECK VALVE
8. HEAT EXCHANGER
9. STORAGE TANK
10. AUXILLARY HEAT SOURCE
11. WATER SUPPLY
12. TO BUILDING

Figure 10-6 Pump Circulating System, Service Water Heating Application, Direct

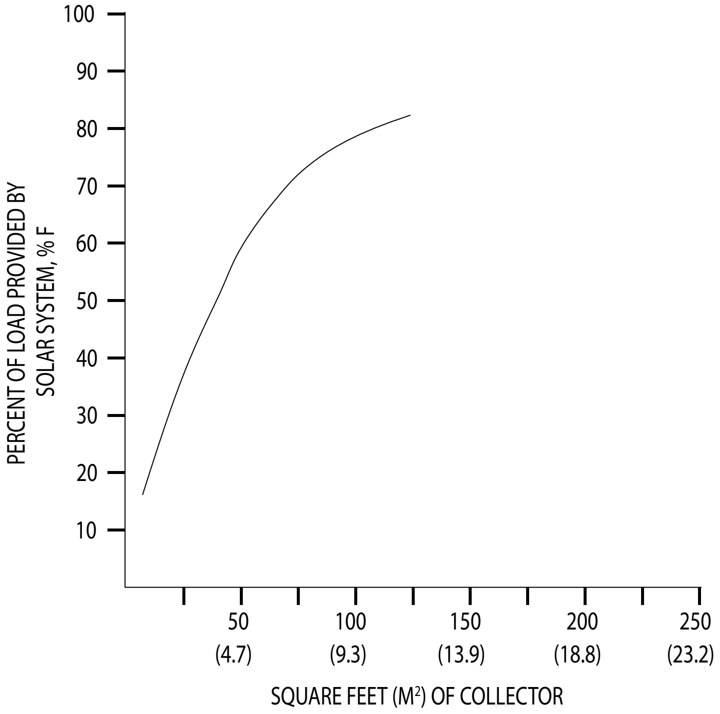


Figure 10-7 f-chart for Memphis, Tennessee

Keys to Sizing

- Building load: What is the daily water demand?
- Building occupancy: On average, how many days per week is the building occupied?
- Location
- Safety measures/devices

Example 10-2

An apartment building occupied at all times has 64 units using 30 gpd each (1,920 gpd total). If one 30-square-foot panel generates 30,000 Btu per day in the summer, how many panels are needed?

- 30,000 Btu / 8.34 pounds per gallon / (120°F – 60°F) = 60 gallons at a 60°F rise per panel
- 1,920 gpd / 60 = 32 solar panels

Example 10-3

For the same apartment building, how much storage is needed?

- 30,000 Btu / 8.34 pounds per gallon / (150°F – 60°F) = 40 gallons at a 90°F rise per panel
- 40 x 32 panels = 1,280 gallons of storage

Keys to Performance

When laying out the panels, consider the following to ensure peak performance.

- What is the flow rate through a panel?
- How do off-peak loads affect temperature and control?
- What temperature does the sensor see?
- How big is the piping (heat loss, installation cost)?
- How efficient is the system?

PANEL LAYOUTS AND PIPING ARRANGEMENTS

Panels in Parallel/Arrays in Parallel

- 32 panels = Eight arrays (see Figure 10-9)
- 1–1.5 gpm per panel = 32–48 gpm total
- 2–2½-inch pipe
- Vents on cold water
- Sensor low at end
- 10°F band in summer; 2–4°F in lower months

Panels in Series/Arrays in Parallel

- 32 panels = Eight arrays (see Figure 10-10)
- 1–1.5 gpm per panel = 32–48 gpm total
- 2–2½-inch pipe
- One vent on hot water
- Sensor high at end
- 10°F band in summer; 2–4°F in lower months

Panels in Series/Arrays in Series

- 32 panels = Eight arrays (see Figure 10-11)
- 1–1.5 gpm per panel = 8–12 gpm total
- 1–1¼-inch pipe
- Vents at high points
- Sensor high at end
- 40°F band in summer; 10–20°F in lower months

Illustrations

Figures 10-12, 10-13, and 10-14 illustrate a dual water heater installation with one storage tank, a dual water heater installation with two storage tanks, and a detail of the solar panel array.

SPECIFICATIONS

The specifications are an important part of any system design. Several formats are used today. Always coordinate and verify the specification format that is to be used for a project.

In the current Construction Specifications Institute (CSI) format, plumbing is found in the 220000 sections. Some of the sections that may be included in a solar water heater system specification follow. Note that a system may require sections other than those listed. These are only listed as an example.

- 220500 Common Work Results for Plumbing
- 22053 General Duty Valves for Plumbing
- 220529 Hangers and Supports for Plumbing
- 220533 Freeze Protection for Plumbing Piping
- 220548 Vibration and Seismic Controls for Plumbing Piping and Equipment
- 220553 Identification for Plumbing Pipe and Equipment
- 230993.13 Controls Point List

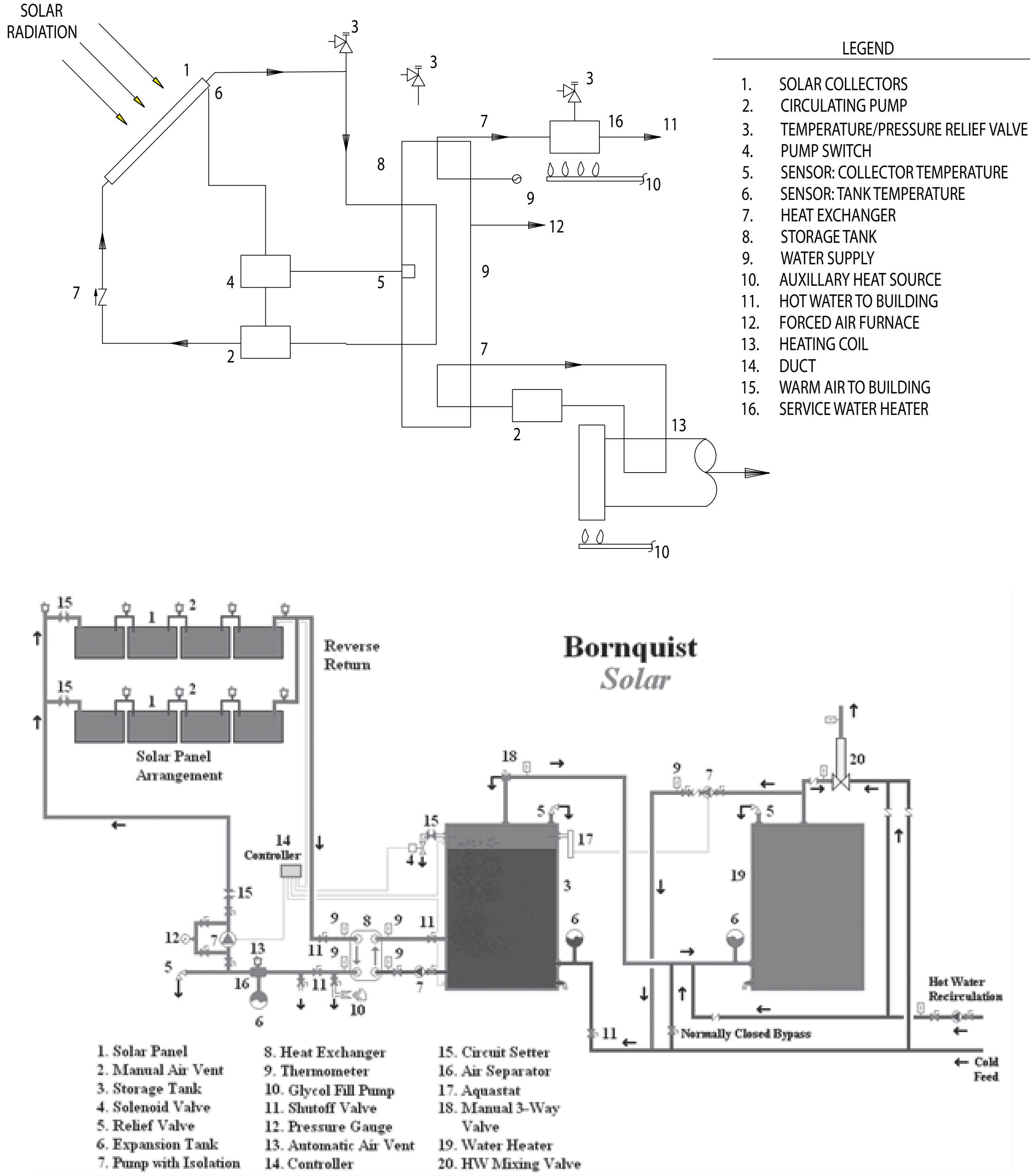


Figure 10-8 Pump Circulating System, Combined Space and Service Water Heating Applications

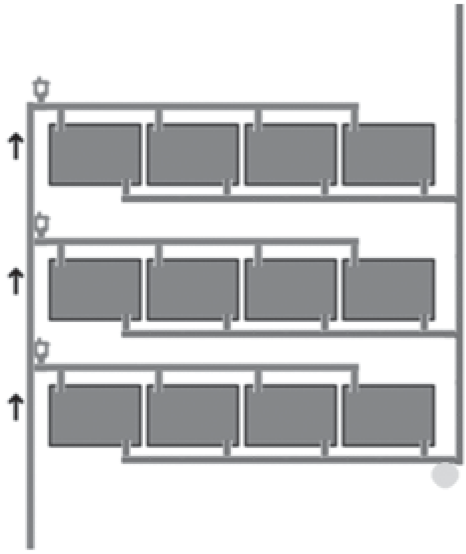


Figure 10-9 Panels in Parallel/Arrays in Parallel

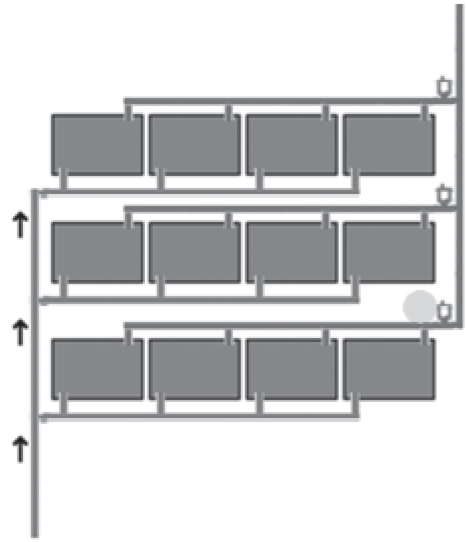


Figure 10-10 Panels in Series/Arrays in Series

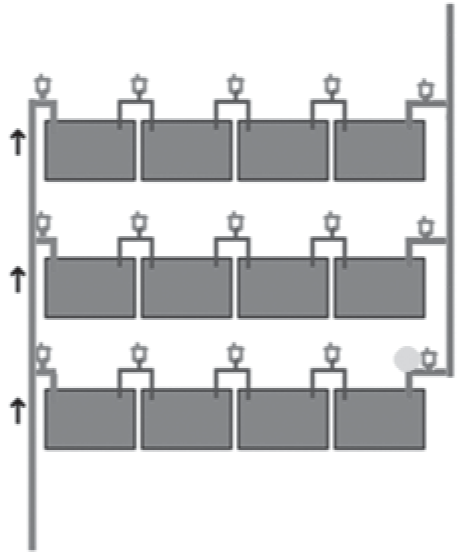


Figure 10-11 Panels in Series/Arrays in Series

Regardless of the format used, the basic objectives and requirements are the same. The following may serve as a guideline to writing specifications for a solar system.

Collectors

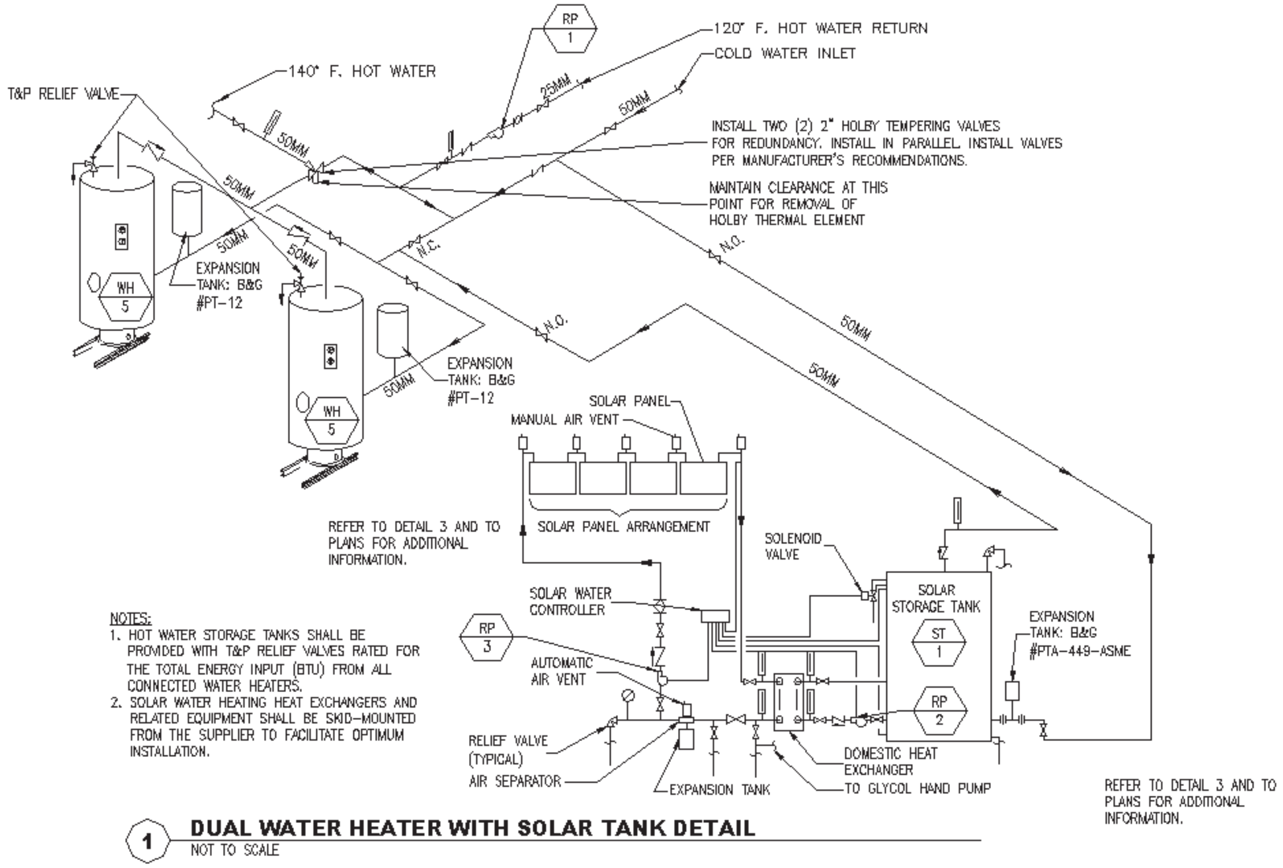
- Manufacturer and model number
- Number of covers
- Performance characteristics
- Testing agency and test method followed
- Stagnation conditions
- Recommended flow rate
- Operating temperatures
- Pressure drop at maximum flow rate
- Materials
- Glazing
- Gaskets
- Insulation
- Absorber plate
- Selective coating
- Recommended heat-transfer fluid
- Physical dimensions
- Module size
- Aperture area
- Weight
- Expected collector life
- Warranty

Heat Exchangers

- Manufacturer and model number
- Construction
- Recommended heat-transfer fluid
- Warranty
- Expected life
- Materials
- Physical dimensions
- Performance
- Testing agency and test method followed
- Operating conditions
- Flow rate
- Pressure drop
- Temperature
- Pressure
- Pumps
- Manufacturer and model number
- Motor coupling
- Mechanical seal
- Warranty
- Estimated life

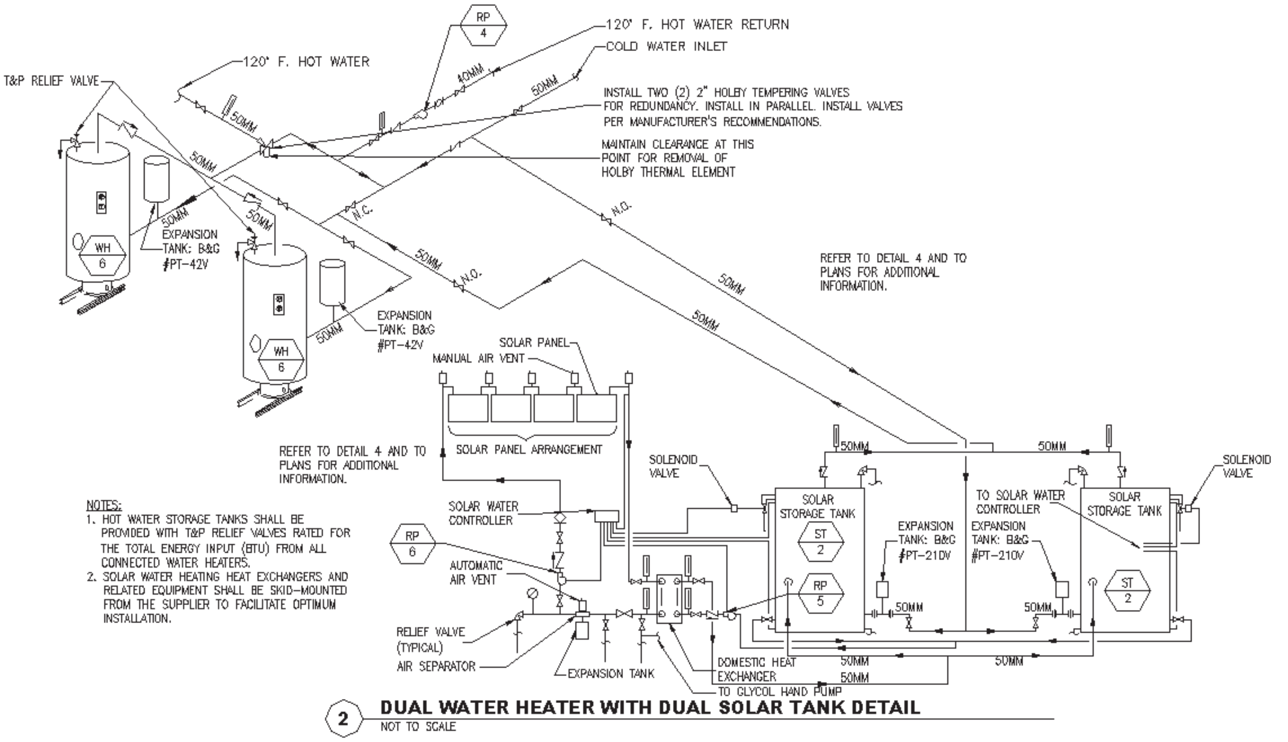
Pump Body and Impeller Material

- Gasketing materials
- Motor voltage
- Amperage
- Operating conditions
- Flow rate
- Pressure drop
- Temperatures



NOTES:
1. HOT WATER STORAGE TANKS SHALL BE PROVIDED WITH T&P RELIEF VALVES RATED FOR THE TOTAL ENERGY INPUT (BTU) FROM ALL CONNECTED WATER HEATERS.
2. SOLAR WATER HEATING HEAT EXCHANGERS AND RELATED EQUIPMENT SHALL BE SKID-MOUNTED FROM THE SUPPLIER TO FACILITATE OPTIMUM INSTALLATION.

Figure 10-12 Dual Water Heater with Solar Tank



NOTES:
1. HOT WATER STORAGE TANKS SHALL BE PROVIDED WITH T&P RELIEF VALVES RATED FOR THE TOTAL ENERGY INPUT (BTU) FROM ALL CONNECTED WATER HEATERS.
2. SOLAR WATER HEATING HEAT EXCHANGERS AND RELATED EQUIPMENT SHALL BE SKID-MOUNTED FROM THE SUPPLIER TO FACILITATE OPTIMUM INSTALLATION.

Figure 10-13 Dual Water Heater with Dual Solar Tanks

- Pressure
- Pump curves
- Flange connections
- Preheater tanks
- Manufacturer and model number
- Storage capacity
- Body material
- Lining
- Insulation
- Plumbing connections
- Jacket
- Sacrificial anode
- Physical size
- Auxiliary heater
- Pressures
- Weight
- Warranty
- Estimated life
- Operating temperatures

Storage Tanks

- Manufacturer and model number
- Capacity
- Operating temperatures
- Storage medium
- Freezing precautions
- Lining
- Working pressure
- Materials of construction
- Insulation
- Plumbing connections
- Jacket
- Physical dimensions
- Pressures
- Weight
- Drain valves
- Manhole
- Live and dead loads
- Warranty
- Estimated life
- Controls
- Manufacturer and model number
- Differential thermostat
- Sensor
- Available functions
- Power input
- Approvals and listings
- Ground provisions
- Warranty
- Estimated life

Heat Pumps

- Manufacturer and model number
- Pump type
- Rated heat and cooling output
- Rated heat and cooling coefficient of performance and energy-efficiency ratio
- Auxiliary heaters
- Filters
- Operating voltage and amperage
- Condenser coil operating range and flow rate
- Physical dimensions
- Weight
- Operating sequence
- Warranty
- Estimated life

Insulation

- Manufacturer and type (material)
- Heat transfer characteristics/thickness
- Flame spread and smoke-developed characteristics
- Vapor barrier/cover
- Method of application
- Warranty

ADDITIONAL READING AND OTHER RESOURCES

A bounty of information is available to assist in the design of solar systems. A more complete understanding will come through further research.

- *The Solar Hydrogen Civilization* by Roy McAlister
- Solar Energy Industries Association: seia.org
- Energy Star: energystar.gov
- Internal Revenue Service: irs.gov
- TIAP: energytaxincentives.org
- Solar Rating Certification Corporation (SRCC): solar-rating.org
- U.S. Department of Energy, Energy Efficiency and Renewable Energy: eere.energy.gov
- Solar and Sustainable Energy Society of Canada: sesci.ca
- Canadian Solar Industries Association: cansia.ca
- Kortright Centre for Conservation: kortright.org

REFERENCES

ASHRAE Handbook — 1989 Fundamentals, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA.

Duffie, J. A. and Beckman, W. A., *Solar Energy Thermal Processes,* Interscience Publishers, New York, NY, 1974.

Kreider, J. F. and Kreith, J., *Solar Heating and Cooling,* McGraw-Hill, New York, NY, 1975.

ASHRAE 93: *Standard of Testing to Determine the Performance of Solar Collections,* American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA, 1986.

Montgomery, R. H. and Budnick, J., *Solar Decision Book,* Dow Coming Corporation, Midland, MI,1978.

ASHRAE 90A: *Energy Conservation in New Building Design,* American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta,GA, 1975.

Beckman, W. A., Klein, S. A., and Duffie, J. A., *Solar Heating Design by the f-Chart Method,* Wiley-Interscience, New York, NY, 1977.

Kreider, J. F., *The Solar Heating Design Process,* McGraw-Hill, New York, NY, 1982.

Solar Design Workbook, Solar Energy Research Institute, Golden, CO, 1981.

Solar Energy System Design, American Society of Plumbing Engineers, Westlake, CA, 1980.

Tully, G. F., *Solar Heating Systems,* McGraw-Hill, New York, NY, 1981.

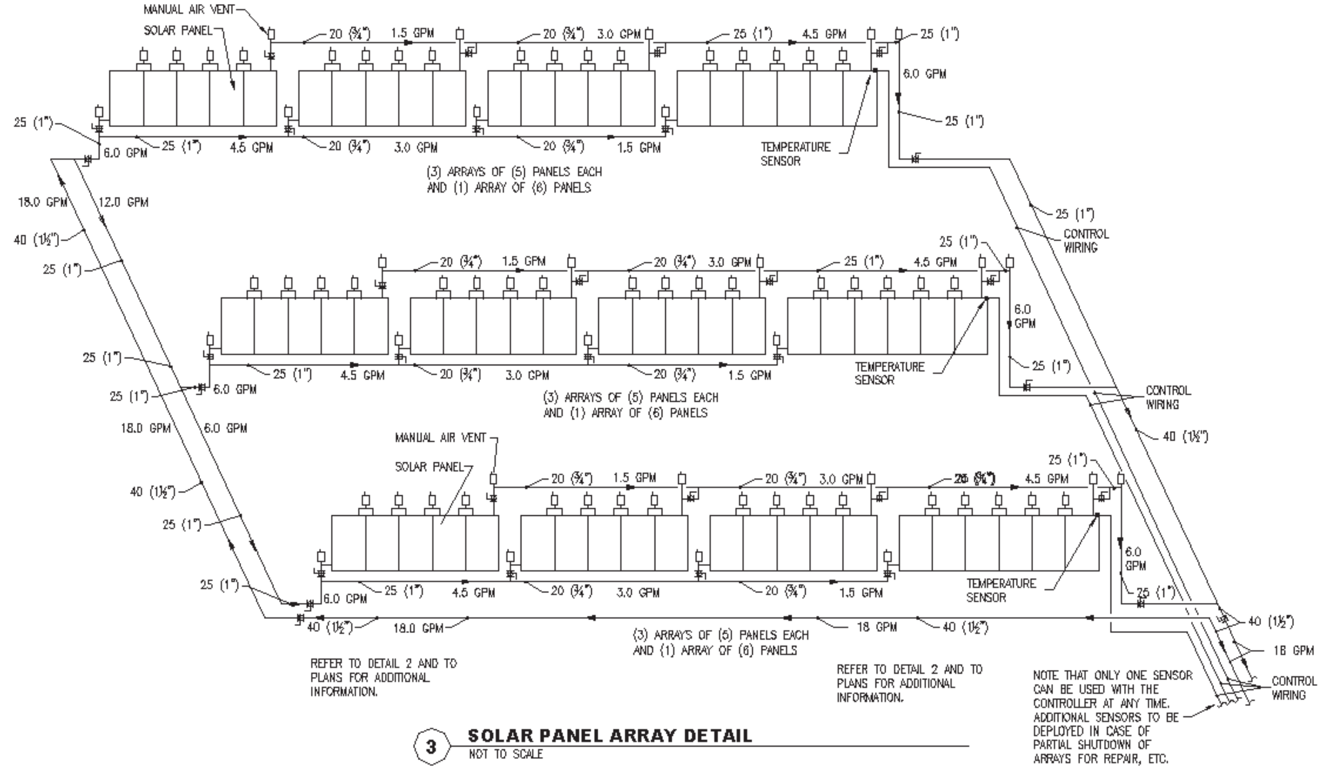
U. S. Department of Energy, *Active Solar Energy System Design Practice Manual*, Solar/0802-79/01, NITS, Springfield, VA, 1979.

ASHRAE Handbook — 1988 Equipment, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA.

ASHRAE Handbook — 1987 Systems and Applications, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA.

Solar Water Heater's: A Buyer's Guide" Natural Resources Canada, Ottawa: Minister of Supply and Services, 1987.

Noble, Duncan and Robert K. Swartman, *The Canadian Renewable Energy Guide,* Burnstown: General Store Publishing House, 1995.



REFER TO DETAIL 2 AND TO PLANS FOR ADDITIONAL INFORMATION.

REFER TO DETAIL 2 AND TO PLANS FOR ADDITIONAL INFORMATION.

NOTE THAT ONLY ONE SENSOR CAN BE USED WITH THE CONTROLLER AT ANY TIME. ADDITIONAL SENSORS TO BE DEPLOYED IN CASE OF PARTIAL SHUTDOWN OF ARRAYS FOR REPAIR, ETC.

3 **SOLAR PANEL ARRAY DETAIL**
NOT TO SCALE

Figure 10-14 Solar Panel Array Installation

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11

Site Utility Systems

This chapter discusses the components and design of building and site utility services for all plumbing systems and their installation from the building wall to their connection to a source. Such connections could be a public water supply or main or, with regard to drainage, any ultimate point of disposal, which could include a public sewer, retention basin, or other method as appropriate. Natural gas supply would connect to a franchised public utility main. The systems discussed include:

- Potable water supply
- Fire protection water supply
- Sanitary sewer
- Site storm water system
- Natural gas service

Other methods of supply, such as wells and surface water, are outside the scope of this chapter.

PRELIMINARY INFORMATION FOR ALL SYSTEMS

The following general information shall be obtained for all systems on each project. Information for specific items is discussed under the individual systems.

- Obtain an architectural site plan showing the location of the building on the site. Part of the site plan should be a location plan of the surrounding area. Also included should be the block and lot number, building address, building classification, and building height. Keep in mind that the actual height and the legal height are different, but both dimensions are necessary to determine fire protection requirements. Other pertinent information includes the location of existing buildings and any natural interference, such as boulders and trees not being removed.
- Obtain an existing utility site plan from the various purveyors or suppliers if the utilities are not shown on the architectural site plan. An investigation should be conducted to ensure the availability of all services that are required.
- For your reference, create a contact sheet showing all of the building and plumbing code officials, fire marshal, fire code officials, and every other person or department necessary for the development, design, and approval of the plumbing systems. One of the most important items for the record is the utility information, such as water pressure, gas information, sanitary sewer disposal information, and storm water sewer and disposal information.
- Make certain that north is clearly and consistently indicated on all drawings.
- If the project is an alteration, obtain all available existing plans, including the legal height of the existing structure.
- Conduct a thorough code search to find all codes applicable to the project, including the requirements for grease traps and storm water management systems.
- Obtain from the plumbing and other code officials all submittal and approval requirements for plans and other contract documents prepared for the project.
- Obtain the requirements for fire protection systems from the fire department, fire marshal, and insurance carrier, including the need for a meter and backflow preventer.
- Include existing and finished grades on a topographical plan, as well as temporary or intermediate grades used for any purpose.
- Obtain soil boring information, including groundwater level.
- Determine if a lawn or turf irrigation system is required.
- Determine the need for a private sewage disposal system.
- Determine if a sewage lift system is required.

Typical general site notes (see Appendix 11-A) apply only to the site. They are intended to be a general series of notes, and some may not apply to a specific project.

DOMESTIC WATER SERVICE

The domestic water system provides water suitable for human consumption to all fixtures and equipment throughout a facility. The domestic water building service conveys water from a public utility or other source into a facility for further distribution.

Codes and Standards

Various codes, particularly the plumbing code, are applicable to domestic water services. It is recommended to check with the local or state authorities to determine which codes apply in the area. Water purveyors also may have regulations with which the project must comply.

Getting Started

The most important piece of information concerning the water service connecting to a public water supply is the residual water pressure available at the entrance into the building. A decision regarding the necessity for a pressure-boosting system is based on this figure. Figure 11-1 provides a step-by-step calculation to find the residual pressure.

The water pressure at the public water main is called the static pressure and usually depends on the time of day this static measurement is taken. Request this reading to be taken between 10 a.m. and noon. From this actual pressure, the pressure losses through the installed components are deducted. In addition, the difference in height between the water main and the building entrance (or point of connection to the interior distribution system) is either added or deducted. After all service losses due to fittings, length of run through a preliminary sized water service, backflow preventer, and other connected equipment and devices have been subtracted, the result is the available, or residual, pressure. From the residual pressure, it is recommended to subtract an additional 5-pound-per-square-inch (psi) (34.5-kPa) pressure loss to allow for future nearby construction that might lower the pressure.

General System Requirements

The first step in determining the general system requirements is to find the water purveyor or utility company providing water to the site. Next, calculate the preliminary (or final, if possible) maximum instantaneous water service requirements, in gallons per minute (gpm) (L/min). This is done from a preliminary (or final, if available) fixture count. An additional 10 percent is added as an allowance for cooling tower fill, boiler fill, and other miscellaneous uses of water in addition to the domestic use. For specialized facilities, add the flow rate obtained from the owner for additional processes and equipment that may use potable water. To calculate the maximum probable gpm, proceed as follows.

1. Count all fixtures to be installed in the facility by fixture type.
2. Based on each type of fixture, find the water fixture unit (wfu) value for each fixture. Refer to Table 11-1 for wfu values for each type of fixture. As stated previously, use the plumbing code that applies to the project's location.
3. Add all facility water fixture units to calculate the total water load in water fixture units.
4. Refer to Figure 11-2 to convert water fixture units to the maximum probable gpm. Several codes, such as the Uniform Plumbing Code (UPC), International Plumbing Code (IPC), state codes, and even city codes, can be used as well. The IPC currently uses the Hunter's curve fixture unit conversion to gpm developed in 1924. If an engineer is designing a facility where this code requirement is in effect, the information must be used. However, recent tests and studies conducted by many authorities have determined that use of Hunter's curves leads to oversized piping, mainly due to the reduced water flow of modern fixtures. If this code is not the approved code for the local area, converting water fixture units to gpm

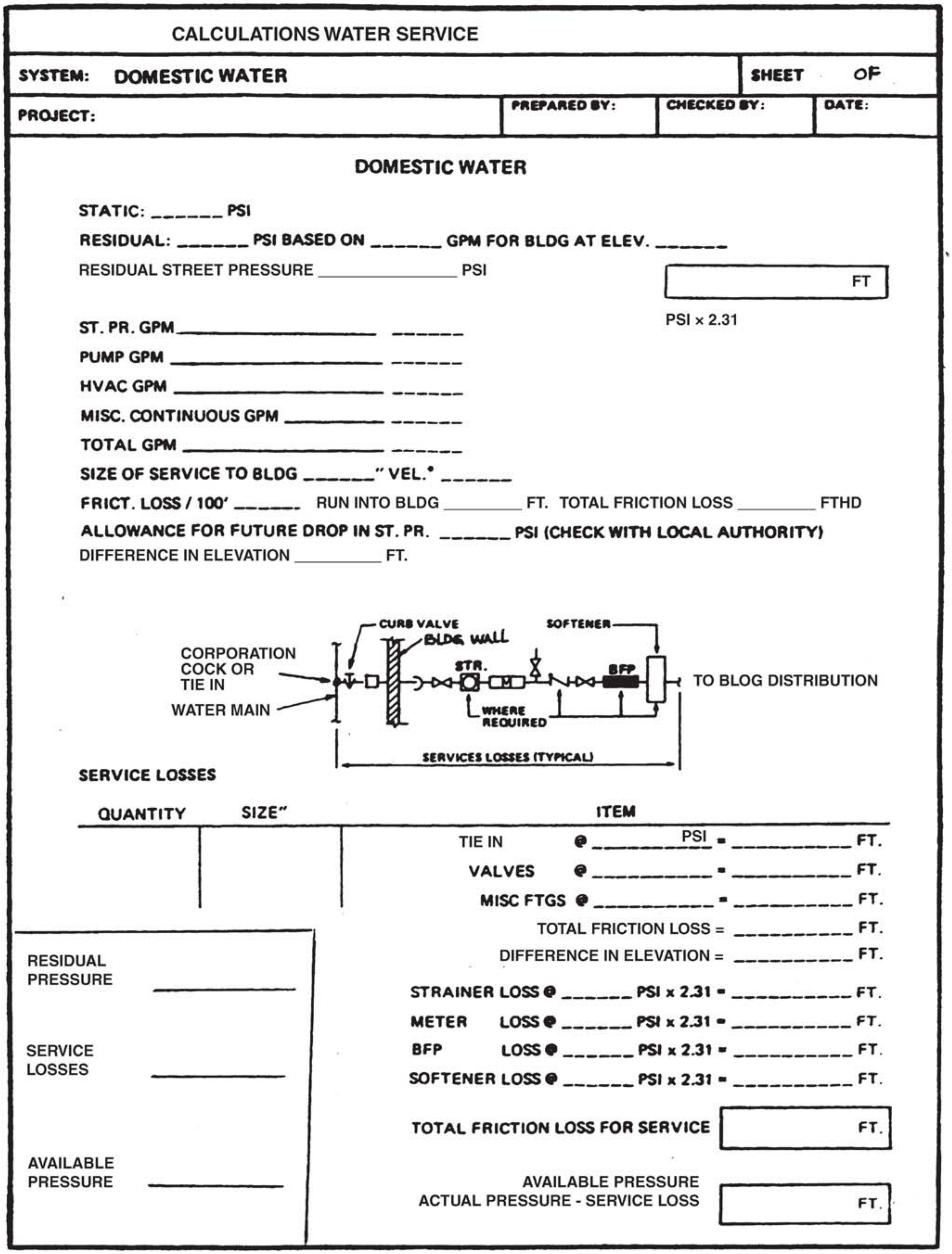
Table 11-1 Water Fixture Unit Values Assigned to Fixtures

Fixture	Occupancy	Type of Supply Control	Water Fixture Units
Bathroom group	Private	Flush tank	3.6
Bathroom group	Private	Flush valve	8.0
Bathtub	Private	Faucet	1.4
Bathtub	Public	Faucet	4.0
Bidet	Private	Faucet	2.0
Combination fixture	Private	Faucet	3.0
Dishwashing machine	Private	Automatic	1.4
Drinking fountain	Offices, etc.	3/8-in. valve	0.25
Kitchen sink	Private	Faucet	1.4
Kitchen sink	Hotel, restaurant	Faucet	4.0
Laundry trays (1–3)	Private	Faucet	1.4
Lavatory	Private	Faucet	1.0
Lavatory	Public	Faucet	2.0
Service sink	Offices, etc.	Faucet	3.0
Shower head	Public	Mixing valve	4.0
Shower head	Private	Mixing valve	1.4
Urinal	Public	1-in. flush valve	10.0
Urinal	Public	¾-in. flush valve	5.0
Urinal	Public	Flush tank	3.0
Washing machine (8 lb)	Private	Automatic	1.4
Washing machine (8 lb)	Public	Automatic	3.0
Washing machine (15 lb)	Public	Automatic	4.0
Water closet	Private	Flush valve	6.0
Water closet	Private	Flush tank	2.2
Water closet	Public	Flush valve	10.0
Water closet	Public	Flush valve	5.0
Water closet	Public or private	Flushometer tank	2.0

Notes:

1. For fixtures not listed, loads should be assumed by comparing to listed fixtures that use water in similar quantities and at similar rates.
2. For SI conversion, 1 in. = 25.4 mm.

Figure 11-1 Water Service Calculations



CALCULATIONS WATER SERVICE

SYSTEM: DOMESTIC WATER SHEET OF

PROJECT: PREPARED BY: CHECKED BY: DATE:

DOMESTIC WATER

STATIC: ______ PSI

RESIDUAL: ______ PSI BASED ON ______ GPM FOR BLDG AT ELEV. ______

RESIDUAL STREET PRESSURE ________________ PSI

FT

PSI × 2.31

ST. PR. GPM ______________________ ______

PUMP GPM ______________________ ______

HVAC GPM ______________________ ______

MISC. CONTINUOUS GPM __________ ______

TOTAL GPM ______________________ ______

SIZE OF SERVICE TO BLDG ______" VEL.* ______

FRICT. LOSS / 100' ______ RUN INTO BLDG _________ FT. TOTAL FRICTION LOSS _________ FTHD

ALLOWANCE FOR FUTURE DROP IN ST. PR. ______ PSI (CHECK WITH LOCAL AUTHORITY)

DIFFERENCE IN ELEVATION __________ FT.

SERVICE LOSSES

QUANTITY	SIZE"	ITEM
		TIE IN @ __________ PSI = __________ FT.
		VALVES @ __________ = __________ FT.
		MISC FTGS @ __________ = __________ FT.

TOTAL FRICTION LOSS = __________ FT.

DIFFERENCE IN ELEVATION = __________ FT.

STRAINER LOSS @ ______ PSI x 2.31 = __________ FT.

METER LOSS @ ______ PSI x 2.31 = __________ FT.

BFP LOSS @ ______ PSI x 2.31 = __________ FT.

SOFTENER LOSS @ ______ PSI x 2.31 = __________ FT.

TOTAL FRICTION LOSS FOR SERVICE FT.

AVAILABLE PRESSURE
ACTUAL PRESSURE - SERVICE LOSS FT.

RESIDUAL PRESSURE ____________

SERVICE LOSSES ____________

AVAILABLE PRESSURE ____________

is recommended. Refer to Table 11-2 for more modern conversions, based on recent studies.

Once this is accomplished, a formal letter to the utility should be written to obtain the following information. The importance of this cannot be overemphasized. The following should be requested:

- A site plan from the utility company showing all water mains adjacent to the site
- Other information appearing in a typical water utility letter (provided in Appendix 11-B)

Once the utility company has answered the utility letter and provided most of the information requested and a site plan showing the location and size of the main and the location of the building on the site has been provided, the information obtained can be used to determine the following major design items.

- Based on a preliminary assessment of available pressure inside the building wall, a decision regarding the method to use to increase water pressure in the facility, if required, can be made. The general space requirements for the necessary pumps and tanks inside the building or water tanks outside on the site shall be determined.
- Using a complete fixture count, the final maximum water supply flow rate can be calculated.
- The run into the building should be determined, and the meter assembly should be selected and located.

A typical domestic water service and all required installed devices can now be discussed in detail. Included are a description of the various required information, installed components, and necessary design criteria.

Typical Domestic Water Building Service Components and Design Considerations

Preliminary Flow Rate Determination

The best way to find the flow, in gpm, for a new building is to use a fixture count, convert it to gpm, and add 10 percent. Use the expected time of occupancy for the flow rate. For a preliminary flow rate for office buildings, it is best to use the number of occupants for this purpose. Use 100 square feet (9.3 m^2) per occupant for a competitive building, 150 square feet (13.9 m^2) per occupant for a normal building, and 200 square feet (18.6 m^2) per occupant for a single-company building. Using 10 gallons (37.9 L) per employee for a 10-hour day, calculate the gpm (L/min). Another figure commonly used for other kinds of buildings is 0.125 gallons per square foot (0.5 L per square meter) of building area for a 10-hour day. To this figure add 10 percent additional for HVAC evaporation and demand, boiler feed water, and any other miscellaneous uses.

Static and Residual Water Pressure

A hydrant flow test is the method most often used to determine static and residual water pressure. This

Table 11-2 Maximum Probable Flow, gpm (L/s)

Water supply fixture units	Tank-type water closets	Flushometer-type water closets	Water supply fixture units	Tank-type water closets	Flushometer-type water closets
1	1	-	120	25.9 (2.0)	76 (5.7)
2	3	-	125	26.5 (2.0)	76 (5.7)
3	5	-	130	27.1 (2.1)	77 (5.8)
4	6	-	135	27.7 (2.1)	78 (5.8)
5	7 (0.53)	27.2 (2.2)	140	28.3 (2.1)	78.5 (5.8)
6	8 (0.60)	29.1 (2.2)	145	29.0 (2.2)	79 (5.9)
7	9 (0.68)	30.8 (2.4)	150	29.6 (2.2)	80 (6.0)
8	10 (0.70)	32.3 (2.5)	160	30.8 (2.3)	81 (6.1)
9	11 (0.83)	33.7 (2.5)	170	32.0 (2.4)	83 (6.2)
10	12.2 (0.92)	35 (2.6)	180	33.3 (2.5)	84 (6.3)
12	12.4 (0.94)	37.3 (2.6)	190	34.5 (2.5)	85 (6.4)
14	12.7 (0.96)	39.3 (2.8)	200	35.7 (2.6)	86 (6.5)
16	12.9 (0.98)	41.2 (3.1)	220	38.1 (2.8)	88 (6.7)
18	13.2 (1)	42.8 (3.2)	240	40.5 (3.0)	90 (6.8)
20	13.4 (1.01)	44.3 (3.3)	260	43.0 (3.2)	92 (7.0)
22	13.7 (1.02)	45.8 (3.5)	280	45.4 (3.4)	94 (7.2)
24	13.9 (1.03)	47.1 (3.6)	300	47.7 (3.6)	96 (7.2)
26	14.2 (1.07)	48.3 (3.7)	400	59.6 (4.5)	102 (7.4)
28	14.4 (1.09)	49.4 (3.8)	500	71.2 (5.3)	108 (8.2)
30	14.7 (1.1)	50.5 (3.9)	600	82.6 (6.3)	113 (8.6)
35	15.3 (1.1)	53.0 (4.0)	700	93.7 (7.1)	117 (8.9)
40	15.9 (1.2)	55.2 (4.1)	800	105 (8.0)	120 (9.1)
45	16.6 (1.3)	57.2 (4.2)	900	115 (8.7)	123 (9.3)
50	17.2 (1.3)	59.1 (4.3)	1,000	126 (9.5)	126 (9.5)
55	17.8 (1.4)	60.8 (4.5)	1,500	175 (13.3)	175 (13.3)
60	18.4 (1.4)	62.3 (4.6)	2,000	220 (16.7)	220 (16.7)
65	190. (1.5)	63.8 (4.7)	2,500	259 (19.7)	259 (19.7)
70	19.7 (1.5)	65.2 (4.9)	3,000	294 (22.3)	294 (22.3)
75	20.3 (1.5)	66.4 (5.0)	3,500	325 (24.7)	325 (24.7)
80	20.9 (1.6)	67.7 (5.1)	4,000	352 (26.7)	352 (26.7)
85	21.5 (1.6)	68.8 (5.2)	4,500	375 (28.5)	375 (28.5)
90	22.2 (1.7)	69.9 (5.3)	5,000	395 (30)	395 (30)
95	22.8 (1.7)	71.0 (5.3)	6,000	425 (32.3)	425 (32.3)
100	23.4 (1.8)	72.0 (5.4)	7,000	445 (34)	445 (34)
105	24.0 (1.8)	73.0 (5.5)	8,000	456 (34.6)	456 (34.6)
110	24.6 (1.9)	73.9 (5.6)	9,000	461 (35)	461 (35)
115	25.3 (1.9)	74.8 (5.7)	10,000	462 (35)	462 (35)

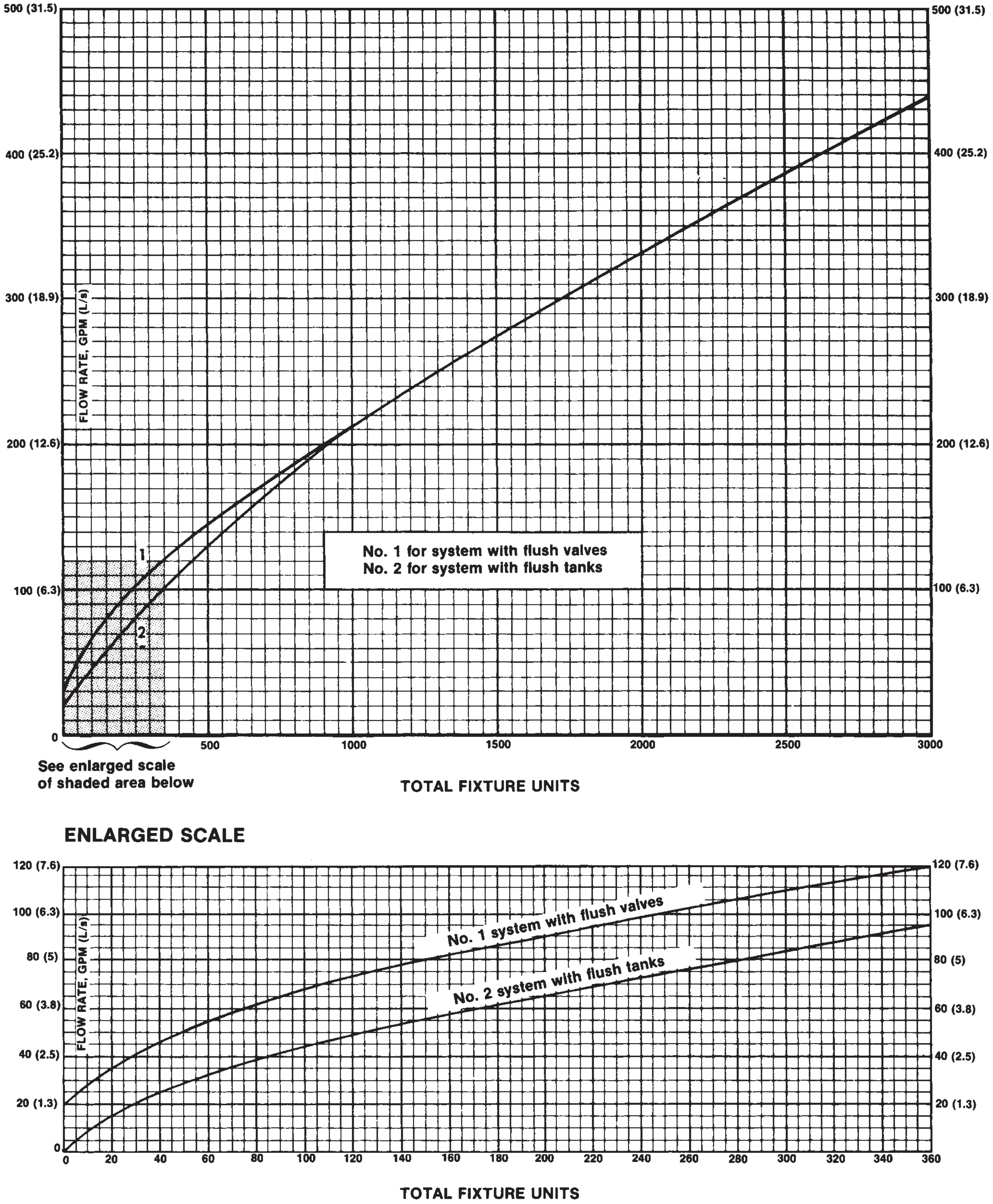


Figure 11-2 Conversion of Fixture Units to gpm

test consists of choosing the two adjacent fire hydrants closest to the site and taking three separate pressure readings, two with water flowing through a hydrant. For a typical test arrangement and nomenclature, refer to Figure 11-3.

The first pressure reading is obtained from a pressure gauge connected to one hydrant (hydrant A) with no water flowing out of either hydrant. This is called the static pressure because there is no flow through the test hydrant. The second reading involves both hydrants. The hydrant with the pressure gauge attached (hydrant A) remains unchanged. The second hydrant (hydrant B) is now opened, and a velocity pressure reading is taken using a pitot tube held directly in the water stream. A pitot tube is illustrated in Figure 11-4, and the method of taking the reading is illustrated in Figure 11-5. At the same time, another reading is taken from the first hydrant (hydrant A) while the second hydrant (hydrant B) is flowing water. The actual flow rate must be known for this test to be meaningful. This is calculated by converting the velocity pressure reading from the pitot gauge into gpm by referring to a typical relative discharge curve, such as that illustrated in Figure 11-6. For fire hydrants, use the curve labeled A for an open hydrant butt.

The time of year and time of day the test is taken are conditions that affect the flow test data. During seasonal variations, such as occurs in the summer, the flow is generally regarded as being greater than it is at other times of the year in generally residential areas. The time of day also often accounts for large differences in flow, leading to lower residual pressures. Consult with the water utility company to decide if these items are important in determining the actual pressure available to the project.

The static and residual pressure and the flow rate represent only two pieces of information. With these two points known, it is now possible to determine the pressure available at any flow rate. This is important since the flow rate for the project under design will almost certainly be less than the flow rate at which the hydrant flow test was conducted. The method used is to plot these two points on hydraulic graph paper. The vertical axis is the pressure, in psi, and the horizontal axis is the flow rate. By connecting the known two flow rates on different points on the graph and using care to use the proper gpm scale, any other point on the line will give the residual pressure if the flow rate desired is plotted on the line drawn. A graph illustrating this is given in Figure 11-7.

Pressure Loss and Installation of Taps

A tap is the connection to any water main. The connection for a private residence or other building that does

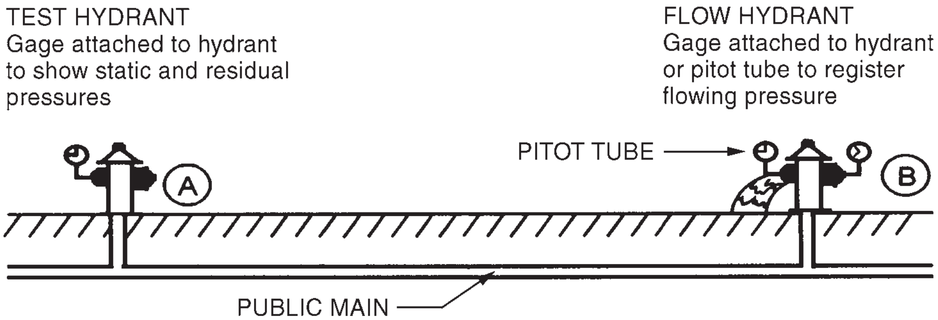


Figure 11-3 Hydrant Flow Test Arrangement

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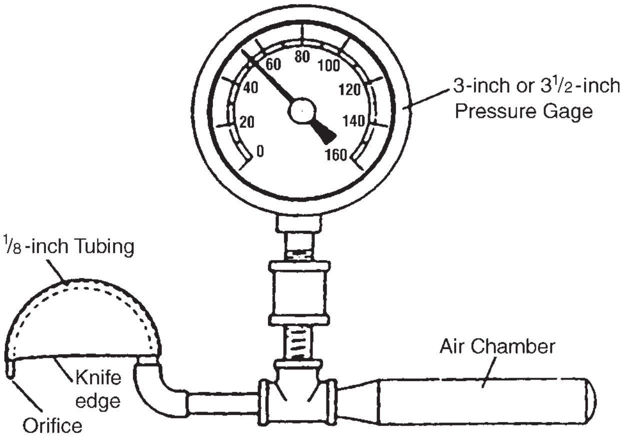


Figure 11-4 Pitot Tube with Gage and Air Chamber

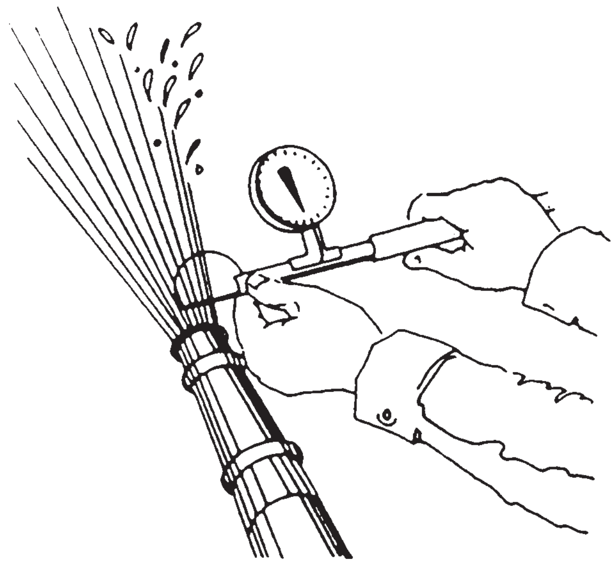
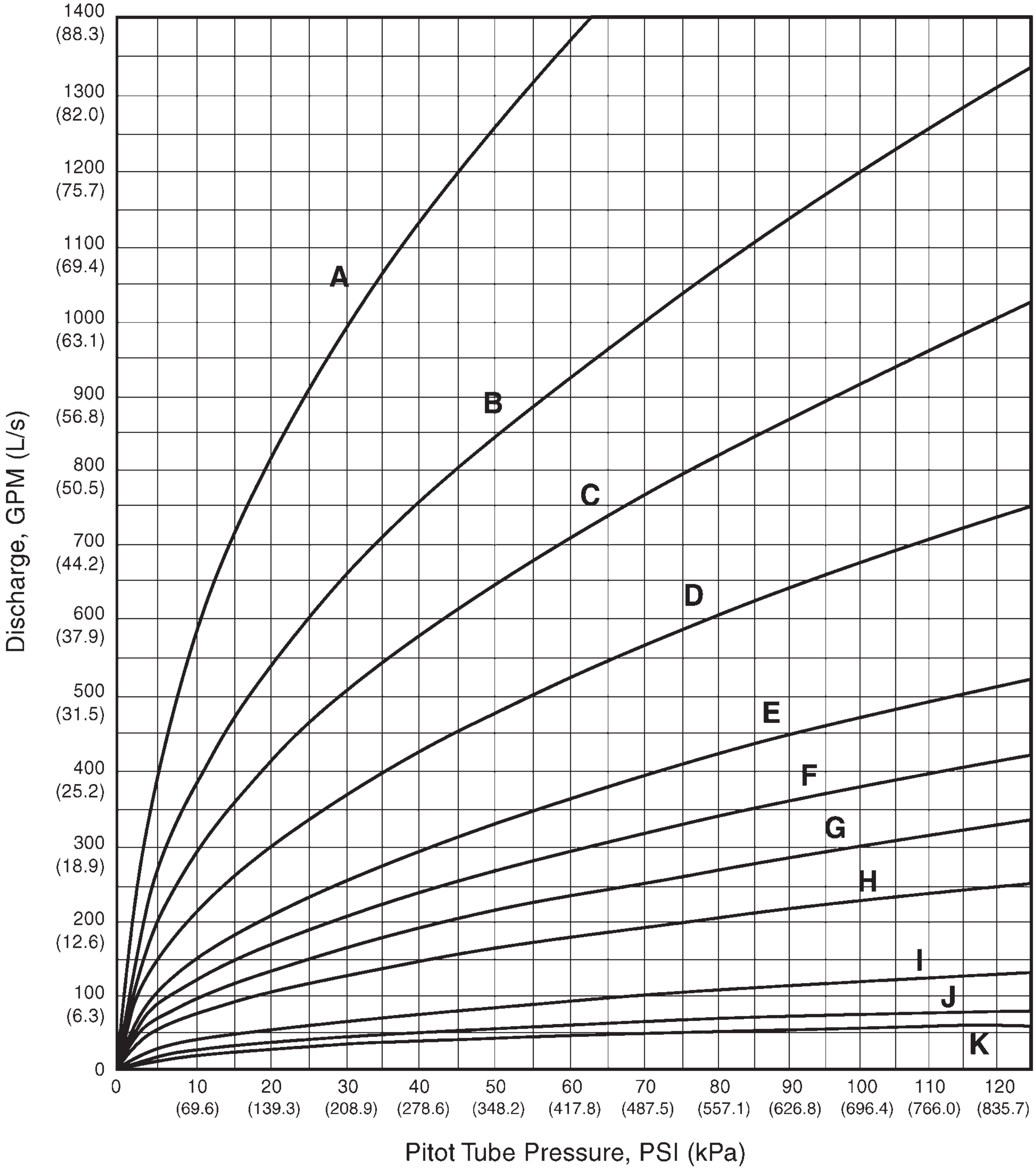


Figure 11-5 Obtaining Nozzle Pressure with a Pitot Tube



A – 2½" open hydrant butt
B – 2" smooth nozzle
C – 1¾" smooth nozzle
D – 1½" smooth nozzle
E – 1¼" smooth nozzle
F – 2½" hose with 1⅛" smooth nozzle
G – 1" smooth nozzle
H – ⅞" smooth nozzle
I – ¾" smooth nozzle
J – ½" smooth nozzle
K – ½" sprinkler head

Figure 11-6 Relative Discharge Curves

Source: *Chemical Engineers' Handbook.* McGraw-Hill.

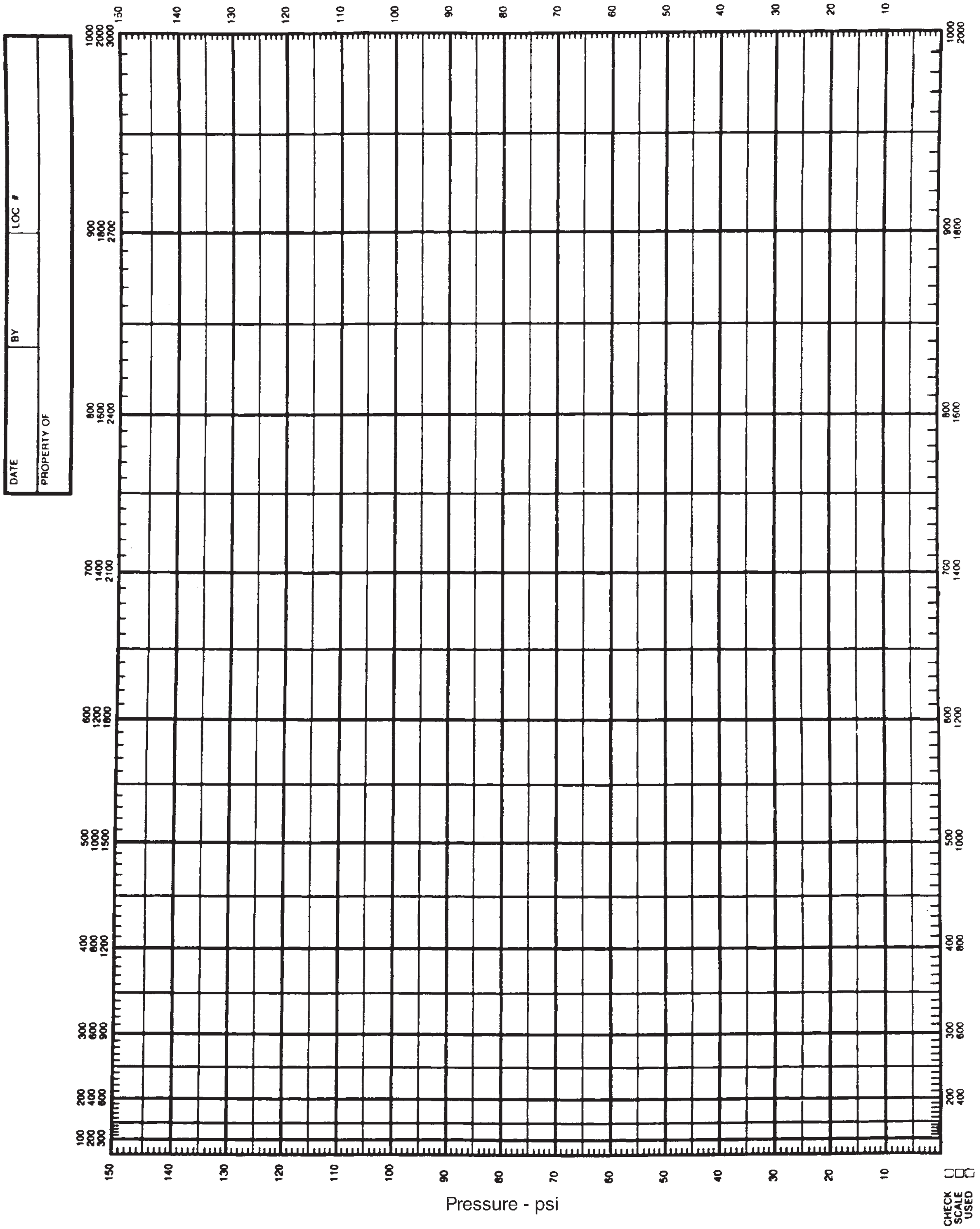
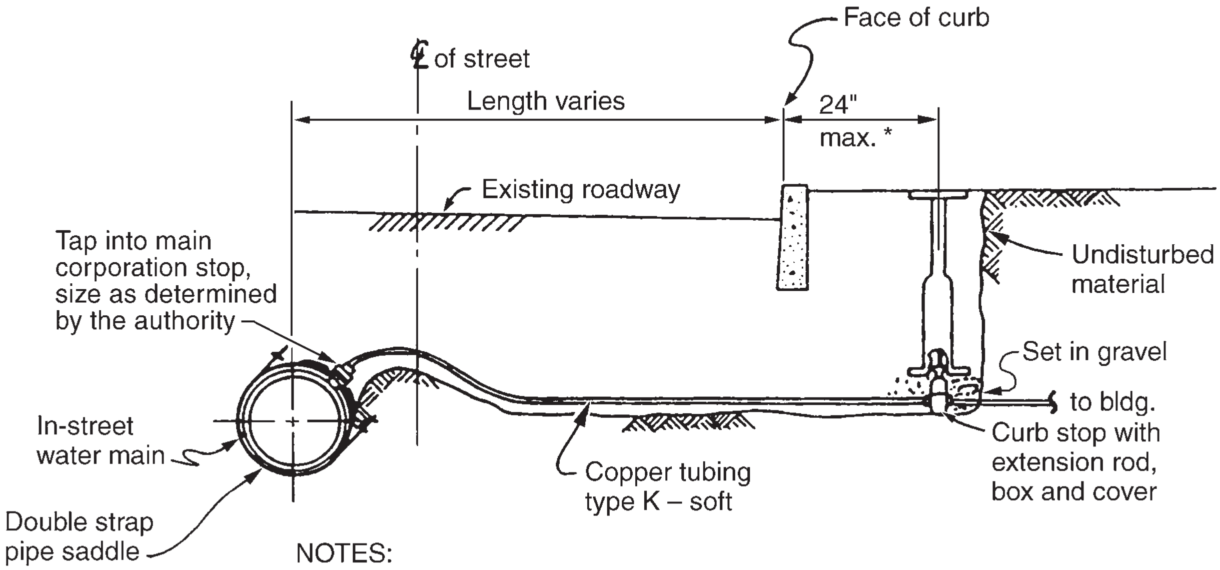


Figure 11-7 Water Supply Graph



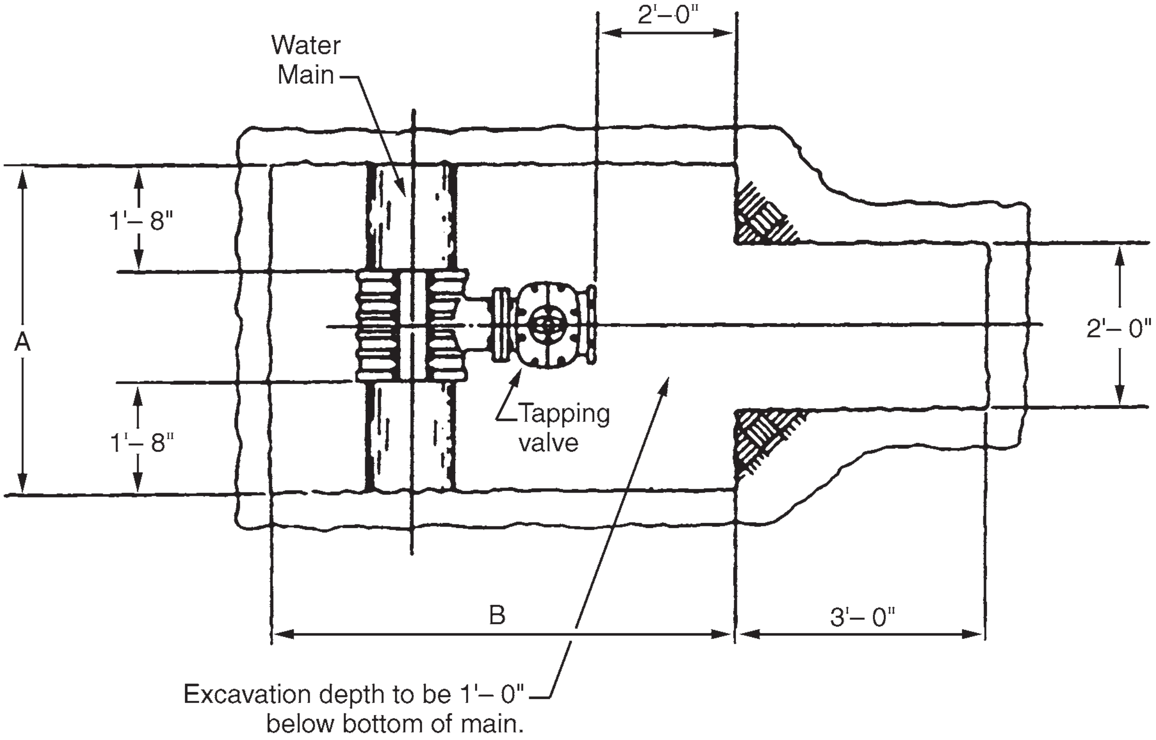
NOTES:

1. The corporation stop, copper tubing, and curb stop shall be all of the same size and shall be determined by the authority in the field.

*2. The location of curb boxes along roads without curbs shall be determined in the field by the authority.

ELEVATION

Figure 11-8 Service Connection Schematic



MINIMUM EXCAVATION DIMENSIONS

Header Size	A	B
3" thru 8"	5'– 0"	5'– 6"
10" thru 12"	5'– 6"	6'– 0"
14" thru 24"	6'– 0"	7'– 0"

Figure 11-9 Large Wet Tap Excavation Dimensions

not require a major service is illustrated in Figure 11-8. This type of service should be limited to approximately 2 inches (50.8 mm) and smaller. Typical large main wet tap (a connection under pressure) excavation dimensions are given in Figure 11-9. Other methods of wet-tapping into a main are available, and the dimensions are approximately the same.

The exact pressure lost through taps or street ells shall be obtained from the specific manufacturer or the public water supply authority.

Pressure Loss Through Valves and Fittings

The pressure loss through valves and fittings is available from standard engineering texts. Because the size of the service could be large, it is recommended to individually count and calculate all valves and fittings, rather than add a set amount common for the distribution network inside a building. The final calculation will result in an equivalent run of pipe. An equivalent straight length of pipe for fittings is given in Figure 11-10.

Total Pressure Loss in the Piping Run

The measured distance is from the main to the point of connection with the water distribution network inside the building. To the measured distance, add the equivalent run of pipe from pressure lost through all valves, fittings, and devices installed in the building service. Using the maximum probable gpm flow and equivalent number of feet run of pipe, the velocity and friction loss for the entire service can be obtained from standard engineering texts such as *Cameron Hydraulic Data* and the *Plumbing Engineering and Design Handbook of Tables*.

Backflow Preventers

The water utility company is responsible for protecting the public water supply from any possibility of contamination by backflow resulting from pollutants and contaminants. The most common reason for the utility company to require a backflow preventer (BFP) is the potential backflow from a facility that uses or produces any pollutant or contaminant. These facilities are separated into three general categories: low, moderate, and severe hazard. The facility category designated by the local authorities will mandate the type of BFP that shall be used. Another consideration is the presence of a close supply of impure water (such as a stream or lake) that could be used by a fire department to supply water that will be pumped into a building to fight a fire. This creates a potential source of contaminated water that could find its way back into a public main due to the pressure of the fire apparatus pumper.

The facility rating or classification should be made only after consulting with the proper authorities. The categories mentioned cannot list every circumstance

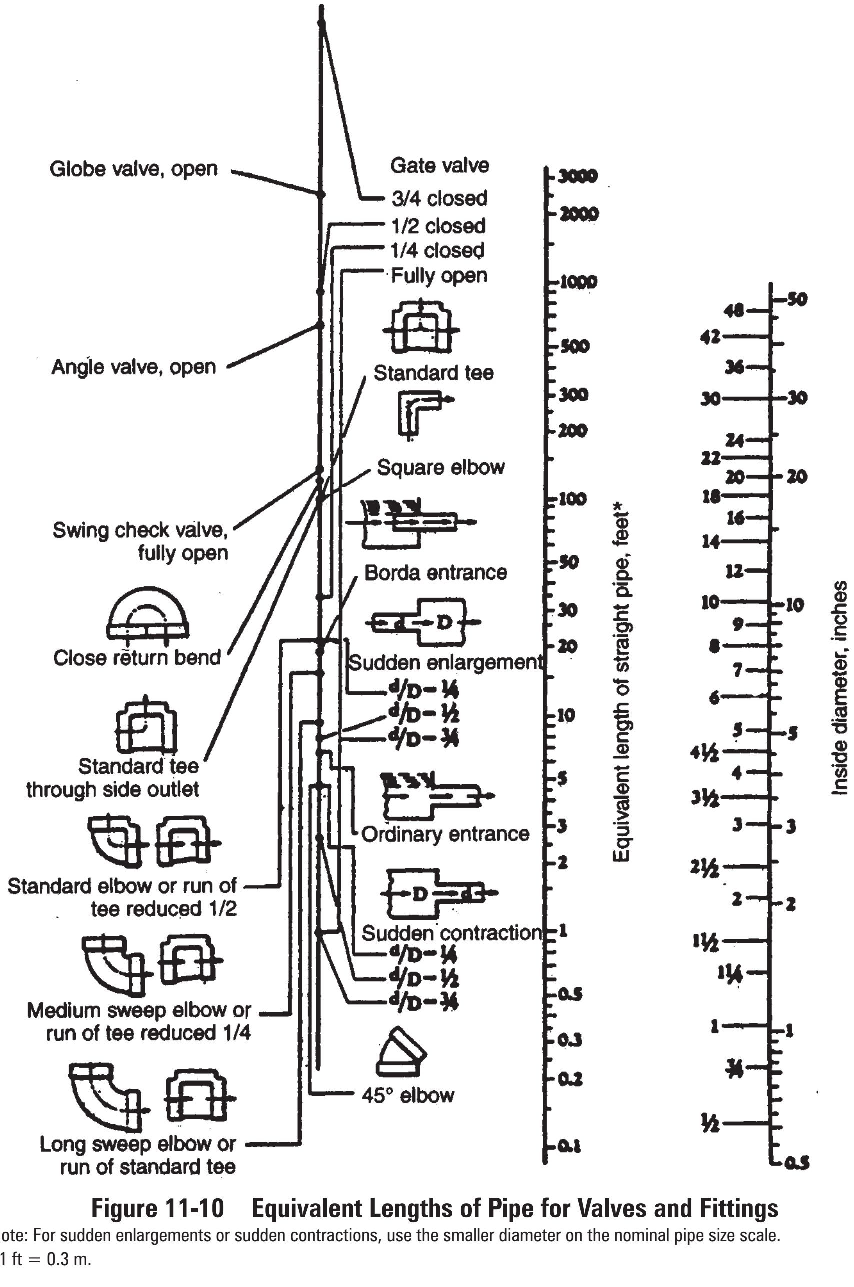


Figure 11-10 Equivalent Lengths of Pipe for Valves and Fittings

Note: For sudden enlargements or sudden contractions, use the smaller diameter on the nominal pipe size scale.

*1 ft = 0.3 m.

and facility type. Judgment must be used in the final selection. Following are often used categories based on the use, toxicity, nature, and availability of contaminants.

- Low (minor) hazard: Private homes and commercial establishments without complex plumbing or fire protection systems
- Moderate (medium) hazard: Commercial buildings and establishments, fire protection storage tanks and mains with no additives, and facilities that discharge water at higher-than-normal temperature. The fire protection system will have only stagnant water present in the pipe.
- Severe (high) hazard: Any facility that uses chemicals considered toxic or has the potential to discharge toxic waste. Typical facilities are hospitals, laboratories, water and sewage treatment plants, and facilities involving chemical, pharmaceutical, food, and industrial manufacturing and processing.

For hazardous locations, a reduced pressure zone (RPZ) BFP will be required near the property line at the connection to the public main or immediately inside a building. Figure 11-11 illustrates an RPZ BFP installed in an exterior aboveground enclosure. Figure 11-12 illustrates an RPZ BFP installed in an exterior belowground enclosure. For lesser hazards, a double check valve (DCV) is often acceptable. A double check valve in a belowground pit is illustrated in Figure 11-13. It is important to allow for adequate drainage from the RPZ discharge. The flow rate of discharge from an RPZ BFP is given in Figure 11-14 at various pressures. There is no discharge from a DCV.

The size of drain or pump required is of critical importance to remove any possible discharge from an RPZ BFP as quickly as possible, especially if it is located indoors or underground. Table 11-3 gives the size of drains based on the discharge and slope of discharge pipe.

A typical pressure loss through an RPZ BFP is 10 psi (68.9 kPa), and a typical pressure loss through a DCV is 5 psi (34.5 kPa). Since many types of backflow preventers are available, check with the manufacturer regarding the exact amount of dis-

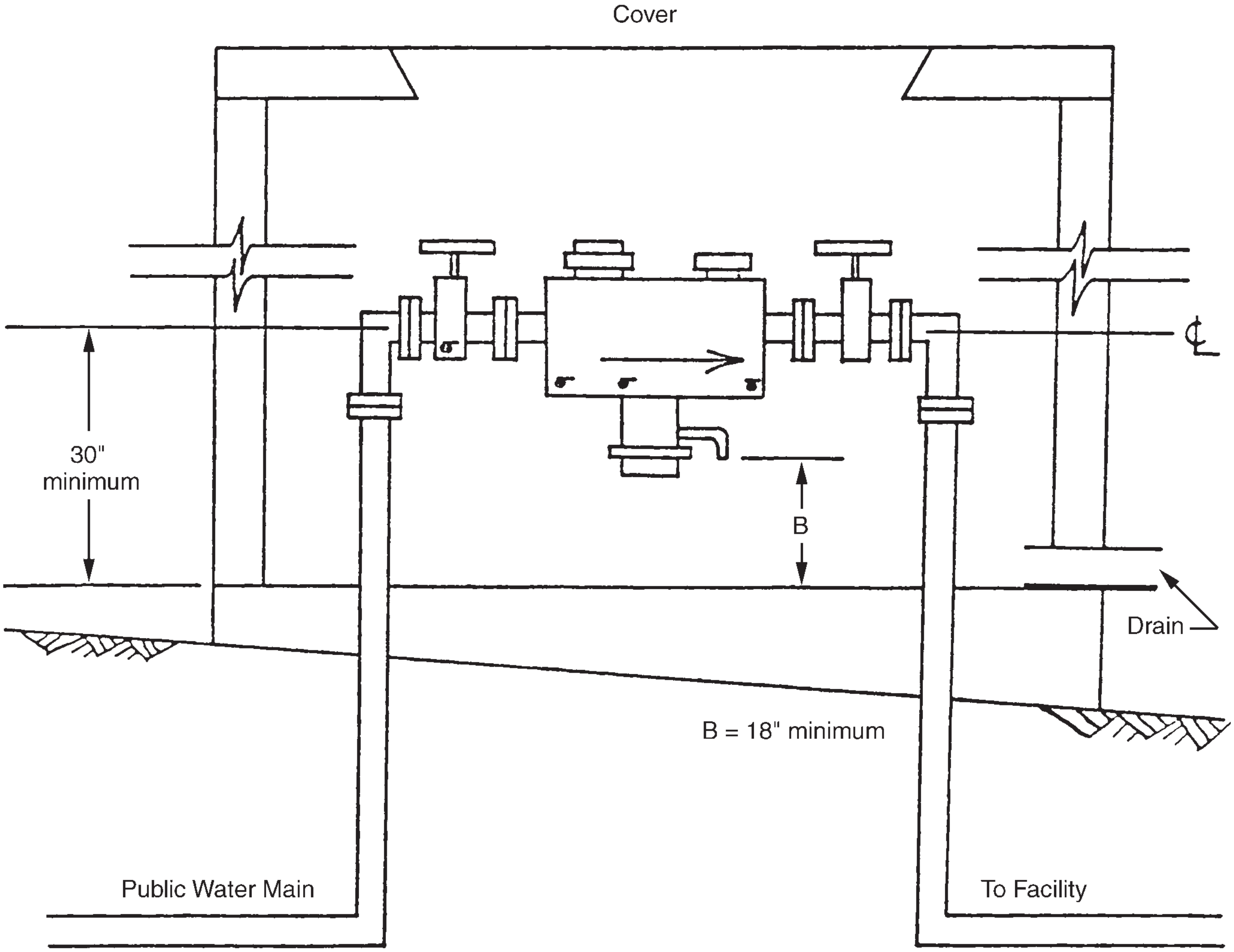


Figure 11-11 Aboveground Reduced Pressure Zone Backflow Preventer

charge and pressure loss. They vary with size. Tests at the independent Foundation for Cross-Connection Control and Hydraulic Research at the University of Southern California have established that various manufacturers do not represent the pressure losses of their backflow preventers correctly. It would be appropriate to request the flow curves produced at the Foundation for the most accurate method of comparing various devices.

Table 11-3 BFP Flow Rate, Drain Size Flowing Full

Drain Size		Maximum Flow Rate, gpm, L/m			
In.	Dn	⅛"/ft	0.5 cm/m	¼"/ft	1.0 cm/m
2	50	13	100	18	135
3	75	36	275	51	390
4	100	77	585	110	835
6	150	220	1,670	314	2,385
8	200	494	3,755	696	5,290
10	250	934	7,100	1,300	9,900

Strainer Losses

Strainers are commonly used for water with known particulate problems. Losses through different strainer types should be obtained from the manufacturer for the greatest accuracy.

Meter Losses

Water meters are usually selected by the water utility company, which very often also provides the installation. Pressure losses through typical meters conforming to American Water Works Association (AWWA) standards are given in ASPE *Plumbing Engineering Design Handbook*, Volume 2, Chapter 5: "Cold Water Systems." Consult the manufacturer for the exact loss.

Difference in Elevation

The difference in elevation from the centerline of the public water main to the centerline of the service inside the building where it connects to the distribution network is an important item to consider. This distance shall be added or subtracted from the actual pressure (depending on whether it is higher or lower than the point of connection) along with all of the above items.

A calculation sheet showing all of the data used to calculate the final water service pressure should be prepared to provide a permanent record (refer back to Figure 11-1).

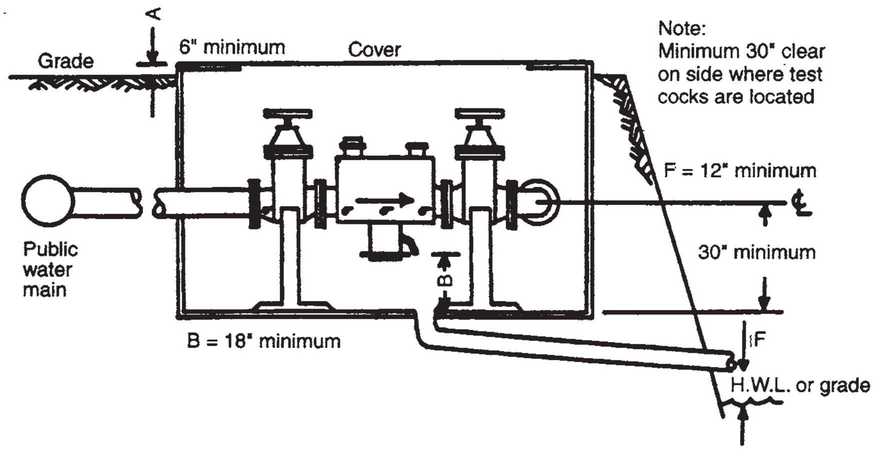


Figure 11-12 Typical Backflow Preventer in Pit

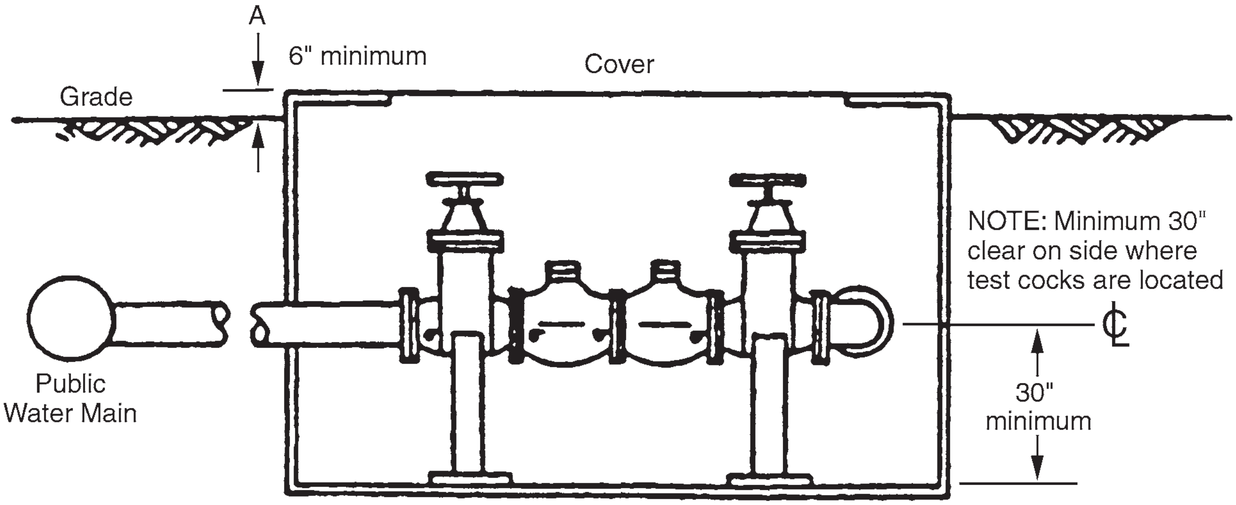


Figure 11-13 Double Check Valve Installed in a Pit

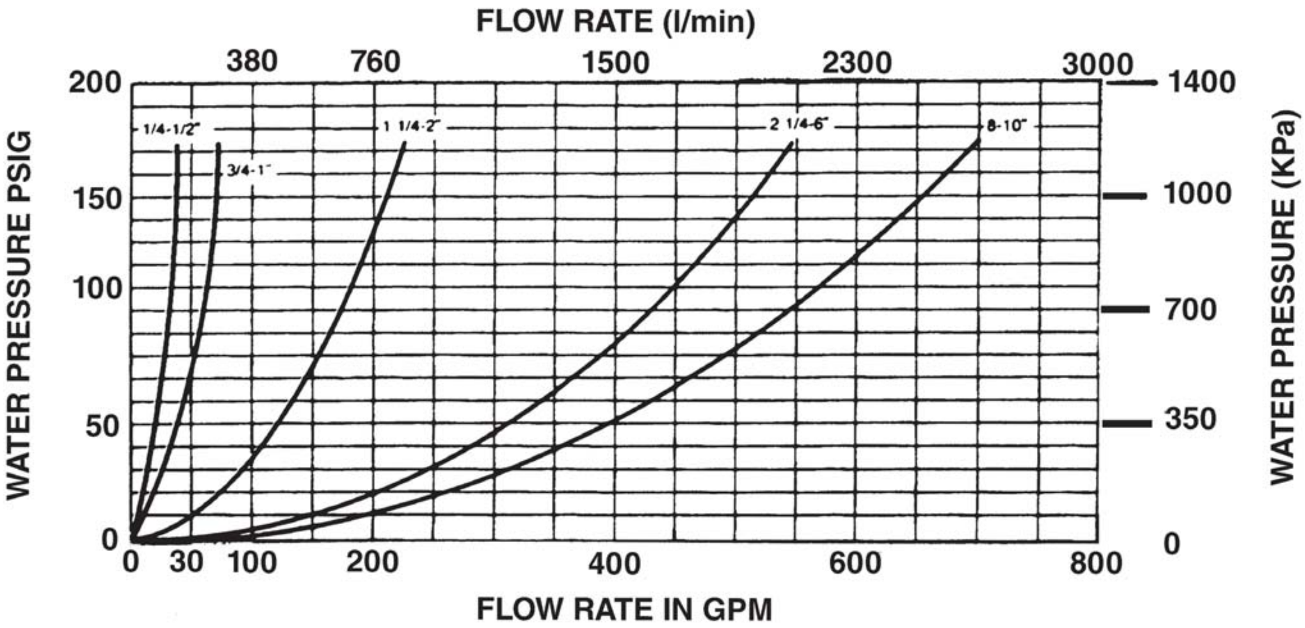
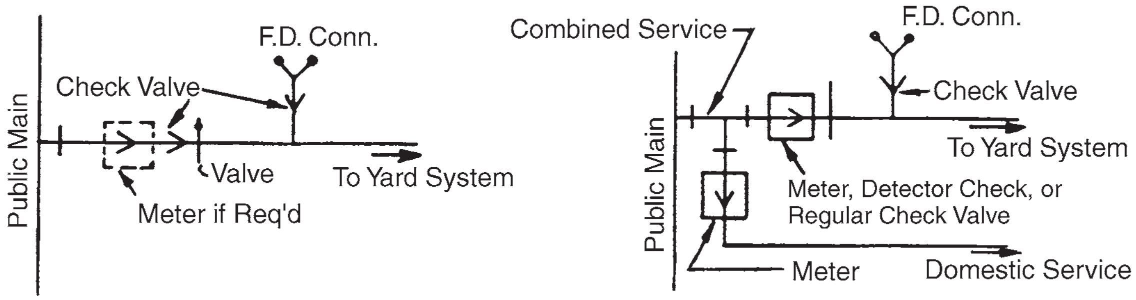
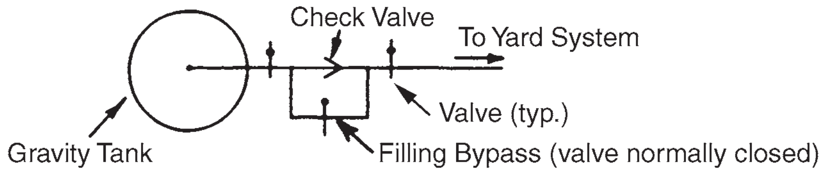


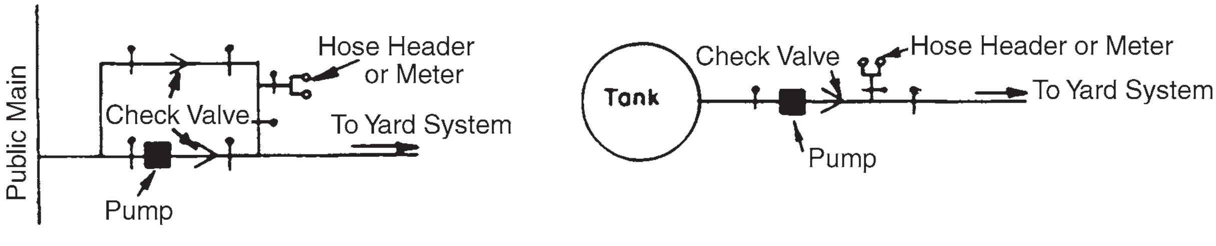
Figure 11-14 RPZ Discharge Flow Rate



PUBLIC WATER CONNECTIONS



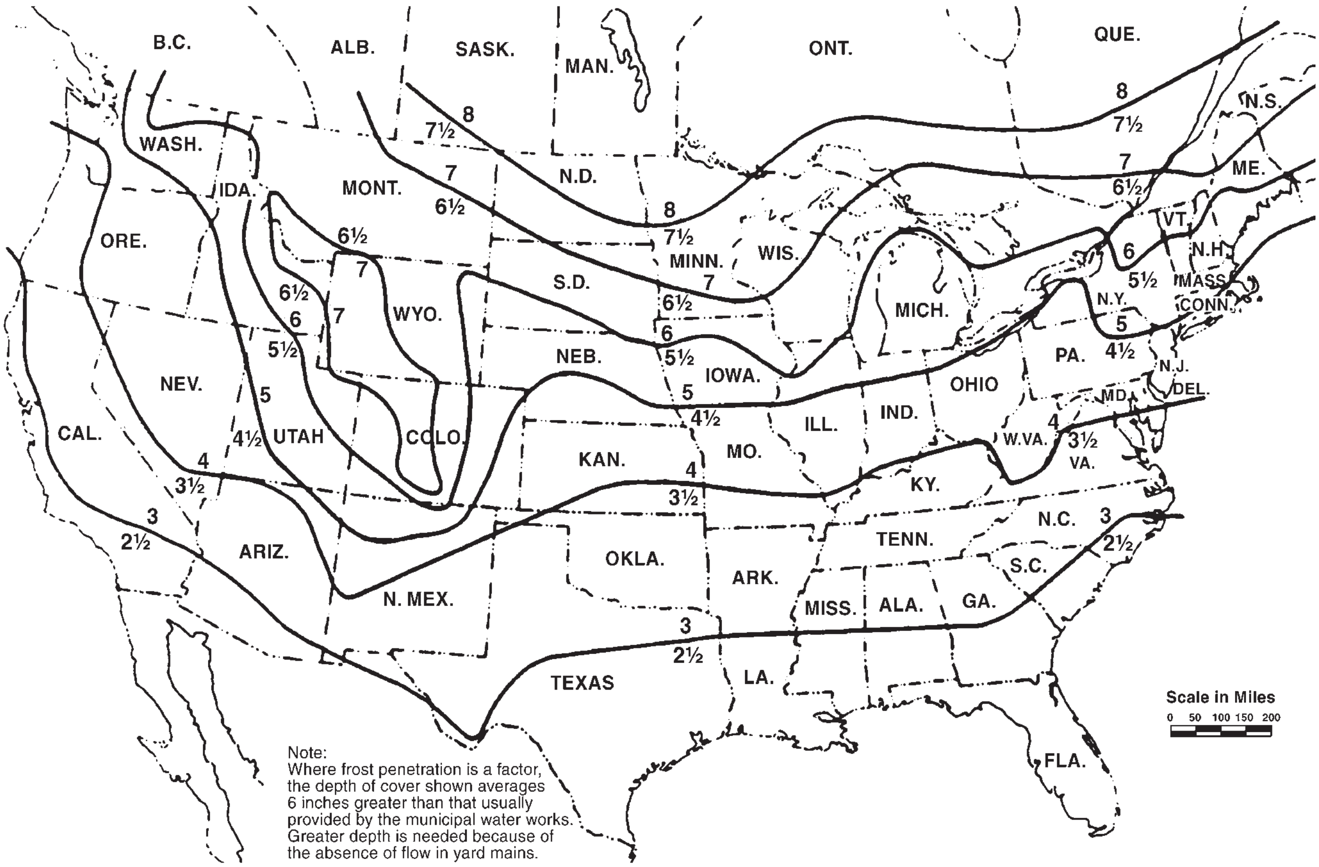
GRAVITY TANK CONNECTION



BOOSTER PUMP CONNECTION

FIRE PUMP AND TANK

Figure 11-15 Connections to a Public Water Main



Note:
Where frost penetration is a factor, the depth of cover shown averages 6 inches greater than that usually provided by the municipal water works. Greater depth is needed because of the absence of flow in yard mains.

Recommended depth of cover (feet) above underground mains. (1 ft. = 0.3 m)

Figure 11-16 Frost Depth Map of the Continental United States

FIRE PROTECTION WATER SUPPLY

The fire protection building service provides the water necessary for fire suppression purposes inside a building, such as sprinkler and fire standpipe systems. This service could be combined with the domestic water supply.

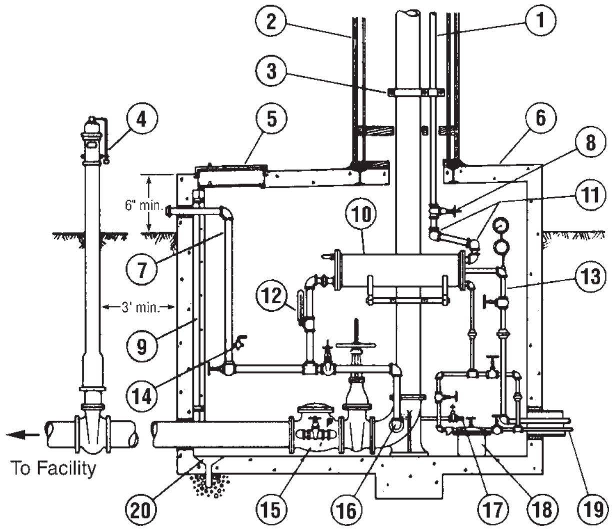
The fire protection building service continues from a connection to a source of water to a point inside a building where a connection to the fire suppression piping network is located. The source is usually a public water main, but other sources also could be used. The building service includes water storage tanks, backflow preventers, meters, valves, hydrants, and other devices that may be required based on the nature of the water service, insurance carrier requirements, and local regulations. This section is not intended to cover a complete private fire service main, which is outside the scope of this chapter.

Codes and Standards

The standard most often used for the design of private fire protection water mains is National Fire Protection Association (NFPA) 24: *Standard for the Installation of Private Service Mains and their Appurtenances*. If FM Global is the fire insurance carrier, the system must conform with FM Global Property Loss Prevention Data Sheet 3-10: *Installation/Maintenance of Fire Service Mains*.

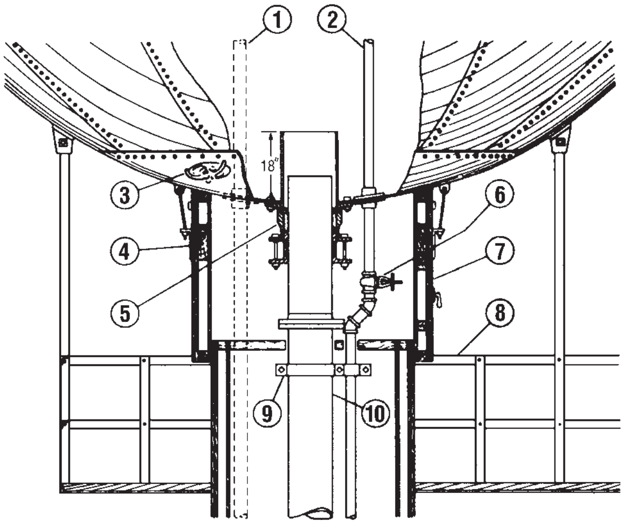
Building Water Supply

If the water supply to a building is a combined service—that is, both domestic and fire service are fed through a single pipe—the main shall be considered a fire service until the domestic water connection is made in the combined service. Typical connections to a public water main are illustrated in Figure 11-15. If the source is a well, an aquifer performance analysis and investigation of the history of adjacent wells should be made. For many facilities where loss of water would be an extreme hardship, such as hospitals, multiple water supplies from two separate public mains is a very desirable feature. This allows water to be supplied to the facility from either of two directions. If multiple connections are made to a single main, a sectionalizing valve installed in the source main somewhere between the two connections shall be required.



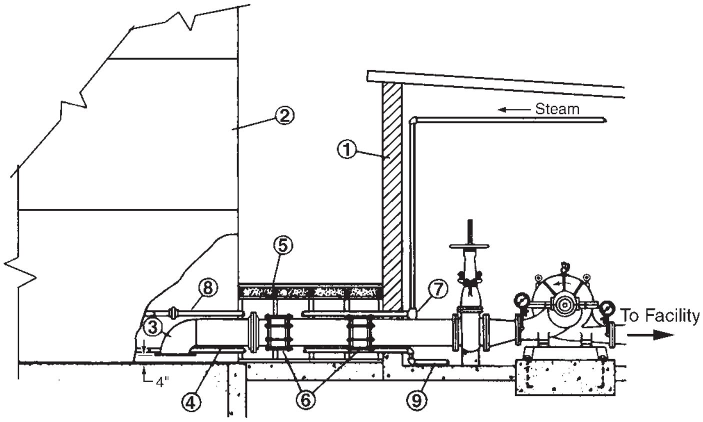
1. Hot water circulating pipe
2. Frostproof casing
3. Pipe clamps. Locate at about 25 ft (7.6 m) intervals. Loose fit around hot water circulating pipe.
4. Indicator-post valve. May be replaced with indicating-type valve in pit on yard side of check valve if space is not available for indicator post.
5. Hatch cover
6. Valve pit
7. Drain pipe
8. OS&Y gate valve
9. Ladder
10. Tank heater with relief valve set at 120 psi (825 kPa)
11. Four-elbow swing joint
12. Thermometer
13. Steam supply pipe
14. Drain cock, 1/2 in. (13 mm)
15. Approved check valve with bypass
16. Cold water circulating pipe
17. Pipe to mercury gauge
18. Steam trap
19. Condensate return
20. Valve-pit drain

Valve pit and pipe connections at base of tank on independent tower. Tank has a pipe riser and steam-heated gravity circulating heating system.



1. Inside brass overflow pipe, if used
2. Hot water circulating pipe
3. Handhole for removing sludge
4. Frostproof casing when required
5. Expansion joint
6. Approved OS&Y gate valve
7. Door in frostproof casing
8. Walkway
9. Brace for hot water circulating pipe
10. Pipe riser

Details of pipe connections to bottom of steel gravity tank with pipe riser.



1. Pump room
2. Approved aboveground suction tank
3. Entrance elbow with vortex plate or flange 4 in. (102 mm) above bottom of tank
4. Suction pipe
5. Frostproof casing, about 4 ft (1.2 m) high and 4 ft (1.2 m) wide
6. Flexible couplings
7. Steam trap on steam supply
8. Heating coil inside tank
9. Condensate return line to steam trap

Discharge pipe connected to side of suction tank.

Figure 11-17 Typical Connections to Water Storage Tanks

Contamination of the public water supply is a prime concern of the water company that supplies water to the project. Determination of the acceptable device for preventing contamination by the fire protection water supply will be made by the health department, water purveyor, or plumbing code official. The two most often used are the double check valve assembly and the reduced pressure zone backflow preventer. These devices were discussed in the domestic water supply section.

The mains shall be buried below the frost line. A generalized map of the United States is given in Figure 11-16 to aid in determining that depth. Local authorities shall be contacted for conditions at the project site.

In many cases, it is not possible to supply the required flow rate or volume of water for firefighting purposes from the public supply. These situations call for the use of a water storage tank. Such tanks can be either elevated or installed on the ground. (The design of these tanks is outside the scope of this chapter.) Connections from the water supply to a storage tank shall terminate 1 foot (0.3 m) over the overflow level. The overflow shall be two pipe sizes larger than the water supply pipe size. Various connections to a storage tanks are shown in Figure 11-17.

Ancillary Devices

Fire Hydrants

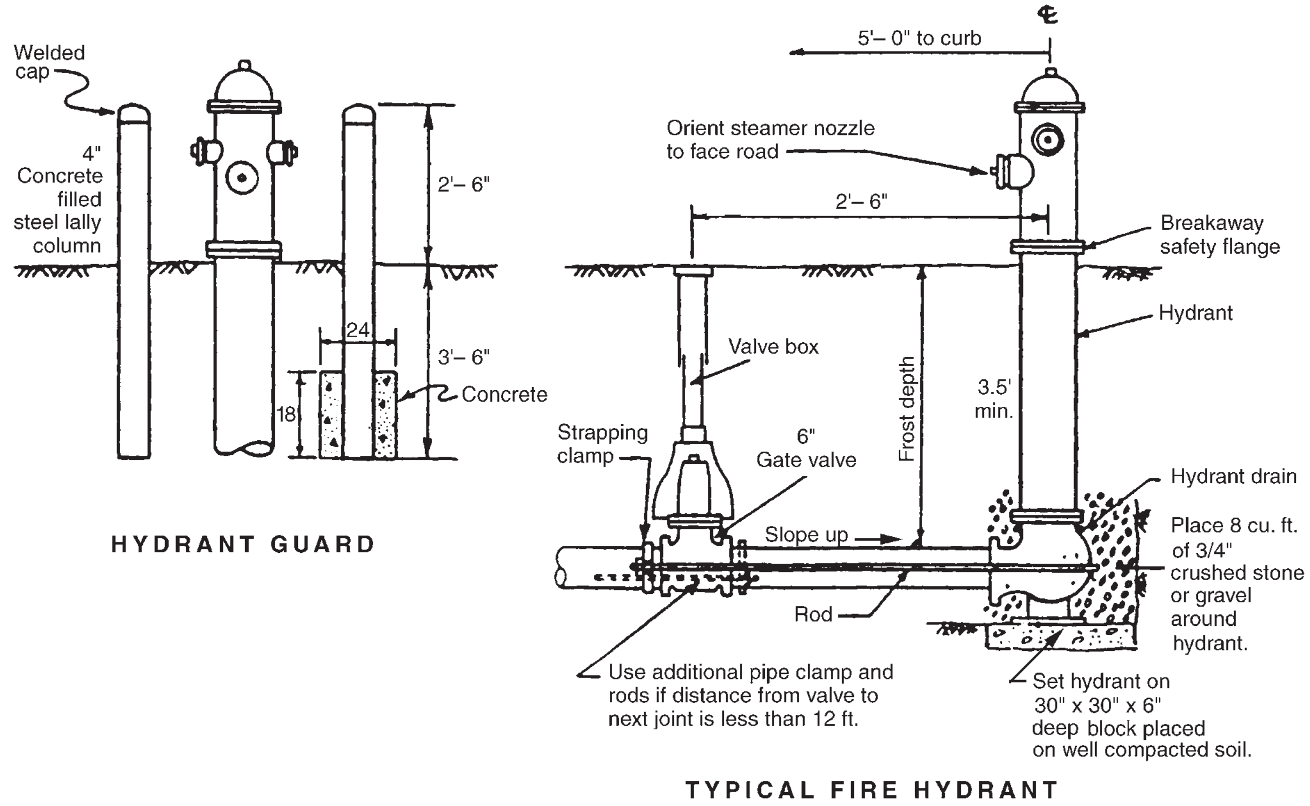
Fire hydrants are directly connected to the site main or the building service. They shall be installed adjacent to roadways to allow easy connection of fire department apparatus. If reasonable, they shall be located on all sides of the building being protected. A desired separation from the building wall is 50 feet (15.2 m) to provide some protection from building wall collapses. The recommended separation between hydrants is 300 feet (91.4 m) at a building location. (Hydrant locations are mandated by the local applicable code.) Hydrants located near a road shall be protected by guard posts. It is good practice to provide a shutoff valve on the branch line to a hydrant to allow easy repair without having to shut down the main or the service. A detail of a typical hydrant is given in Figure 11-18.

Guard Posts

Guard posts may be necessary to protect any device that is installed above grade near roads. A typical guard post is illustrated in Figure 11-19.

Post Indicator Valve

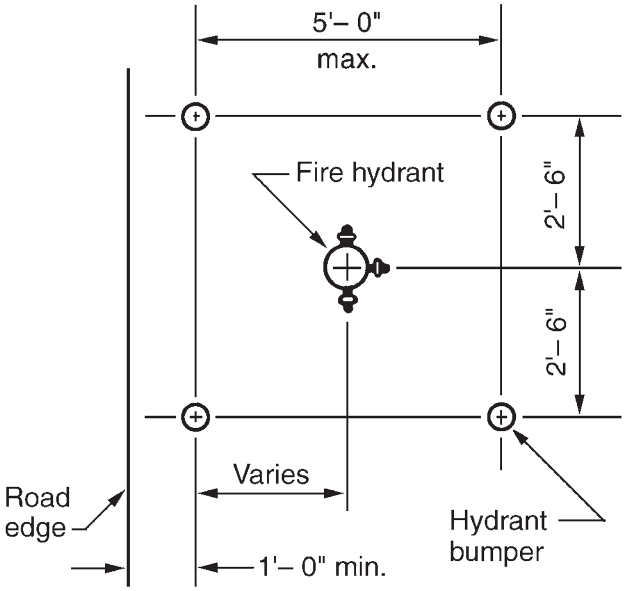
A post indicator valve (PIV) is used only to shut off the supply of water, never to control the flow. It is used as



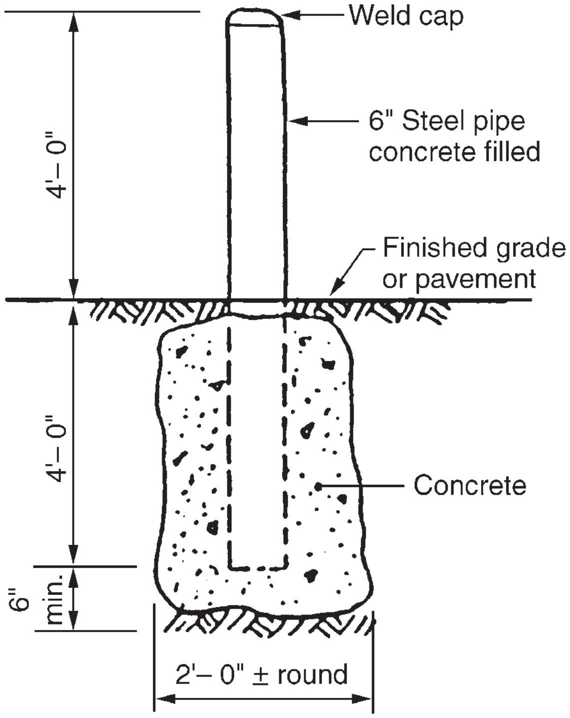
HYDRANT GUARD

TYPICAL FIRE HYDRANT

Figure 11-18 Typical Fire Hydrant



BUMPER ARRANGEMENT
FOR HYDRANTS AND P.I.V.



TYPICAL HYDRANT
BUMPER DETAIL

Figure 11-19 Typical Guard Post

a section valve on water mains and also on building services. Since it is critical for emergency personnel to be certain that any control valve is open or closed, an indicator is positioned above grade with a window or some other method of allowing easy observation of the valve position. A typical post indicator valve is illustrated in Figure 11-20.

Joint Restrainers

When run in a straight line, properly specified joints will provide a leakproof installation. Where changes in pipe direction occur, pressure is exerted by the flowing water on the fitting, and the joints may not provide sufficient resistance to the force exerted by the pressure of the water against the fitting. To prevent joint failure due to the pressure exerted, most pipe joints must be restrained in some manner.

Mechanical and push-on joints are sealed by a rubber-type gasket compressed in a space between the spigot end of the pipe and the bell. These joints will not resist the pressure of the water on the joint. The method of restraint used is external clamps and rods. Friction clamps are bolted around the pipe on both sides of the joint. These clamps engage steel tension rods, sometimes called tie rods, across the joint, preventing it from separating. This will combine the resistance of these joints to prevent separation. Calculations are necessary to determine the actual number of joints to be restrained.

Another method of restraint used is integrally cast glands for mechanical joint pipe with internally locked, grooved, and keyed push-on joints. This type of restraint is usually recommended only for the repair of existing systems.

The most common method of restraint is to use a block of concrete contacting the fitting and poured against undisturbed soil. The size of the block varies with the water pressure (the higher the pressure, the larger the block), the pipe size (the larger the pipe, the larger the block), and the bearing pressure of the soil (the less the soil bearing pressure, the larger the block). A detail of typical thrust block dimensions is given in Figure 11-21. Table 11-4 gives values for soil-bearing loads, and Table 11-5 gives the pressure, in pounds, at various joints. The main problems with this method are that on many project sites there is often no undisturbed soil against which to base the thrust block and that the size of the concrete block prevents piping from being placed adjacent to the run of pipe being protected.

Sizing the Fire Protection Water Service

When all of the information required for the design of the domestic water system has been obtained, the fire marshal, fire protection code official, and insurance company shall be contacted for their installation requirements.

Table 11-4 Soil Bearing Loads

Soil	Bearing Load (lb/ft^2)
Muck	0
Soft clay	1000
Silt	1500
Sandy silt	3000
Sand	4000
Sandy clay	6000

Table 11-5 Pressure Exerted at Joints by Flowing Water

Total pounds resultant thrust at fittings at 100 psi water pressure					
Nom. Pipe Diameter, in.	**Dead End**	**90° Bend**	**45° Bend**	**22½° Bend**	**11¼° Bend**
4	1,810	2,559	1,385	706	355
6	3,739	5,288	2,862	1,459	733
8	6,433	9,097	4,923	2,510	1,261
10	9,677	13,685	7,406	3,776	1,897
12	13,685	19,353	10,474	5,340	2,683
14	18,385	26,001	14,072	7,174	3,604
16	23,779	33,628	18,199	9,278	4,661
18	29,865	42,235	22,858	11,653	5,855
20	36,644	51,822	28,046	14,298	7,183
24	52,279	73,934	40,013	20,398	10,249
30	80,425	113,738	61,554	31,380	15,766
36	115,209	162,931	88,177	44,952	22,585
42	155,528	219,950	119,036	60,684	30,489
48	202,683	286,637	155,127	79,083	39,733
54	256,072	362,140	195,989	99,914	50,199

Note: To determine thrust at pressures other than 100 psi, multiply the thrust obtained in the table by the ratio of the pressure to 100. For example, the thrust on a 12-in, pipe with a 90° bend at 125 psi is 19,353×125/100 = 24,191 lb.

What constitutes an adequate water supply has generated much discussion over time. Many factors, when all are considered, result in an adequate water supply. The water supply should be capable of supplying the largest demand, which is usually the sprinkler or standpipe system, and expected hose flow under reasonably adverse conditions. If other factors such as building occupancy, yard storage, external structures that must be protected, exposure protection, and catastrophic hose demand are considered, they will all add to the flow rate.

Demand Flow Rate

The demand flow rate used to size the building service for the facility under design usually is based on several factors. The first is the gpm based on the calculated flow rate for the sprinkler system, which is based on hydraulic

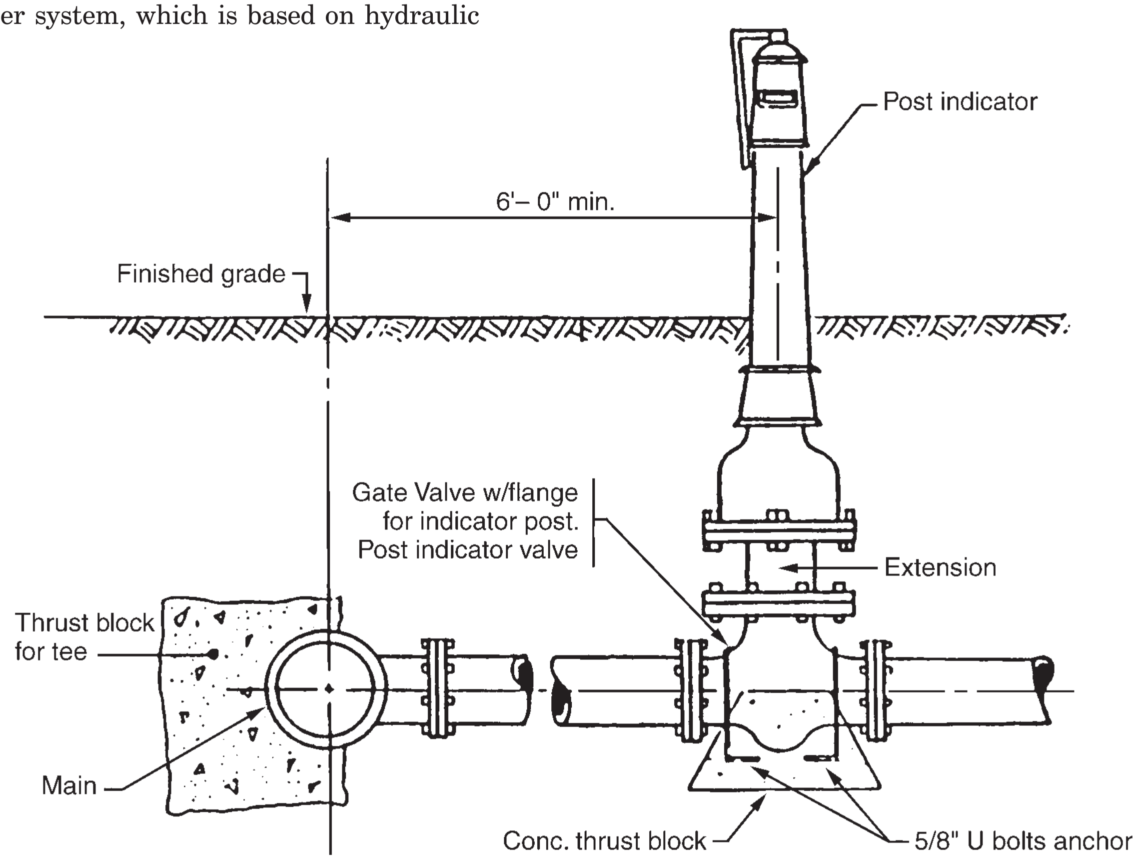
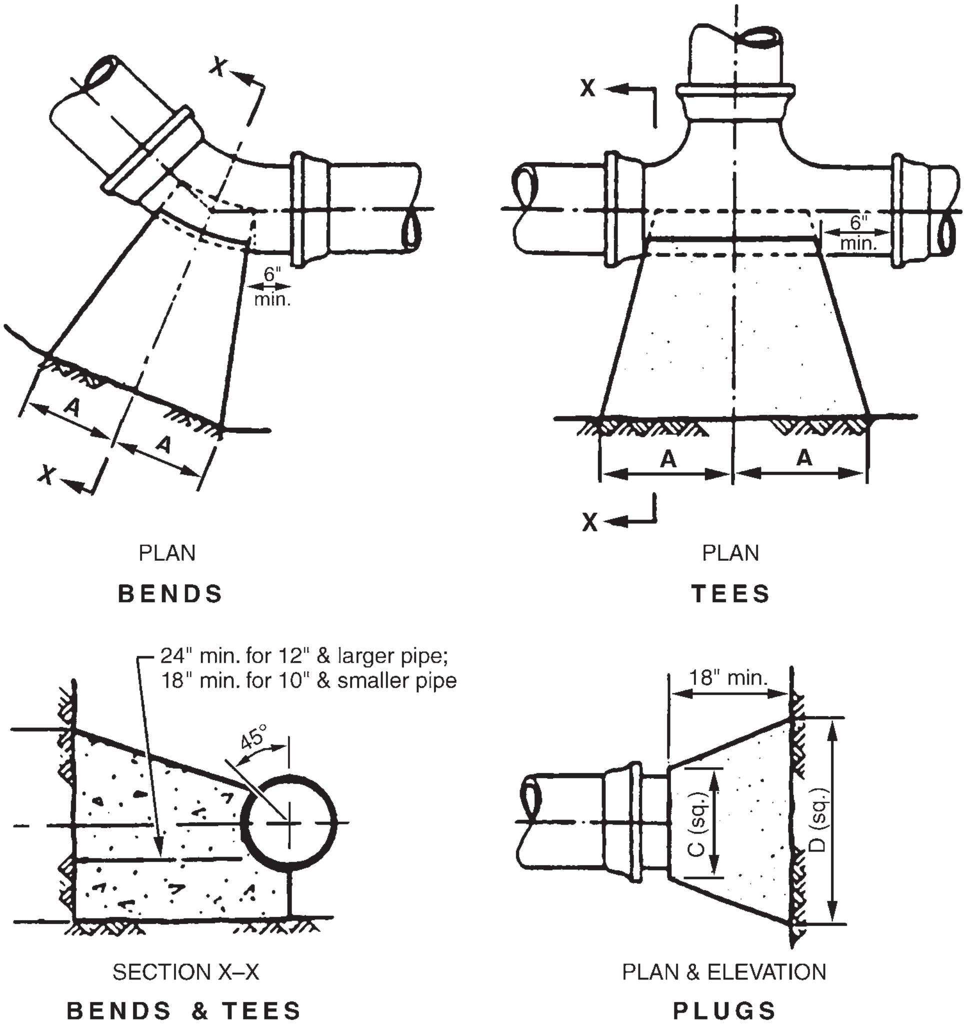


Figure 11-20 Typical Post Indicator Valve



Thrust Block Dimensions

		1/4 Bends		1/8 Bends		1/16 Bends		Tees		Plugs	
Type	Size (in.)	A (in.)	B (in.)	A (in.)	B (in.)	A (in.)	B (in.)	A (in.)	B (in.)	C (in.)	D (in.)
Type I 4000 PSF Soil	6	8	10	6	8	3	8	8	8	10	15
	8	12	12	8	10	5	9	9	12	12	20
	10	16	14	10	12	6	10	11	14	14	25
	12	19	16	12	14	8	11	14	16	16	30
	14	23	18	14	16	10	12	16	18	18	34
	16	26	20	16	18	11	13	18	20	20	38
Type II 2000 PSF Soil	6	16	10	9	10	6	8	10	12	10	21
	8	22	13	12	13	8	10	13	16	12	29
	10	26	17	14	17	10	13	16	20	14	36
	12	29	21	16	21	11	16	18	24	16	41
	14	35	24	19	24	12	20	22	27	18	48
	16	38	27	21	27	12	24	24	30	20	54

Note: Based on 100 psi static pressure plus AWWA water hammer. All bearing surfaces to be carried to undisturbed ground.

Figure 11-21 Thrust Block Installation

Table 11-6 Typical Fire Protection Flow Rate Requirements

Land Use	GPM range	Average GPM
Single-family residential	500 – 2,000	750
Multifamily residential	1,500 – 3,000	2000
Commercial	2,500 – 5,000	3000
Industrial	3,500 – 10,000	
Central building district	2,500 – 15,000	3000

Table 11-7 Sewer Size Based on Velocity and Slope

Slopes of cast-iron, soil-pipe sanitary sewers required to obtain self-cleansing velocities of 2.0 and 2.5 fps (based on Manning's Formula with n = 0.012)

Pipe Size (in.)	Velocity (fps)	1/4 Full		1/2 Full		3/4 Full		Full	
		SLOPE (ft/ft)	FLOW (gpm)	SLOPE (ft/ft)	FLOW (gpm)	SLOPE (ft/ft)	FLOW (gpm)	SLOPE (ft/ft)	FLOW (gpm)
2.0	2.0	0.0313	4.67	0.0186	9.34	0.0148	14.09	0.0186	18.76
	2.5	0.0489	5.84	0.0291	11.67	0.0231	17.62	0.0291	23.45
3.0	2.0	0.0178	10.77	0.0107	21.46	0.0085	32.23	0.0107	42.91
	2.5	0.0278	13.47	0.0167	26.82	0.0133	40.29	0.0167	53.64
4.0	2.0	0.0122	19.03	0.0073	38.06	0.0058	57.01	0.0073	76.04
	2.5	0.0191	23.79	0.0114	47.58	0.0091	71.26	0.0114	95.05
5.0	2.0	0.0090	29.89	0.0054	59.79	0.0043	89.59	0.0054	119.49
	2.5	0.0141	37.37	0.0085	74.74	0.0067	111.99	0.0085	149.36
6.0	2.0	0.0071	43.18	0.0042	86.36	0.0034	129.54	0.0042	172.72
	2.5	0.0111	53.98	0.0066	107.95	0.0053	161.93	0.0066	215.90
8.0	2.0	0.0048	77.20	0.0029	154.32	0.0023	231.52	0.0029	308.64
	2.5	0.0075	96.50	0.0045	192.90	0.0036	289.40	0.0045	385.79
10.0	2.0	0.0036	120.92	0.0021	241.85	0.0017	362.77	0.0021	483.69
	2.5	0.0056	151.15	0.0033	302.31	0.0026	453.46	0.0033	604.61
12.0	2.0	0.0028	174.52	0.0017	349.03	0.0013	523.55	0.0017	698.07
	2.5	0.0044	218.15	0.0026	436.29	0.0021	654.44	0.0026	872.58
15.0	2.0	0.0021	275.42	0.0012	550.84	0.0010	826.26	0.0012	1101.68
	2.5	0.0032	344.28	0.0019	688.55	0.0015	1032.83	0.0019	1377.10

Table 11-7(M) Sewer Size Based on Velocity and Slope

Slopes of cast-iron, soil-pipe sanitary sewers required to obtain self-cleansing velocities of 0.6096 and 0.762 m/s (based on Manning's Formula with n = 0.012)

Pipe Size (mm)	Velocity (m/s)	1/4 Full		1/2 Full		3/4 Full		Full	
		Slope (m/m)	Flow (L/s)	Slope (m/m)	Flow (L/s)	Slope (m/m)	Flow (L/s)	Slope (m/m)	Flow (L/s)
50	0.6096	0.0313	0.295	0.0186	0.59	0.0148	0.89	0.0186	1.18
	0.762	0.0489	0.369	0.0291	0.74	0.0231	1.11	0.0291	1.48
75	0.6096	0.0178	0.68	0.0107	1.35	0.0085	2.03	0.0107	2.71
	0.762	0.0278	0.85	0.0167	1.69	0.0133	2.54	0.0167	3.38
100	0.6096	0.0122	1.2	0.0073	2.4	0.0058	3.6	0.0073	4.8
	0.762	0.0191	1.5	0.0114	3.0	0.0091	4.5	0.0114	6.0
125	0.6096	0.0090	1.89	0.0054	3.77	0.0043	5.65	0.0054	7.54
	0.762	0.0141	2.36	0.0085	4.72	0.0067	7.07	0.0085	9.42
150	0.6096	0.0071	2.72	0.0042	5.45	0.0034	8.17	0.0042	10.9
	0.762	0.0111	3.41	0.0066	6.81	0.0053	10.22	0.0066	13.62
200	0.6096	0.0048	4.87	0.0029	9.74	0.0023	14.61	0.0029	19.48
	0.762	0.0075	6.09	0.0045	12.17	0.0036	18.26	0.0045	24.34
250	0.6096	0.0036	7.63	0.0021	15.26	0.0017	22.89	0.0021	30.52
	0.762	0.0056	9.54	0.0033	19.08	0.0026	28.61	0.0033	38.15
300	0.6096	0.0026	11.01	0.0017	22.02	0.0013	33.04	0.0017	44.05
	0.762	0.0044	13.77	0.0026	27.53	0.0021	41.3	0.0026	55.06
380	0.6096	0.0021	17.38	0.0012	34.76	0.0010	52.14	0.0012	69.52
	0.762	0.0032	21.72	0.0019	43.45	0.0015	65.17	0.0019	86.9

calculations. The second is the flow of water for additional hose streams used by the fire department to fight a fire.

The following figures are presented for preliminary discussion purposes only. They are not to be used for actual design calculations, which should be made only on a specific project basis after consulting with the fire marshal, insurance carrier representative, and fire code official.

The fire department hose streams depend on the occupancy hazard, which can be as follows.

- Light and ordinary hazard: 500 gpm (1,900 L/min)
- Extra hazard, Group 1: 750 gpm (2,900 L/min)
- Extra hazard, Group 2: 1,000 gpm (3,800 L/min)
- High-piled storage: As required by the insurance company

The hose demand shall be increased by 25 percent for the following conditions:

- Combustible construction
- Possible delay in response by the fire department
- Minimum protection less than recommended by insurance company requirements
- Limited access to remote interior sections

For the design of a large site consisting of multiple buildings, the typical fire protection flow rate requirements are given in Table 11-6.

Tank Capacity

If the gravity tank is the sole source of water, the tank should be capable of being filled in eight hours. In evaluation of the total capacity, consideration should be given to the following storage capacities, based on the categories appearing in NFPA 13: *Standard for the Installation of Sprinkler Systems*.

- Light and ordinary hazard occupancies, Group 1: Two hours
- Ordinary hazard occupancies, Groups 2 and 3: Three hours
- Extra hazard occupancies: Four hours

SANITARY SEWER

The purpose of the sanitary house sewer is to convey all sanitary waste from a facility to an approved point of disposal, which is usually a public sewer.

The first step is to find the department or jurisdiction responsible for the approval, design, and installation of sanitary sewers. Also, find the authority having jurisdiction (AHJ) responsible for the disposal of other kinds of waste, notably kitchen waste that contains fats, oil, and grease (FOG). Once this is established, a formal letter should be written to obtain the following information. A typical sewer letter is given in Appendix 11-B.

- What is the size, location, and invert of all available sewers fronting the property?
- Are the sewers sanitary, storm, or combined?
- What is the material of these sewers?
- If no sewers are available, who is the AHJ for a private disposal system (septic tank and field)? What codes and standards regulate the design and installation of the septic system?
- Are street sewer connections preferred at spurs between manholes, or shall a manhole be used for the connection? Are standard details available? Will these manholes be constructed by the plumbing contractor or the AHJ?

When the utility company has answered the letter and provided most of the information requested, the following work can be accomplished.

- The run from the building to the sewer can be selected. If the invert elevations are not suitable, determine if a force main will be necessary.
- The house sewer can be sized based on the fixture count and the slope of the sewer.

Sizing the Sanitary Sewer

The size of the sewer from the building to the property line is based on the applicable plumbing code requirements. If the house sewer extends beyond the property line to connect to a pubic sewer, the plumbing code may not apply. However, other codes may be applicable in the area. A self-scouring velocity must be maintained to avoid the settling out of solids and stopping the pipe. Table 11-7 is provided to allow sizing at a minimum slope to maintain a velocity of 2 to 2.5 feet per second (fps) (0.61 to 0.76 m/s). Figure 11-22 can be used to convert the sanitary drainage fixture units to gpm. Since sanitary effluent has a viscosity similar to water, Figure 11-23 can then be used to size the sewer based on flow and pitch. Good engineering practice is to use a pipe size based on flowing half full.

Sewer Components and Design Criteria

Public Sewer Availability

The question of availability is a concern. It is up to the AHJ to determine whether the project shall connect to any particular sewer. This is a potential problem in rural areas, where considerable distances are necessary to connect to a sewer. A run by gravity is the preferred method, but this is costly for a long run and a large size. A force main, which is discussed later, may be desirable.

Trenching and Bedding

Bedding is the point of contact between the pipe and the earth. The type of bedding has an important influence on the load the pipe can support.

The bedding for metallic pipe is different than that for plastic pipe because trench walls are needed to help support plastic pipe. A typical trench for plastic pipe is shown in Figure 11-24, and one for metallic pipe is shown in Figure 11-25. The methods shown are for class B bedding, as is suitable for the majority of piping buried underground. If the weight placed on the buried pipe is a concern, other bedding methods that increase the resistance of the pipe can be used (see Figure 11-26).

Grease Interceptors

When a project has a kitchen or cafeteria, fats, oil, and grease are bound to be discharged. If they are not removed from the waste stream, they must be intercepted before entering the public sewer by means of a FOG interceptor.

Typical Sewer House Connection

A typical small house or building will connect to the sewer in a manner similar to that illustrated in Figure 11-27 where a spur is provided. A spur is a pre-installed fitting located at fixed distances along the length of a sewer line.

Drainage Structures

A drainage structure is any appurtenance built into a sewer run, including manholes, storm water inlets, and catch basins.

Manholes can be made of poured concrete, bricks, blocks, or precast sections. Precast manholes (see Figure 11-28) are the most widely used type. Manholes are installed for the following reasons:

- At changes of direction in the sewer
- For inspection and cleaning purposes
- At substantial changes of grade
- At changes of pipe size
- To make a connection to a public sewer for large sewers

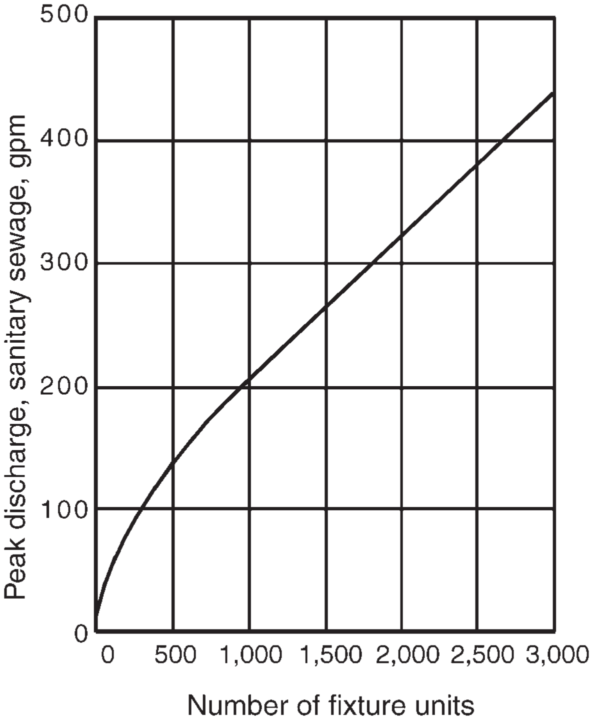
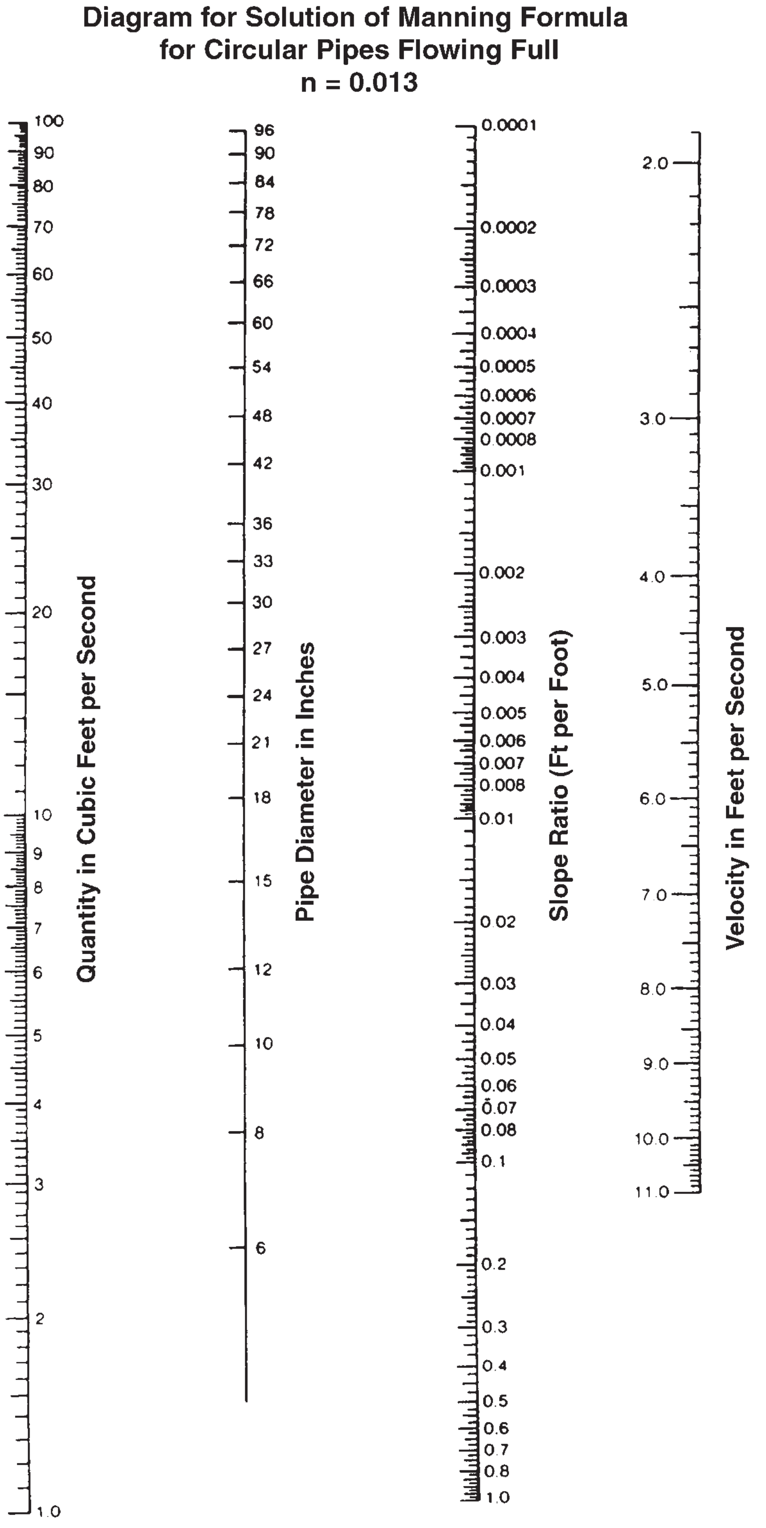
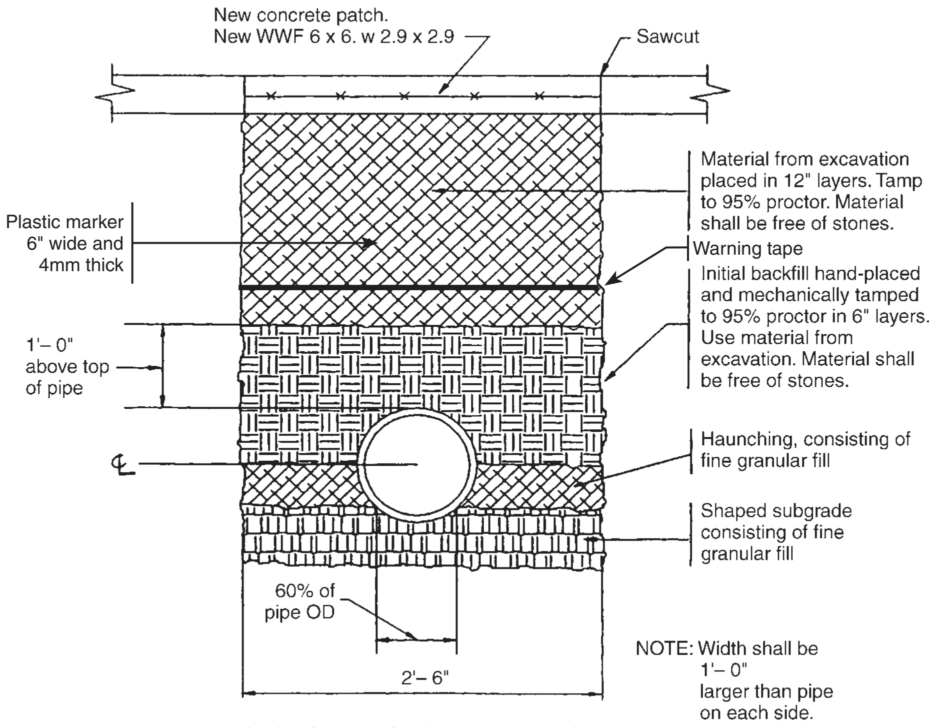


Figure 11-22 Fixture Unit Conversion to gpm



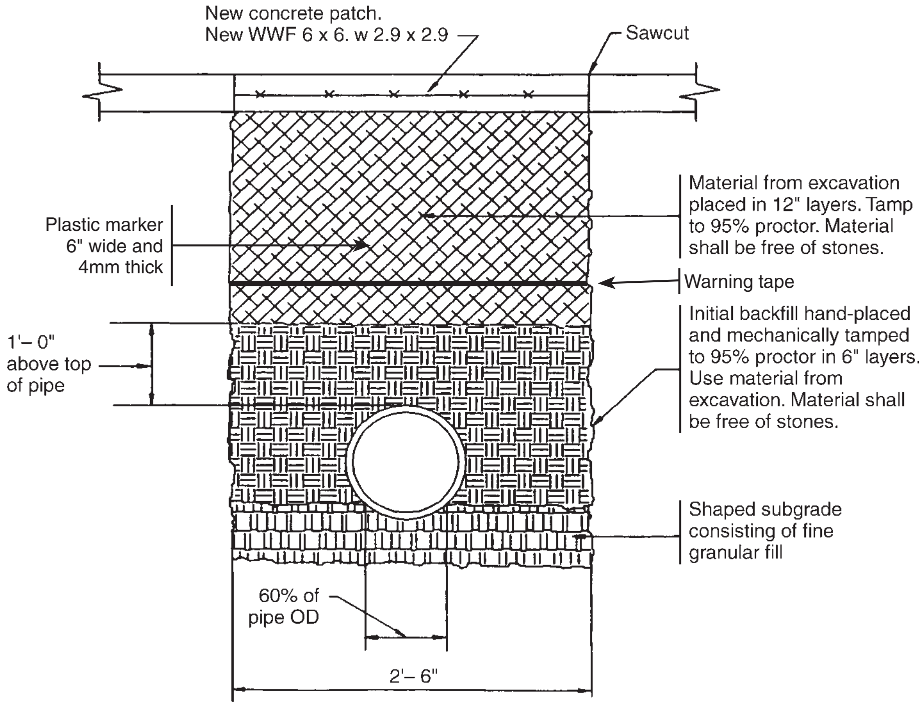
Value of n	0.008	0.010	0.011	0.012	0.013	0.015	0.019	0.021	0.024
Conversion factor for discharge and velocity	1.62	1.30	1.18	1.08	1.00	0.87	0.68	0.62	0.54

Figure 11-23 Pipe Sizing Using the Manning Formula



SECTION THROUGH PIPE TRENCH
(PLASTIC PIPE)

Figure 11-24 Bedding for Plastic Pipe



SECTION THROUGH PIPE TRENCH
(METALLIC PIPE)

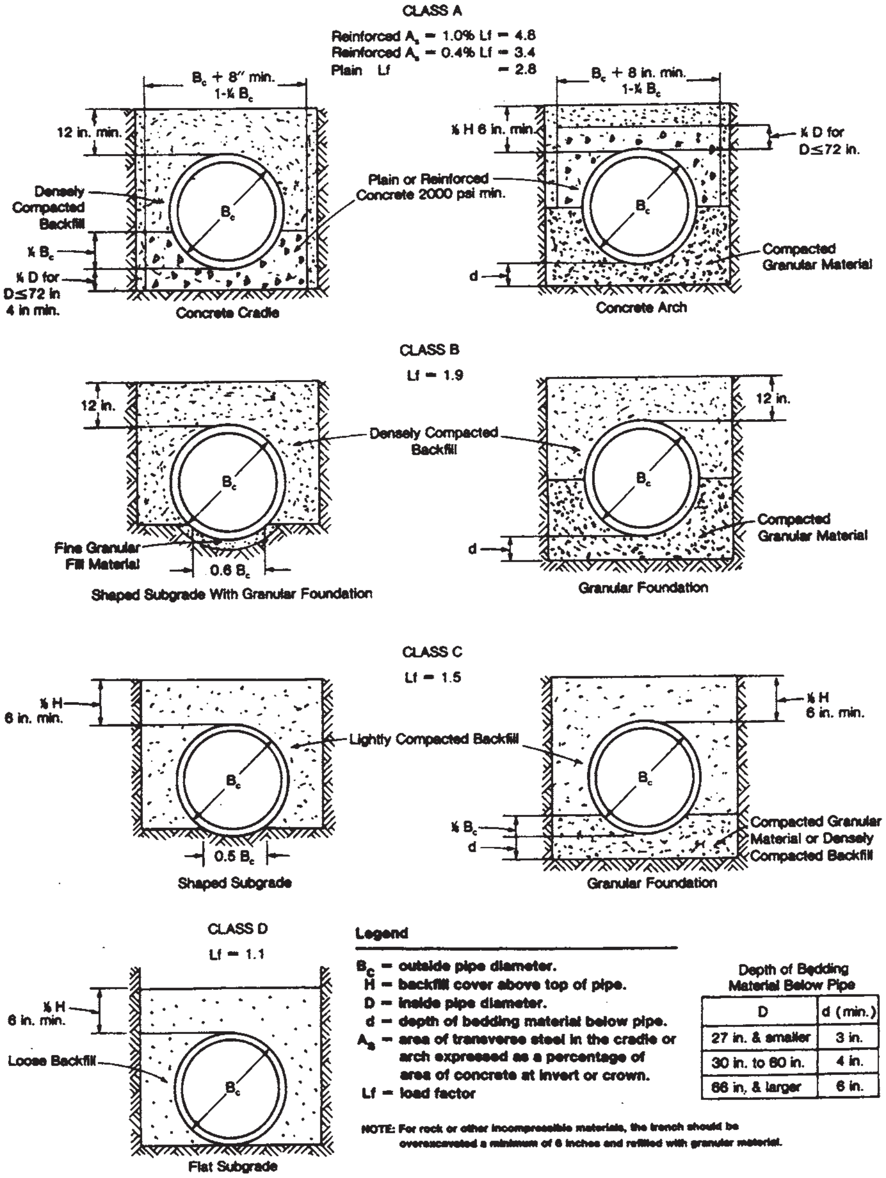
Figure 11-25 Bedding for Metallic Pipe

The primary purpose of a manhole is to provide a smooth invert to allow pipes that join the main sewer to have an unimpeded entry to that sewer and to provide a smooth invert when pipes change size and pitch. To accomplish this, the bottom of the manhole is channeled smooth from the invert of all the pipes entering the manhole. It is accepted practice for the tops of the joining sewer pipes to be even. Manhole construction requirements should be verified with the authority having jurisdiction.

If the building has an acid drainage component, a separate line shall be provided from the building to the point of disposal. A detail of an acid manhole is given in Figure 11-29.

If the depth from finished grade to the invert of the sewer is 3 feet (0.9 m) or less, a shallow manhole should be used. A shallow manhole is illustrated in Figure 11-30.

When a difference in the inverts of the pipes is more than approximately 2 inches to 2 feet (50.8 mm to 0.61 m), the falling water will cause the lower pipe to erode. When this is the case, a chute shall be created at the manhole bottom. If the difference in the inverts of the pipes is greater than 2 feet, a drop manhole should be installed, as shown in Figure 11-31.



D	d (min.)
27 in. & smaller	3 in.
30 in. to 60 in.	4 in.
66 in. & larger	6 in.

Figure 11-26 Rigid Pipe Bedding Methods

Other manhole accessories are manhole steps and standard manhole and watertight frames and covers. In some cases where the watertight manhole cover is required, an outlet for the air that accumulates in the manhole may not exist. Where this is a concern, a vent should be installed, as illustrated in Figure 11-32.

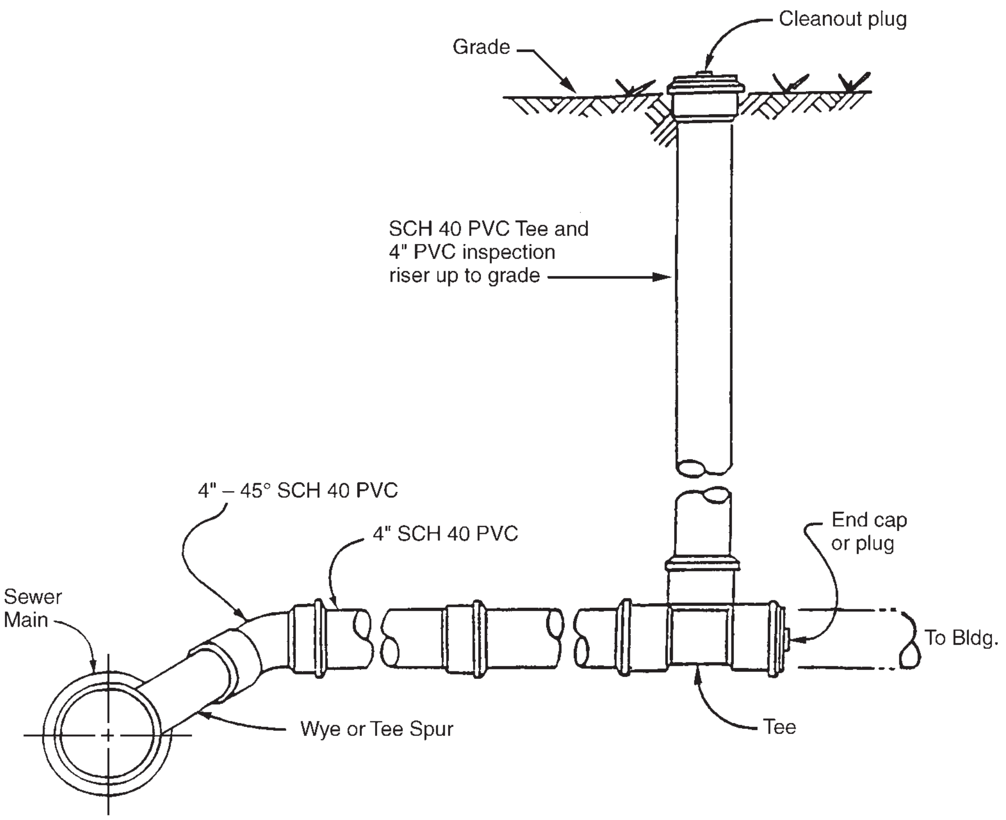
For short runs of sewers into the main, cleanouts shall be provided on the site every 75 feet (22.9 m) or as dictated by code to allow the line to be rodded out in the event of a stoppage.

General manhole spacing and locations are given in Table 11-8.

Sewage Lift Stations

When the discharge of the sanitary sewer from a facility is lower than the public sewer intended for disposal due to topography or low elevation, pumping will be required to reach that higher elevation. A sewage lift station or sewage pumping station is the system used to accomplish this. The following discusses only the methods used to pump sewage discharged from an industrial/commercial type of facility

The difference in terminology between a sewage ejector and a lift station is one of scope. In general, the ejector system is used to pump discharge from a portion of the building up to the main house sewer for disposal, while the lift station is used to pump discharge from an entire building or site for disposal. The components of a sewage ejector system and sewage lift station are very similar to the ejector system discussed in *Plumbing Engineering Design Handbook* Volume 2, Chapter 1: Sanitary Drainage Systems.



ELEVATION

Figure 11-27 Typical House Sewer Connection

The components of a sewage lift station are the sewage pumps, basin, discharge pipe (routed to the public sewer or point of disposal), controls, and alarms. The sewage pump discharge line often is called a force main. The design of the complete sewage lift station as a whole is an iterative one, where the selection of each component somewhat depends on other components for size and capacity.

Sewage Pumps

The types of pumps used in sewage lift stations are similar to the ejector systems discussed in Volume 2.

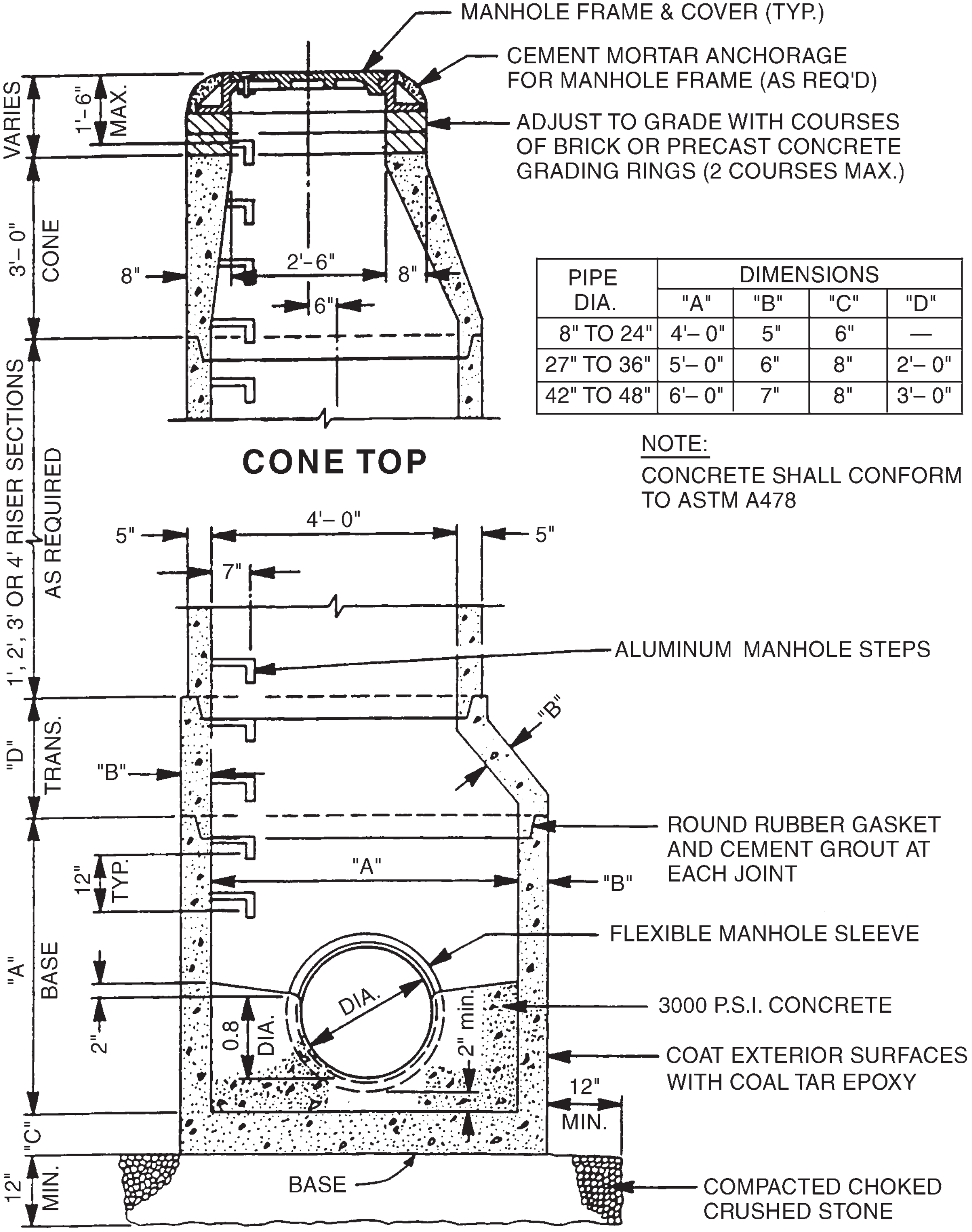
The pump most often selected is the submersible type because of its low initial cost, wide range of capacities, and tolerance of many starts. Another advantage is that a smaller basin can be used because additional height below grade is not required to house the motor of a conventional vertical, submerged ejector pump. A typical submersible pump assembly is shown in Figure 11-33.

For a facility sewage pump, it is accepted practice for the pump capacity to equal the highest instantaneous flow rate expected from the facility. The reasoning is that in the event the basin is incapable of being used, a single pump must be capable of discharging all possible effluent from all sources. It is also critical that at least a duplex set of pumps be included, each one with the same capacity, to ensure that the facility will be kept in operation if one pump is out of service. If a wide range of instantaneous flow rates is possible, a three-pump system, with each pump sized at 75 percent of the maximum calculated flow, should be considered. One pump typically would always be on standby.

The maximum discharge is calculated for two conditions. The first is for the maximum possible inflow. This is done by adding the plumbing fixture load, in gpm, obtained from Hunter's curve and other possible sources of discharge to arrive at a maximum probable instantaneous flow rate. If the facility is discharging mostly effluent from plumbing fixtures, add 10 percent to that figure as a safety factor. The second condition is based on a reasonable number of starts per hour.

Required Head

The required system head is calculated by adding the static height (in feet) from the bottom of the basin to the point of discharge (or the highest point of the force main run) to the friction loss of the liquid running through the pipe based on the equivalent length of run. The friction loss is obtained from standard engineering charts for the material selected using water as the liquid. For more viscous liquids, appropriate charts shall be used.



PIPE DIA.	DIMENSIONS			
	"A"	"B"	"C"	"D"
8" TO 24"	4'– 0"	5"	6"	—
27" TO 36"	5'– 0"	6"	8"	2'– 0"
42" TO 48"	6'– 0"	7"	8"	3'– 0"

NOTE:
CONCRETE SHALL CONFORM TO ASTM A478

Figure 11-28 Typical Precast Manhole

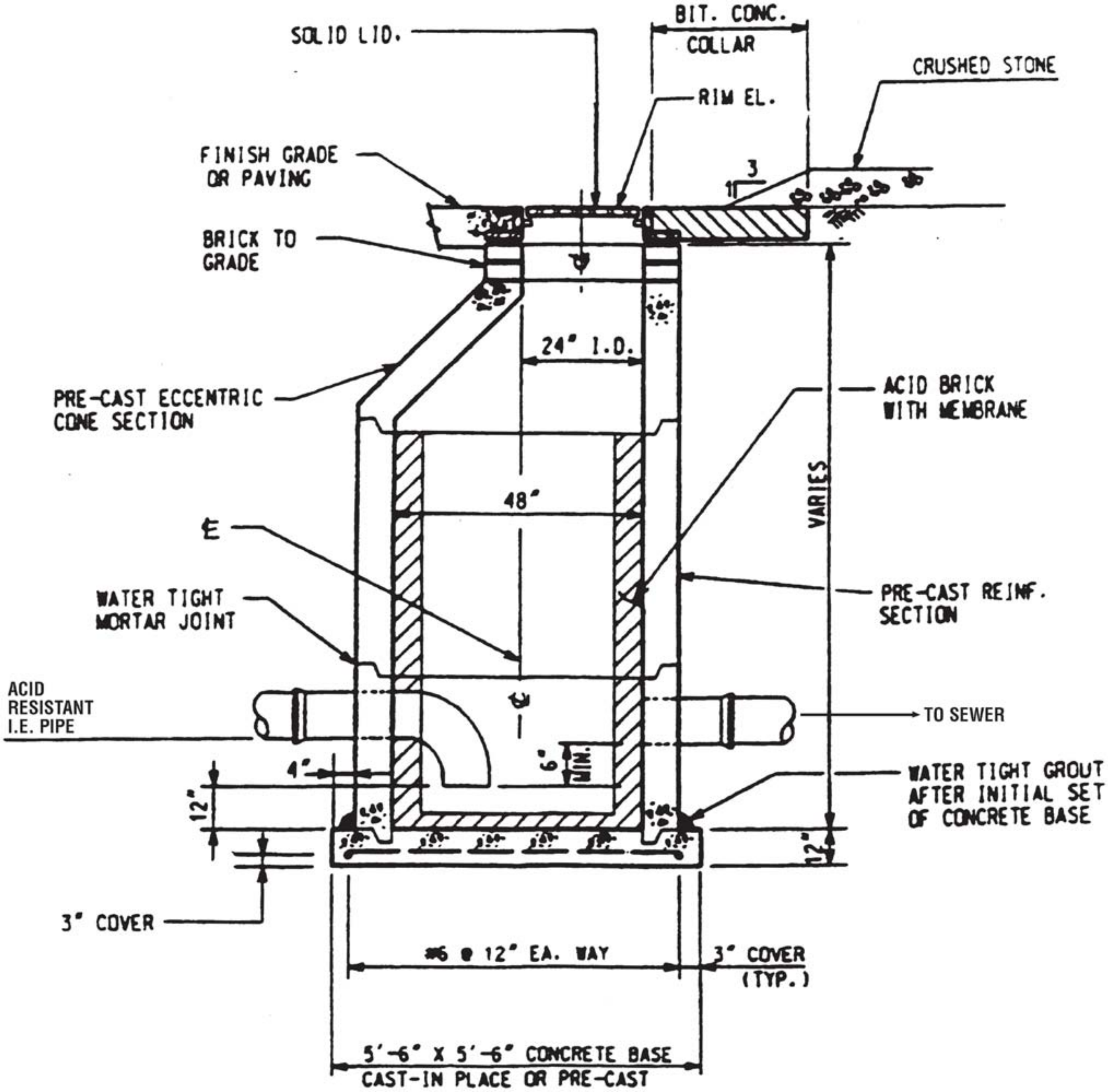
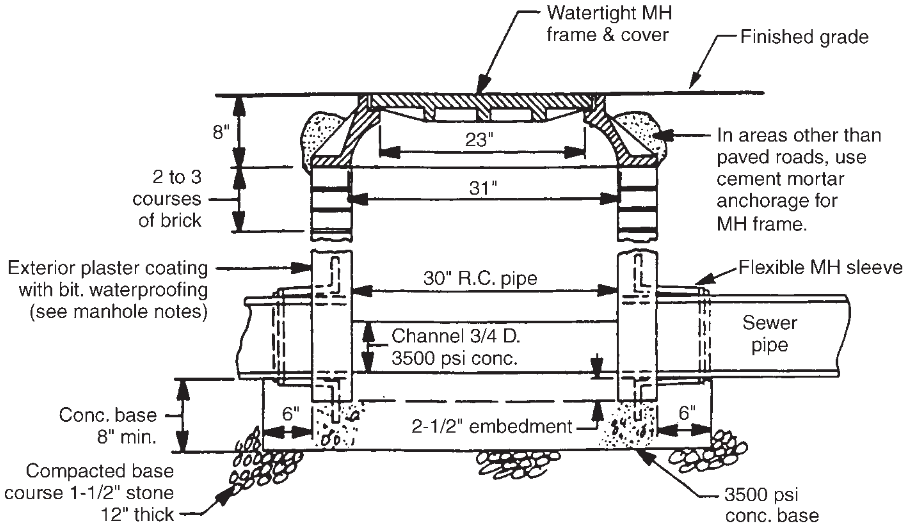
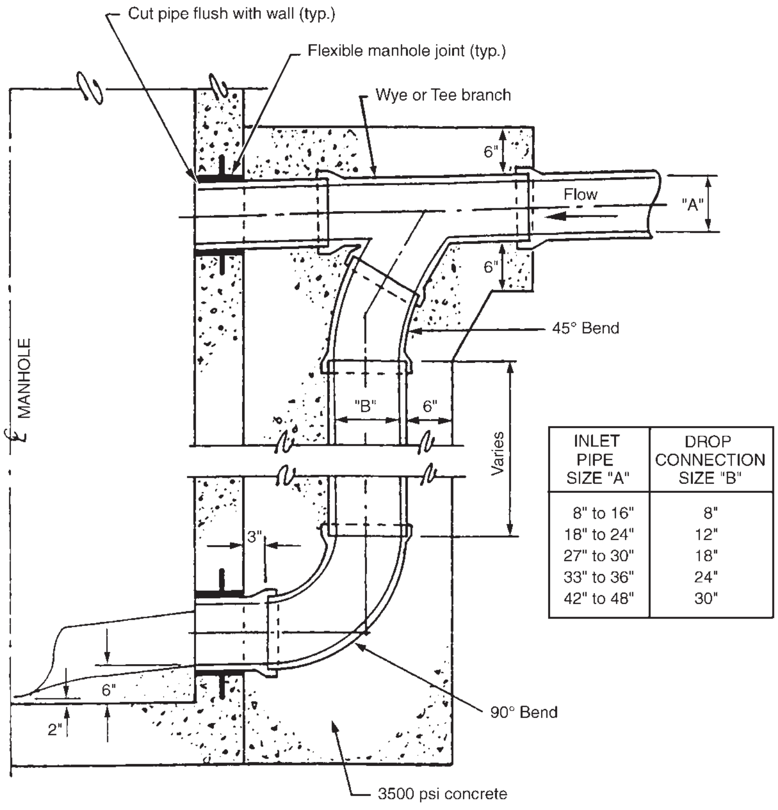


Figure 11-29 Typical Acid Manhole



NOTES:
1. Shallow MH (circular) to be used at locations where distance from finished grade to pipe invert is 3'– 0" or less.
2. For depths of 3'– 0" and less, measured from the top of the pipe, contractor shall install ductile iron pipe, Class 52, under traffic areas.

Figure 11-30 Shallow Manhole



INLET PIPE SIZE "A"	DROP CONNECTION SIZE "B"
8" to 16"	8"
18" to 24"	12"
27" to 30"	18"
33" to 36"	24"
42" to 48"	30"

NOTE: Drop pipe to be used in all cases where difference between inlet invert and lowest outlet invert is 2 feet or greater.

Figure 11-31 Drop Manhole

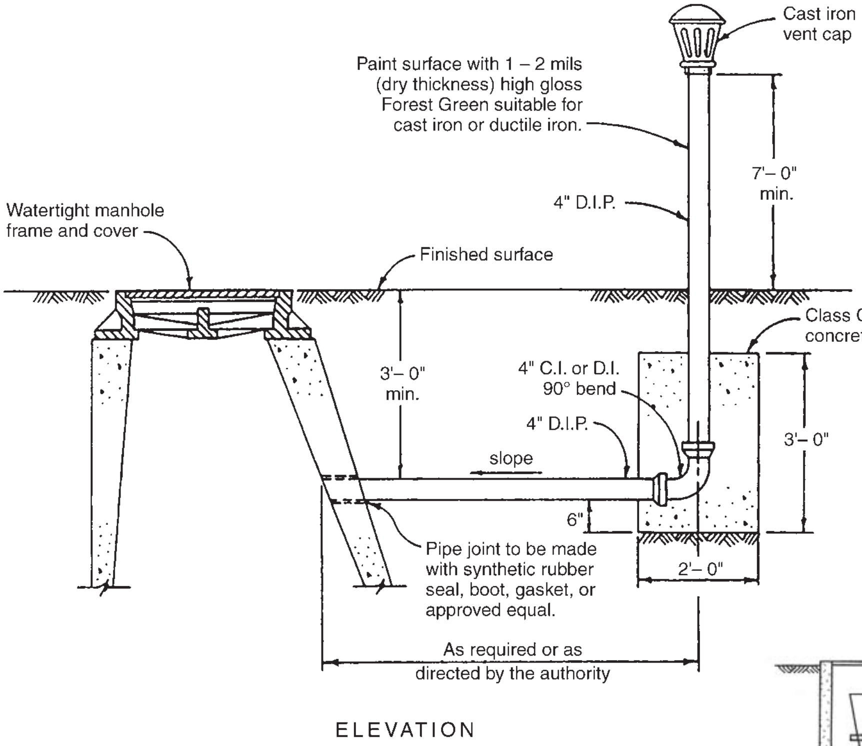


Figure 11-32 Detail of Waterproof Manhole

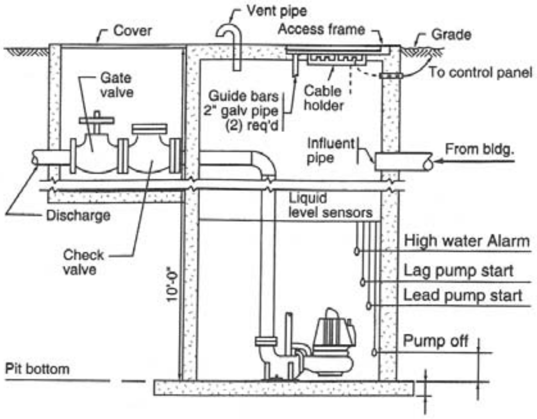


Fig 11-33 Submersible Pump Assembly

Table 11-8 Manhole Spacing and Location of Pipe Sewers

A. Maximum Spacing of Manhole on Pipe Sewers		
Pipe Sizes, in. (mm)	Recommended Max. Spacing, ft (m)	Absolute Max. Spacing, ft (m)
10 Dia. to 24 Dia. (254 to 610) Circular 14 H×23 W (356×584) Horiz. Elliptical Pipe 23 H×14 W (584×356) Vert. Elliptical Pipe	150 (45.7)	200 (61)
27 Dia. to 48 Dia. (686 to 1219) Circular 19 H×30 W to 48 H×76 W (483×762 to 1219×1930) Horiz. Elliptical Pipe 30 H×19 W to 49 H×32 W (962×483 to 1245×813) Vert. Elliptical Pipe	300 (91.4)	400 (121.9)
54 Dia. to 66 Dia. (1372 to 1676) Circular 53 H×83 W to 68 H×106 W (1346×2108 to 1727×2692) Horiz. Elliptical Pipe 53 H×34 W to 68 H×43 W (1346×864 to 1727×1092) Vert. Elliptical Pipe	400 (121.9)	500 (152.4)
72 Dia. (1829) and larger Circular 72 H×113 W (1829×2870) and larger Horiz. Elliptical Pipe 76 H×48 W (1930×1219) and larger Vert. Elliptical Pipe	500 (152.4)	600 (182.8)
B. Manhole Location on Pipe Sewers 1. Change in grade or elevation (a) At all changes in grade or elevation for all sizes of sewers. 2. Change in alignment (a) At all changes in alignment for circular sewers up to and including 42 in. (1067 mm) diameter. (b) At all changes in alignment for elliptical pipe sewers up to and including 43 in. H×68 in. W (1092 mm×1727 mm) and 42 in. H×27 in. W (1067 mm×686 mm) sizes.		

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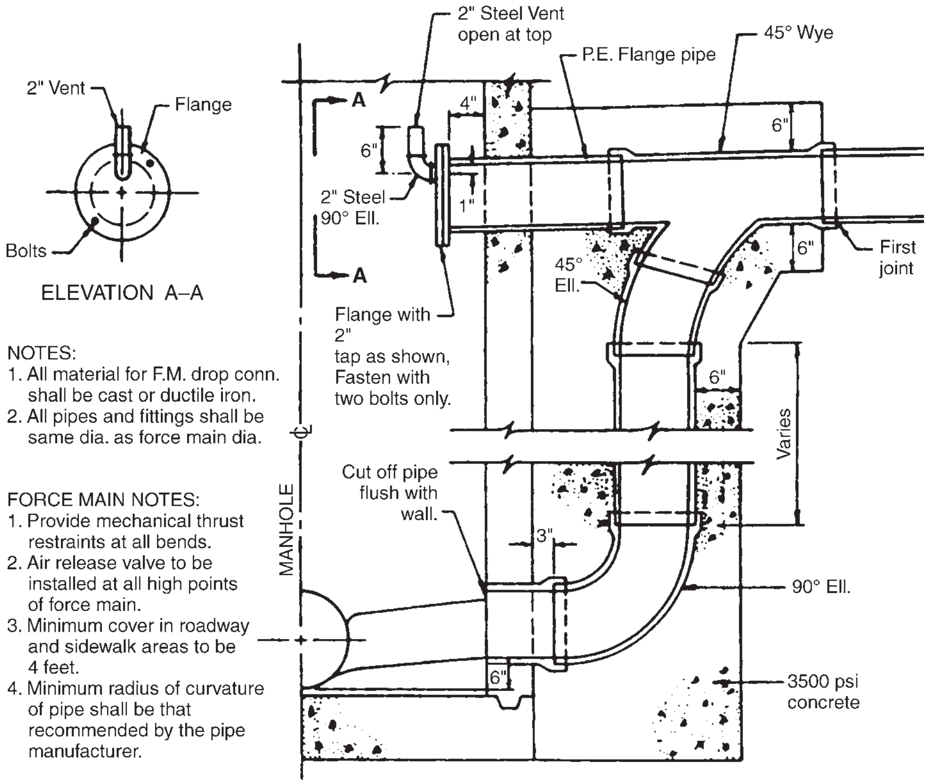

NOTES:
1. All material for F.M. drop conn. shall be cast or ductile iron.
2. All pipes and fittings shall be same dia. as force main dia.

FORCE MAIN NOTES:
1. Provide mechanical thrust restraints at all bends.
2. Air release valve to be installed at all high points of force main.
3. Minimum cover in roadway and sidewalk areas to be 4 feet.
4. Minimum radius of curvature of pipe shall be that recommended by the pipe manufacturer.

Figure 11-34 Detail of Force Main Connection to Public Sewer

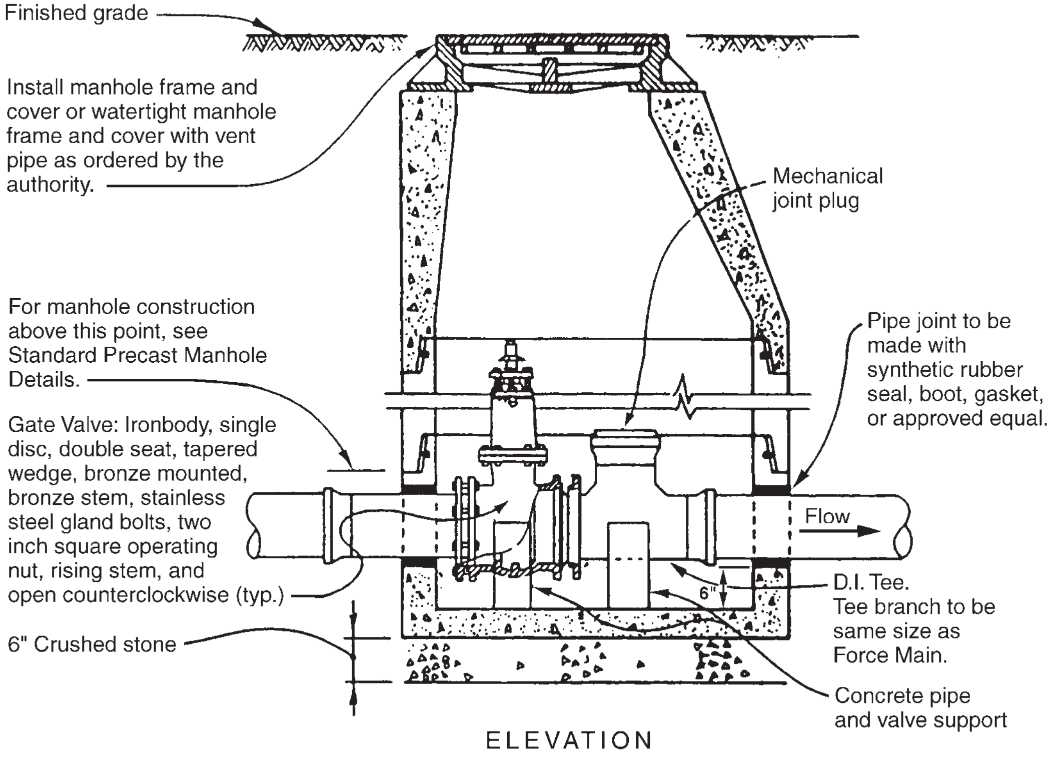

Figure 11-35 Force Main Cleanout in Manhole

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12

Laboratory Gases

This chapter describes the design criteria and central piping distribution methods for various laboratory-grade specialty gas systems, including pure compressed air used for laboratory processes. For the purposes of this chapter, a compressed gas is any gas at a pressure higher than atmospheric pressure. Also included in the discussion are various specialty compressed air and gas systems typically used for organic and inorganic chemistry, physics, and biological laboratories and those used for research, development, and commercial purposes. The gases and their delivery systems used in these types of facilities are characterized by low delivery pressures, low and intermittent volumes, and high purity requirements. This chapter concentrates on cylinder and dewer supply and the local generation of such gases.

For a discussion of all phases of standard compressed air, compressor types, compressor accessories, fundamentals, and definitions not discussed here, refer to Chapter 9 of this volume. For a discussion of compressed air for healthcare facilities, refer to Chapter 2.

CODES AND STANDARDS

The building codes and standards impacting the design and installation of the various specialty gas systems have been put in place to protect the safety and health of operating personnel and building occupants. The building codes also have requirements concerning fire and the structural consequences of accidents. However, no mandated code requirements have been written concerning the sizing or purity of any of the specialty gases. These requirements are usually specific to the type of facility and end use.

Minimum purity requirements, called "commodity standards," are listed in the Compressed Gas Association (CGA) standards for various gases. Often, the actual on-site purity requirement is higher than that listed in the standard and is determined by the proposed use of the gas and the requirements of the user. The CGA also has material, pressure, and dimensional standards for pipe connections and terminations. For standards for gases not covered by the CGA and the National Fire Protection Association (NFPA), good engineering practice is used to adequately locate the tanks, piping systems, and components.

The NFPA has codes for the storage of flammable gases both inside and outside a building. NFPA 55: *Compressed Gases and Cryogenic Fluids Code* covers bulk oxygen at consumer sites and the storage of hydrogen. NFPA 99: *Standard for Health Care Facilities* lists the requirements for the storage of flammable and nonflammable gases in cylinders. This standard does not actually apply to laboratories outside of healthcare facilities, but it often is used for guidance in determining the amount and location of these cylinders. The final decision to adhere to provisions of this standard depends on the client, the requirements of the client's insurance carrier, and the authority having jurisdiction (AHJ).

The U.S. Environmental Protection Agency (EPA) provides health hazard classifications, fire hazard classifications, and sudden release of pressure hazard classifications. All of these ratings and the associated precautions are available on material safety data sheets (MSDS). For instance, gases that fall under the "Reactive Hazard" classification must be kept separate from each other, typically with walls, nonpermanent solid separators available from the gas supplier, or gas cabinets. The EPA also publishes threshold limit values for the degree of concentration of any particular gas in ambient air for breathing purposes.

PHYSICAL PROPERTIES OF AIR

Because purified air is a specialty gas, it is important for the engineer to analyze standard laboratory (free) air to determine if the end use requires further purifying of the air and how to select equipment to accomplish this.

Free air is a mixture of many elements and compounds. The composition of dry air is listed in Table 12-1. Pure air is odorless, tasteless, and free of chemi-

Table 12-1 General Composition of Dry Air

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

Table 12-2 Elevation Correction Factor

Altitude, ft (meters)	Correction Factor
0 (0)	1.00
1,600 (480)	1.05
3,300 (990)	1.11
5,000 (1,500)	1.17
6,600 (1,980)	1.24
8,200 (2,460)	1.31
9,900 (2,970)	1.39

cals unless some foreign matter is suspended in the mixture in error.

The air pressure exerted at the Earth's surface is due to the weight of the column of air above that point and is measured barometrically at a standard pressure of 14.7 pounds per square inch gauge (psig) (101.4 kPa). Because free air is less dense at higher elevations, a correction factor must be used for standard air to determine the equivalent volume at the higher elevation. The elevation correction factors are given in Table 12-2. By multiplying the volume of air at sea level by the correction factor, the actual quantity of air at a higher elevation can be found.

Temperature is also a consideration. Because an equal volume of any gas at a lower temperature will exert a higher pressure at a higher temperature, a correction factor must be used to determine the equivalent volume of air at different temperatures. The temperature correction factors are given in Table 12-3. By multiplying the volume of air at the lower temperature by the correction factor, the actual quantity of free air at the higher temperature can be found.

Table 12-3 Temperature Correction Factor

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

Impurities and Contamination

A knowledge of the various pollutants in the air is necessary when determining the equipment required to effectively reduce or remove them, and the air must be tested to achieve this knowledge. When selecting appropriate and specific air purification components, remember that no single piece of equipment or device can accomplish the job of removing all contaminants.

The required level of protection from the various contaminants depends on the purpose for which the air will be used.As well as identifying and quantifying the pollutants, the performance criteria for each individual system also must be determined prior to selecting any equipment.

The four general classes of contaminants are liquids (oil and water), vapor (oil, water, and hydrocarbons), gases, and particulates.

Liquids

Water enters a system with the intake air, passes through the compressor as a vapor, and condenses afterward into liquid droplets. When water settles on or within pipes, corrosion begins, ultimately ruining machinery and tools, causing product

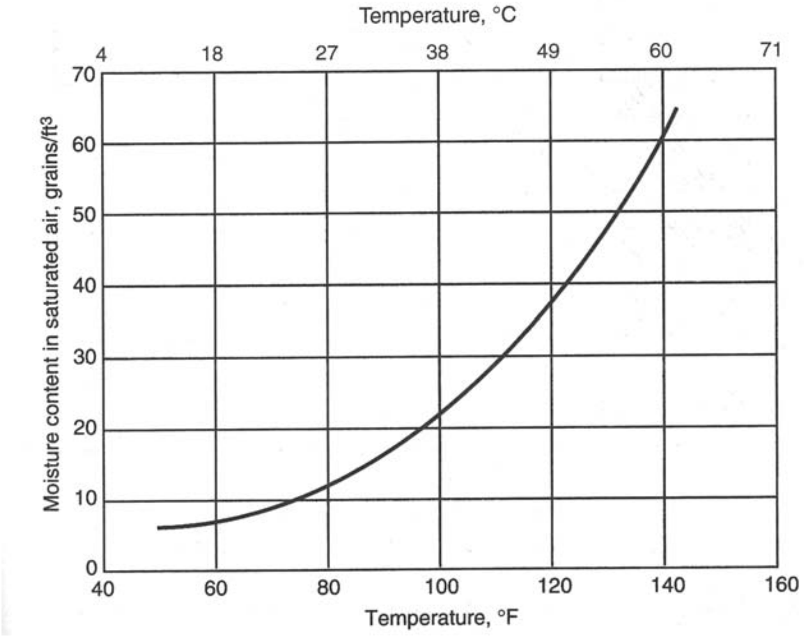


Figure 12-1 Moisture Content of Saturated Air

rejection and contamination. Water also allows microorganisms to grow.

Most liquid oil contamination originates at the intake location or in an oil-lubricated compressor. As the droplets are swept through the system at velocities approaching 4,000 feet per minute (fpm) (1,200 m/min), they gradually erode obstructions in their path by repeated collisions. At high temperatures, oils break down to form acids. In the presence of particulates, oil forms sludge. Oil also can act like water droplets and cause erosion.

Liquid chemicals react with water and also corrode surfaces. There is no safe level of liquids in the airstream. They should be removed as completely as practical.

Vapor

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

The level of acceptable water vapor varies with end-use requirements. A dewpoint of -30°F (-34°C) is required to minimize corrosion in pipelines. For critical applications, a dewpoint of -100°F (-73°C) may be required. Oil vapor remaining in the air should be reduced to as close to zero as practical. Chemical concentrations should be reduced to zero, where practical.

Gas

Gases in any quantity that are potentially harmful to the system or process requirements should be reduced to zero or to a point that will cause no harm, depending on practical considerations. Condensable hydrocarbons should be removed as completely as practical. Gases such as carbon dioxide, sulfur dioxide, and nitrogen compounds react with heat and water to form acids.

Particulates

Particulates enter the system from the air intake, originate in the compressor due to mechanical action, or are released from some air-drying systems. These particles erode piping and valves or cause product contamination. However, the most harmful effect is that they clog the orifices or passages of, for example, tools at the end-use points. These particulates include metal fines, carbon and Teflon particles, pollen, dust, rust, and scale.

Particulate contamination must be reduced to a level low enough to minimize end-use machine or tool clogging, cause product rejection, or contaminate a process. These values must be established by the engineer and client and will vary widely. The general range of particles in a typical system is between 10 and 0.01 micrometer (μm) in diameter.

Water Vapor in Compressed Air

Water vapor is present in all free air and is the most common contaminant. In many cases, it will be necessary to remove any water vapor above that required for air normally used for general laboratory purposes.

Saturated Air and Dry Air

Saturated air contains the maximum amount of water vapor possible based on its temperature and pressure. Dry air contains no water vapor. To determine the moisture content of saturated air (100 percent relative humidity) based on its temperature, refer to Figure 12-1.

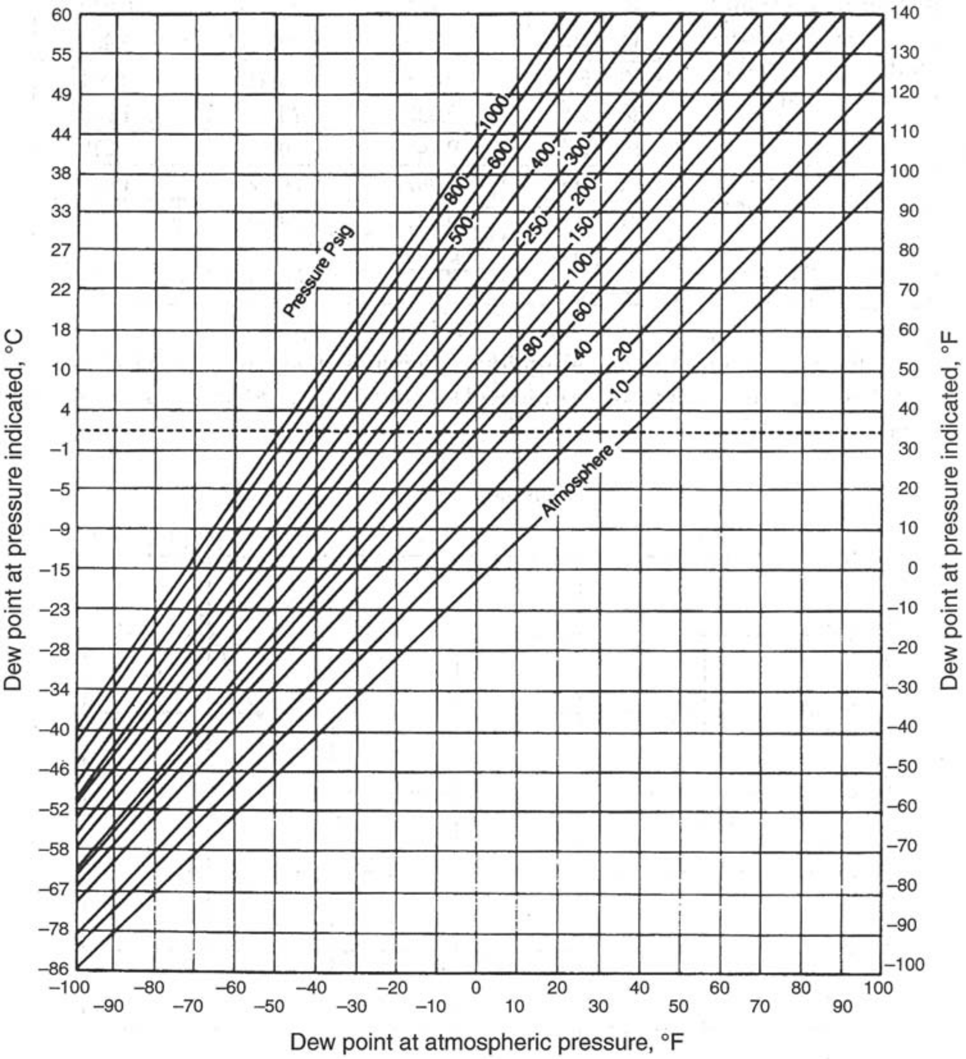
Relative Humidity

Relative humidity is the amount of water vapor present in air expressed as a percent of the total amount capable of being present when the air is saturated. Relative humidity depends on pressure and temperature and is not the preferred method to refer to water vapor in air.

Dewpoint

The dewpoint is that temperature at which water in the air will start to condense on a surface. It is the preferred method used to express the dryness of compressed air since it does not depend on temperature. As the dewpoint decreases, the air gets dryer. Since the dewpoint of air varies with air pressure, it is referred to as the pressure dewpoint.

To find the dewpoint of air at various pressures and temperatures, refer to the dewpoint conversion chart in Figure 12-2. To use the chart, first determine the temperature of the ambient air. Extend a line horizontally until the ambient pressure is found, and then extend a line vertically from the intersection down to read the dewpoint at 1 atmosphere.



Note: Multiply pressure in PSIG by 6.9 to obtain KPa

Figure 12-2 Dewpoint Conversion Chart

Source: Hankison Corp.

CLASSIFICATION OF SPECIALTY LABORATORY GASES

Specialty laboratory gases are prepared to perform specific tasks. Examples include the following:

- Span and calibration gases to calibrate gas chromatographs
- Carrier gases to exclude impurities and sweep a sample through a column
- EPA protocol gases to monitor atmospheric discharge from power plants, chemical plants, and refineries
- Process gases to promote specific reactions
- Gases for analysis functions

Specialty compressed gases are classified into the following general categories:

- Oxidizers are nonflammable but support combustion. No oil or grease is permitted to be used with any device associated with the use of this type of gas, and combustibles shall not be stored near these gases. Oxygen is an example.
- Inert gases, such as helium, do not react with other materials. If released into a confined space, they will reduce the oxygen level to a point that asphyxiation could occur. Rooms where these gases are stored should be provided with oxygen monitors and should be well ventilated.
- Flammable gases are those that when combined with air or oxidizers will form a mixture that will burn or possibly explode if ignited. Flammable mixtures have a range of concentration below which they are too lean to be ignited and above which they are too rich to burn. The most often used figure is the lower explosive level (LEL), which is the minimum percent, by volume, that will form a flammable mixture at normal temperatures and pressures. The high level for alarms is generally one-half of the LEL, with warnings issued at one-tenth of the LEL. The area where flammable gases are stored must be well ventilated, use approved electrical devices suitable for explosive atmospheres, and restrict all ignition sources. The flammability limits and specific gravities of common gases are given in Table 12-4

Table 12-4 Flammability Limits and Specific Gravity for Common Gases

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

- Corrosive gases will attack the surface of certain substances and also damage human tissue upon contact.
- Toxic and poisonous gases will harm human tissue by contact or ingestion. Protective clothing and equipment must be used.
- Pyrophoric gases will spontaneously ignite upon contact with air under normal conditions.
- Cryogenic gases are stored as extremely cold liquids under moderate pressure and vaporized when used. If the liquid is spilled, bare skin will suffer severe burns, and splashing into the eyes will cause blindness.

GRADES OF SPECIALTY LABORATORY GASES

Many grades of pure and mixed gases are available. Due to the lack of an industry-recognized standard grade designation for purity, each supplier has its own individual designations. It is possible for the same gas used for different purposes or provided by a different supplier to have different designations for the same purity. The instrument manufacturer and the end user must be consulted to learn the maximum acceptable levels for the various impurities based on the type of instrument used and the analytical work to be performed. The supplier then must be informed of these requirements to determine what grade of gas to supply to meet or exceeds the levels of the various impurities.

The following list, although not complete, covers some manufacturers' designations for different grades of gases. Specific instruments have additional grades, such as "Hall" grades of gases.

- Research grade
- Carrier grade
- Zero gas
- Ultra zero
- Ultra-high purity plus
- Ultra-high purity
- Purified
- USP

STORAGE AND GENERATION OF GASES

Cylinder Storage

It is convenient and inexpensive to store compressed gases in cylinders. Cylinders are available in various pressure ratings, with the nomenclature differing among the manufacturers. High-pressure cylinders store gas at pressures ranging up to 6,000 psig (41,368.5 kPa), with the most common pressures between 2,000 and 2,500 psig (13,789.5 and 17,236.9 kPa). Low-pressure cylinders or dewers store gases at pressures up to 480 psig (3,309.5 kPa).

When more than one cylinder is used to supply a system, the multiple arrangement is referred to as a bank of cylinders. Cylinder banks generally are classified as primary, secondary, and reserve based on end-use requirements. They are connected by a header and controlled by a manifold assembly. The arrangement of the cylinders is determined by the space available for the installation and the relative ease desired for changing the cylinders. They can be placed in a single row, double row, or staggered. The space typically required for various arrangements is shown in Figure 12-3. Any additional space between banks of cylinders required for specialized devices such as manifold controls, purging devices, filters, and purifiers should be added to the cylinder bank dimensions.

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

Equation 12-1

$$VC = \frac{CP}{14.7} \times CV$$

where:

VC = Volume of gas in the proposed cylinder at pressure, cubic feet (m^3)
CP = Actual proposed cylinder pressure, psi (kPa)
CV = Actual cylinder volume, cubic feet (m^3)

Cylinders are available in many sizes and pressure ratings. Figure 12-4 illustrates the typical sizes. The cylinders themselves are available in four general categories. The first is the plain carbon steel tank. The second is called the ultra-clean tank, which is made of a slightly different alloy steel and has been completely cleaned, prepared, and dried to reduce contaminants in the cylinder. The third classification is aluminum tanks, in which the tank interior has been specially prepared and the walls treated to maintain stability and reduce particulates. Aluminum is used for cleanliness and for gases that will react with steel. In many cases, the exterior also is treated to be easily cleaned, such as required for clean room installations. The fourth type of cylinder is made of stainless steel, which is often used for ultra-pure gases.

Following are the general recommendations for the installation and storage of cylinders:

- The room or area in which the cylinders are placed shall have adequate ventilation and be free from combustible material and separated from sources of ignition.
- Consideration should be given for the storage of additional full and empty cylinders in the same room for convenience.
- Enough room should be allowed for the easy changing of cylinders. They are brought in on a hand truck or cart, and room, usually 3 feet (0.91 m), should be allowed for their maneuvering.
- Gas cylinders in active use shall be secured against falling by means of floor stands, wall brackets, or bench brackets. These brackets use straps to attach the cylinder to the bracket. Also available are floor racks and stands that can be provided for the installation and support of cylinders that cannot be located near walls.
- Empty cylinders also shall be secured against falling.

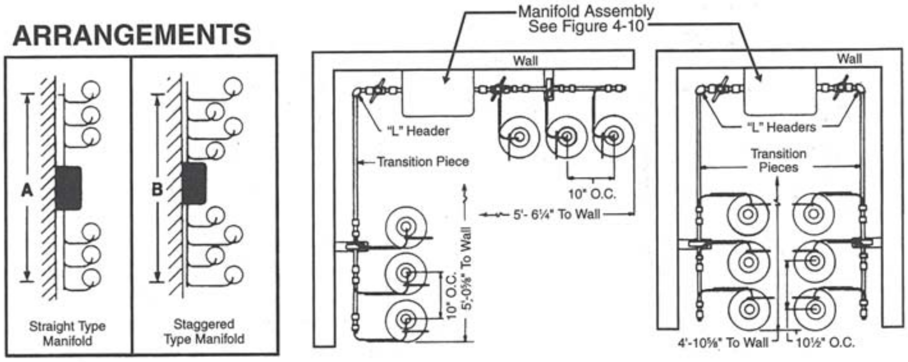
Dewers

When a larger amount of gas storage is desired, dewers typically are used. Typical dewers are illustrated in Figure 12-5. Dewers should be placed at least 3 inches (1.5 cm) apart for easy changing.

Gas Cabinet

When toxic or reactive gases are used, the cylinders should be placed in a vented gas cabinet. The basic purpose of the cabinet is to isolate the cylinders and to contain the gases in the event of a leak. Escaped gases shall be directed away from the immediate vicinity of the cylinder and cylinder storage area to a point outside the building where they can be diluted with the outside air.

The typical cabinet construction is 11-gauge painted steel or thicker to provide a one-half hour fire rating. The cabinet can contain panel-mounted manifolds, purging equipment, and other devices to allow some degree of control of operating parameters. They



DIMENSIONAL DATA

Cylinders Per Bank	Dimension "A"	Dimension "B"
2 banks of 2 each	5'- 0"	4'- 6"
2 banks of 3 each	6'- 8"	5'- 8"
2 banks of 4 each	8'- 4"	6'-10"
2 banks of 5 each	10'- 0"	8'- 0"
2 banks of 6 each	11'- 8"	9'- 2"
2 banks of 7 each	13'- 4"	10'- 4"
2 banks of 8 each	15'- 0"	11'- 6"
2 banks of 9 each	16'- 8"	12'- 8"
2 banks of 10 each	18'- 4"	13'-10"

Figure 12-3 Typical Arrangements and Dimensions of Cylinder Installations (9-in. diameter)

Table 12-5 Sizing for Oxygen, Nitrogen, and Air

scfm	acfm	Copper Tube Type L, 55 psi, Specific Gravity = 1								
		½ in.	¾ in.	1 in.	1¼ in.	1½ in.	2 in.	2½ in.	3 in.	4 in.
		psi per 100 feet of pipe								
5	1.1	0.15	0.04	0.01						
10	2.2	0.51	0.13	0.04	0.01					
15	3.3	1.04	0.27	0.09	0.02	0.01				
20	4.3		0.45	0.14	0.04	0.02				
25	5.4		0.67	0.21	0.06	0.03	0.01			
30	6.5		0.93	0.29	0.08	0.04	0.01			
35	7.6		1.18	0.39	0.10	0.05	0.02	0.01		
40	8.7			0.49	0.13	0.06	0.02	0.01		
45	9.8			0.60	0.16	0.08	0.02	0.01		
50	10.9			0.73	0.20	0.09	0.03	0.01		
60	13.0			1.01	0.27	0.13	0.04	0.02	0.01	
70	15.2			1.28	0.36	0.17	0.05	0.02	0.01	
80	17.4				0.45	0.22	0.07	0.03	0.01	
90	19.5				0.56	0.27	0.08	0.03	0.01	
100	21.7				0.68	0.32	0.10	0.04	0.02	0.00
110	23.9				0.81	0.38	0.12	0.05	0.02	0.01
120	26.0				0.94	0.45	0.14	0.06	0.02	0.01
130	28.2				1.09	0.52	0.16	0.07	0.02	0.01
140	30.4				1.22	0.59	0.18	0.08	0.03	0.01
150	32.6					0.67	0.20	0.09	0.03	0.01
175	38.0					0.89	0.27	0.11	0.04	0.01
200	43.4					1.13	0.34	0.14	0.05	0.01
225	48.8					1.28	0.42	0.18	0.06	0.02
250	54.3						0.51	0.22	0.08	0.02
275	59.7						0.60	0.26	0.09	0.02
300	65.1						0.71	0.30	0.11	0.03
325	70.5						0.82	0.35	0.12	0.03
350	76.0						0.94	0.40	0.14	0.04
375	81.4						1.06	0.45	0.16	0.04
400	86.8						1.18	0.51	0.18	0.05
450	97.7							0.63	0.22	0.06
500	108.5							0.76	0.27	0.07
550	119.4							0.90	0.32	0.09
600	130.2							1.06	0.37	0.10
650	141.1							1.21	0.43	0.12
700	151.9								0.49	0.13
750	162.8								0.56	0.15
800	173.6								0.63	0.17
850	184.5								0.70	0.19
900	195.3								0.78	0.21
950	206.2								0.89	0.23
1,000	217.0									0.25
1,100	238.7									0.30
1,200	260.4									0.35
1,300	282.1									0.41
1,400	303.8									0.47
1,500	325.5									0.53

Note: Values in table are for flow velocities not exceeding 4,000 fpm.

Table 12-6 Factors for the Sizing of Any Gas, Based on Specific Gravity

Specific Gravity	Factor
.05	4.50
.10	3.16
.15	2.58
.20	2.20
.25	2.00
.30	1.79
.35	1.68
.40	1.57
.45	1.49
.50	1.41
.55	1.33
.60	1.28
.65	1.23
.70	1.19
.75	1.15
.80	1.12
.85	1.07
.90	1.05
.95	1.02
1.00	1.00
1.10	.95
1.20	.91
1.30	.87
1.40	.85
1.50	.81
1.60	.78
1.70	.76
1.80	.74
1.90	.72
2.00	.70
2.10	.69
2.20	.67
2.30	.65
2.40	.63
2.50	.62
2.60	.61
2.70	.60
3.00	.56
4.50	.25

Note: Multiply factor by scfm in Table 12-8. Calculate adjusted scfm. Use adjusted scfm to obtain friction loss.

also can be provided with vertical and horizontal adjustable cylinder brackets. The following options also are available with the cylinder cabinet:

- Automatic shutoff of gas in the event of a catastrophic failure (flow limit)
- Purging of gas lines after cylinder changes
- Mechanical cabinet exhaust (typically 13 air changes per minute with the access window open)
- A sprinkler head for flammable gases, typically rated at 135°F (57.2°C) with a minimum water pressure of 25 psig (172.4 kPa)
- For toxic and reactive gases, a small access window could be provided to operate the valves without opening the main door and compromising the exhaust system. A fixed access window is acceptable for inert gases.

Specialty Gas Generators

In some cases, it is more desirable for a small facility to generate their own high-purity specialty gases rather than having them supplied in cylinders. A limited number of gases is available for which the anticipated volume allows this choice in laboratory or research facilities. Among them are nitrogen, hydrogen, helium, and compressed air. The generating units have their own filters and purifiers that can create gases of ultra-high purity. In particular, the use of these units for the generation of hydrogen eliminates flammable cylinders in the laboratory or separate storage areas and keeps the actual amount of gas stored below that needed for explosion to take place. These units may need to be supplied with utilities such as electrical power, compressed air, or deionized water.

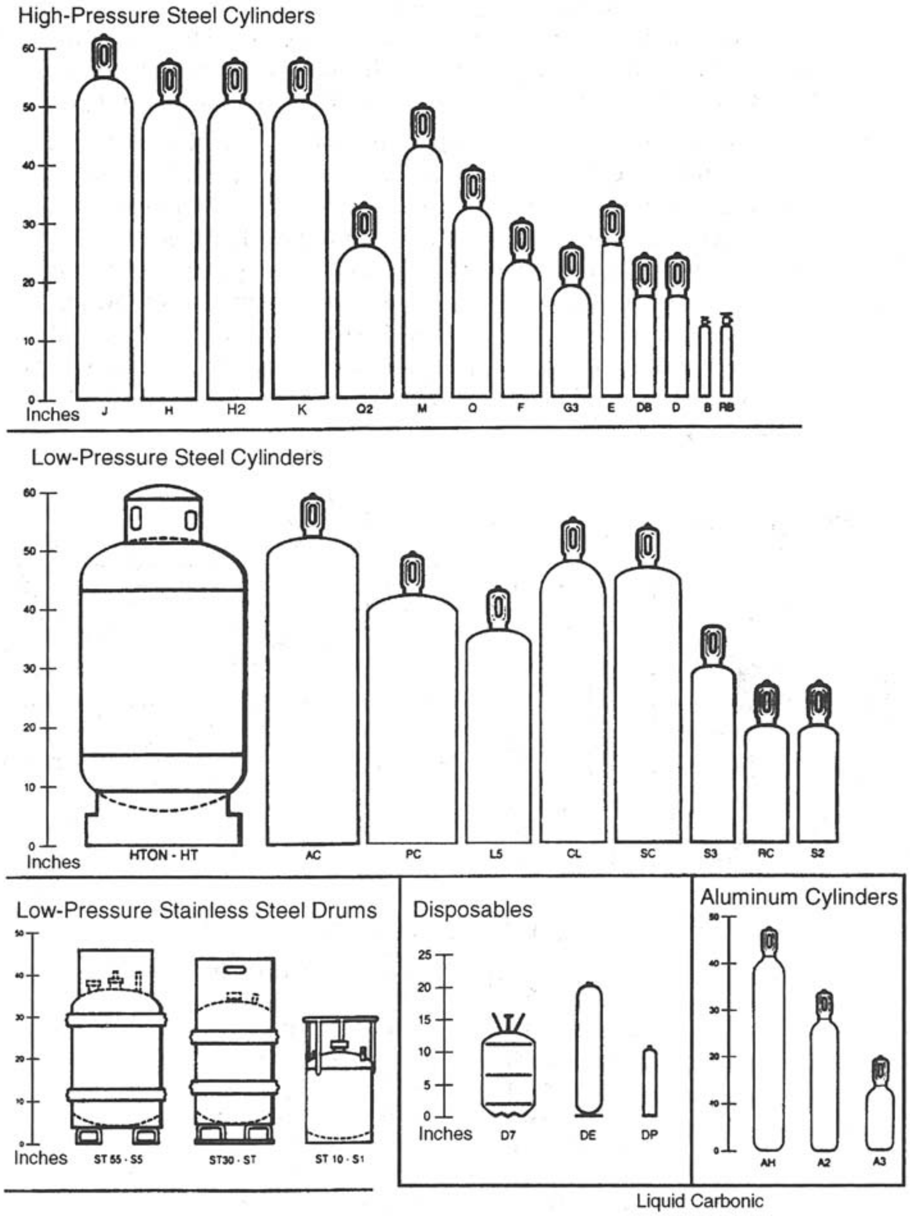


Figure 12-4 Typical Cylinder Dimensions

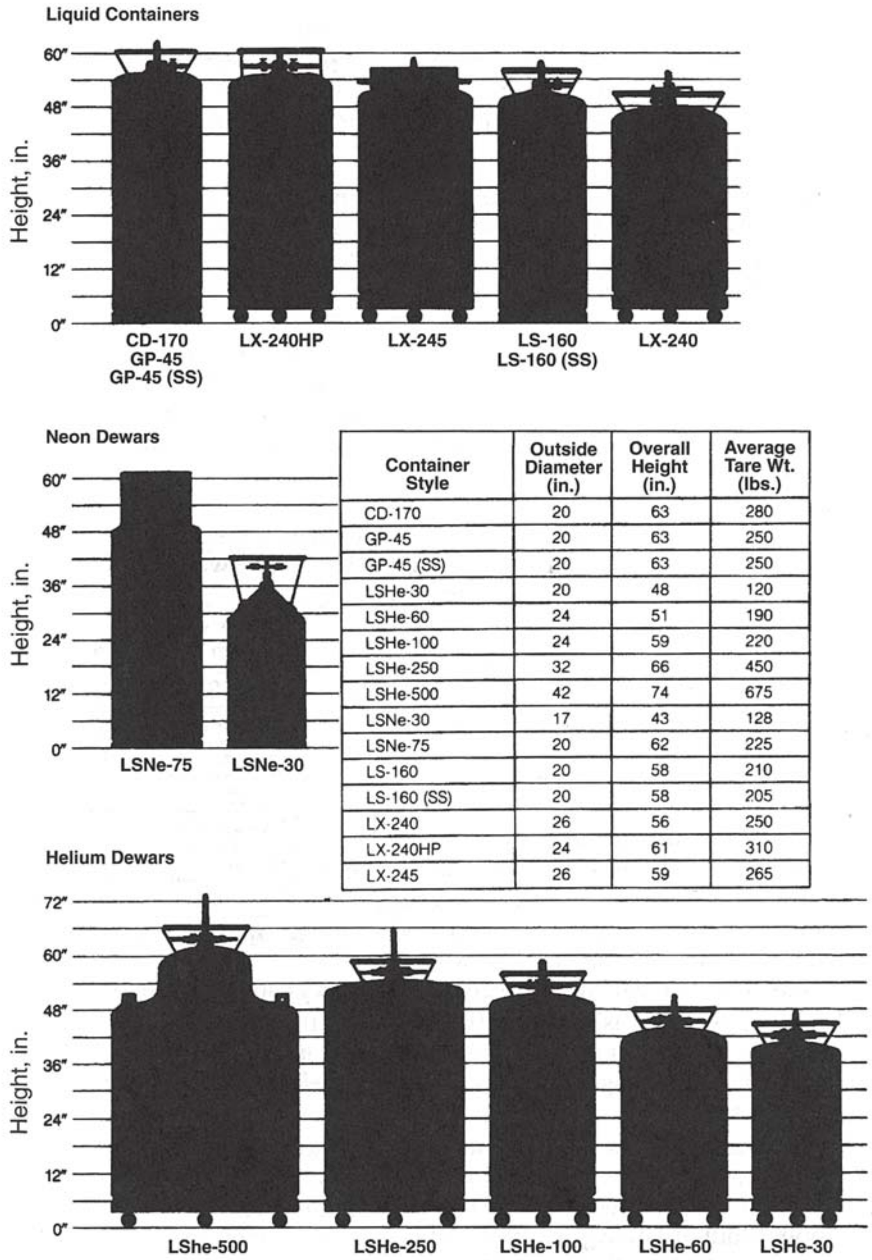
Source: Liquid Carbonic

DISTRIBUTION SYSTEM COMPONENTS

The components that distribute high-purity gas are different than those that distribute standard laboratory gases. Following is a discussion of only those accessories and considerations that are necessary to accomplish higher purity.

Manifolds

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



Container Style	Outside Diameter (in.)	Overall Height (in.)	Average Tare Wt. (lbs.)
CD-170	20	63	280
GP-45	20	63	250
GP-45 (SS)	20	63	250
LSHe-30	20	48	120
LSHe-60	24	51	190
LSHe-100	24	59	220
LSHe-250	32	66	450
LSHe-500	42	74	675
LSNe-30	17	43	128
LSNe-75	20	62	225
LS-160	20	58	210
LS-160 (SS)	20	58	205
LX-240	26	56	250
LX-240HP	24	61	310
LX-245	26	59	265

Figure 12-5 Cryogenic Containers

Source: Mathison

stainless steel flexible connections connecting the cylinders to the header.

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

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

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

A typical manifold assembly is illustrated in Figure 12-6. Exact manifold dimensions vary and need to be obtained from the specific manufacturer.

Regulators

A regulator is a device used to reduce a variable high inlet pressure to a constant lower outlet pressure. The two broad categories of regulators are cylinder and line. Cylinder pressure regulators are mounted directly on high-pressure cylinders to reduce high-pressure gases, generally in the range of 2,000 to 6,000 psig (13,789.5 to 41,368.5 kPa), to a lower pressure, generally around 150 psig (1,034.2 kPa). Line regulators are inline devices used to reduce a higher

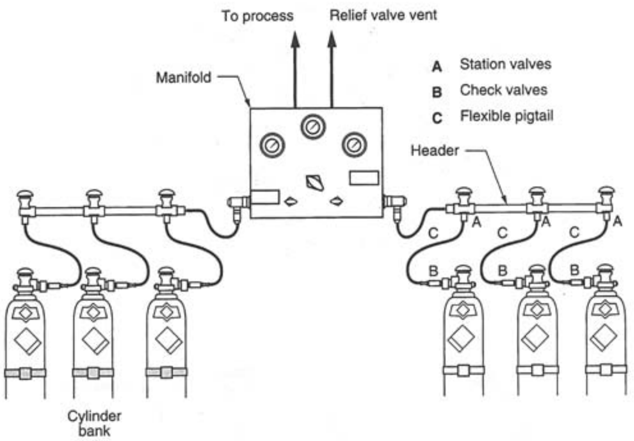


Figure 12-6 Typical Manifold Assembly
Source: Scott

pressure to a lower working pressure of 55 psig (379.2 kPa) and also are used on cryogenic tanks to reduce the pressure of the vapor above the vaporized liquid, generally in the range of 150 to 250 psig (1,034.2 to 1,723.7 kPa). The regulator is the first device installed in the distribution system. Depending on the purity of the gas, an integral inlet filter should be considered to keep particulates from entering the regulator.

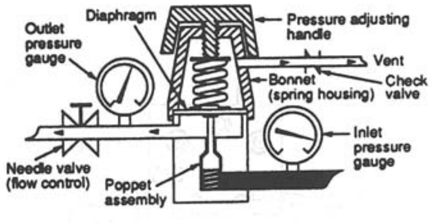
Regulators are available in two types: single and double stage. The single stage is less costly and less accurate. This type should be chosen if maintenance of exact pressure is not a major factor in system operation. The double stage is more costly and more accurate and able to achieve a constant outlet pressure within a narrow operating range. When selecting a regulator for specific accuracy requirements, obtain the accuracy envelope diagrams from the manufacturer to check the device's parameters using actual anticipated system design pressures and flow rates. Typical single- and double-stage regulators are illustrated in Figure 12-7.

The single-stage regulator reduces pressure in one step. Typical differences in outlet pressure could vary as much as 7 psig (48.2 kPa) from low to high flow rates. The double-stage regulator reduces the pressure in two steps. Typical differences in outlet pressure could vary as much as 3 psig (20.7 kPa) from low to high flow rates.

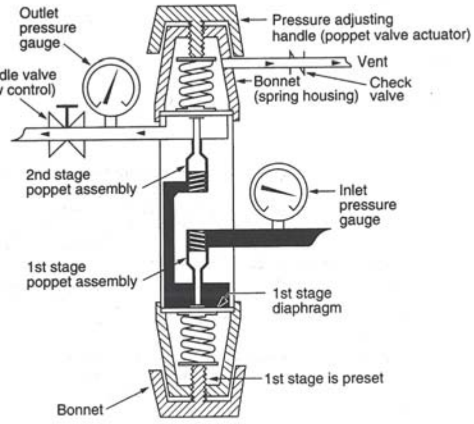
Another parameter that may be important in some installations is regulator creep. This is the rise in delivery pressure due to differences in motion of the internal mechanical components caused by aging. Creep is also caused by foreign material interfering with the mechanical operation of the unit. This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

The following should be considered when selecting a regulator:

- The regulator should have a positive gas vent.



Single-stage regulator



Two-stage regulator

Figure 12-7 Typical Single- and Double-stage Regulators
Source: Scott

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

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

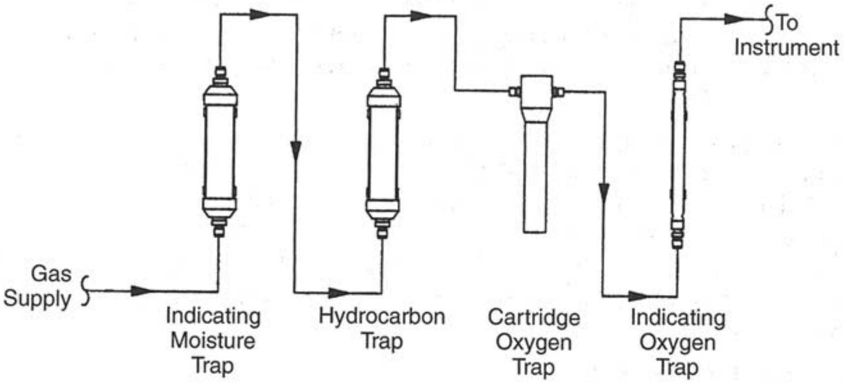


Figure 12-8 Typical Purifier Arrangement

Filters and Purifiers

Filters and purifiers are necessary to reduce or eliminate unwanted contaminants and particulates in the gas stream. The most common purifiers are those used to remove oxygen, water vapor, hydrocarbons, and particulates. For delivery of sterile gases, a 0.2-μ filter is used to remove any organisms suspended in the air stream. Filters also are used to eliminate other unwanted trace elements.

Many different types of filters are available.

- The most often used filter removes particulates 0.2 μm and larger.
- To remove hydrogen, palladium filters are used.
- Ceramic, fiberglass, sintered metal, and other adsorbent materials are used to remove oil, moisture, and other trace contaminants to make the main gas as pure as possible. For some filter mediums, colored materials can be added to indicate when it is time to replace the filter medium.
- The molecular sieve filter is a synthetically produced crystalline metal powder that has been activated for adsorption by removing the water of hydration. This material is manufactured with precise and uniform sizes and dimensions. The size determines what can be filtered. Sieves are available as powder, pellets, beads, and mesh, although mesh is not used in laboratories.

The requirements of the end user will dictate the filter medium and type. A filter shall be placed before any flow meter and any other type of equipment where required.

The housing must be compatible with the gas being filtered and the pressure involved. No filter should be subject to pressures more than the 60 psig (413.7 kPa) normally used in most laboratories unless specified for a higher pressure.

Pressure drop through the filter medium is a critical factor in the selection of the material used. For large installations, pressure gauges on each side of the filters are used to monitor their effectiveness. Usually, a 5-psig (34.5-kPa) drop means that replacement is required.

It is not possible to improve the purity of a gas with the use of purifiers. If a gas of a certain purity is required, a gas of that grade must be used from the outset.

Refer to Figure 12-8 for a typical system purifier arrangement. Components shall be eliminated as required.

Gauges

Gauges (other than those integral to regulators) for pressures up to 10 psig (68.9 kPa) are usually the diaphragm sensing-element type. For pressures more than 10 psig (68.9 kPa), use the bourdon style. They should be cleaned for oxygen service, and the materials must be compatible with the intended gas. For single gauges, provide a small gas cock of the needle valve type between the pipeline and the gauge to shut off the flow and allow the gauge to be replaced without shutting down the system.

Flash Arresters

Flash arresters (see Figure 12-9) are required when the gas being used is flammable, particularly hydrogen and acetylene. They are mounted inline to prevent any flame from going back into the tank in the event that gas in the delivery piping system has ignited. It is standard procedure for a check valve to be made an integral part of a flash arrester, although this is not true in all cases.

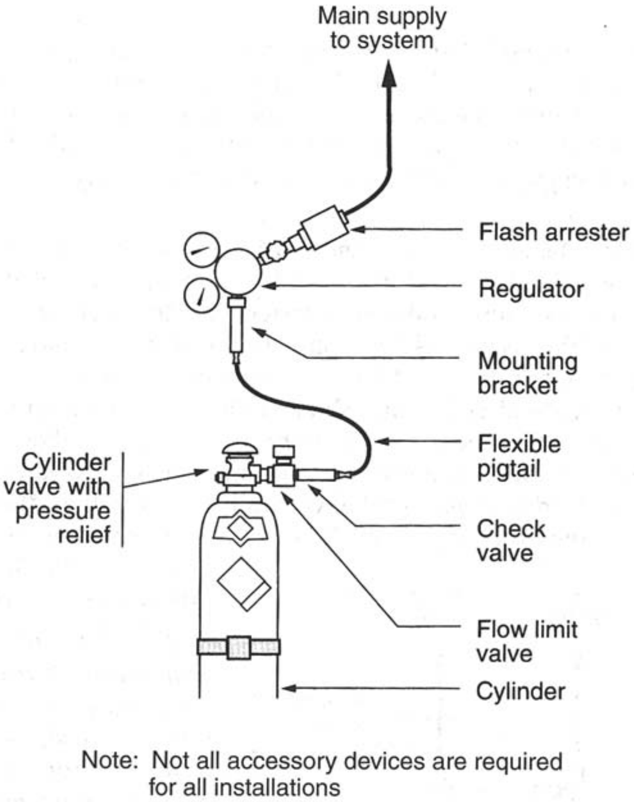
Valves

Valves are an often overlooked component of any system, but the selection of valve type and material is important to efficiency and operating life. The valves used should have been designed for the type of service for which they will be used. Be careful to examine valve specifications for airway ports or openings smaller than the nominal size indicated or expected. The most often used shutoff valves are ball valves. Three-piece valves are the most desired because the body can be separated from the end connections when being installed and serviced.

For exacting control and modulating purposes, needle valves are used because of the precise level of control permitted. The materials of the valve and seals must be compatible with the gas used.

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

The following should be considered when selecting valves:



Note: Not all accessory devices are required for all installations

Figure 12-9 Typical Single-cylinder Installation Detail

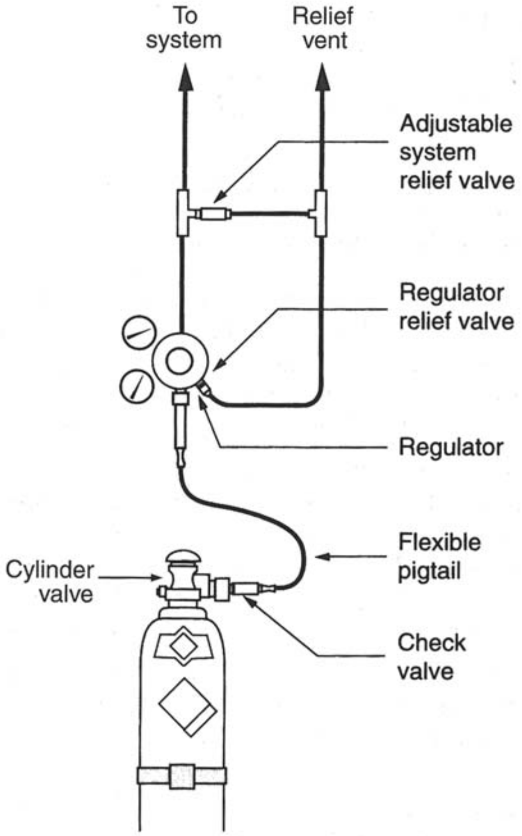


Figure 12-10 Typical Relief Venting

- The most important valve feature is minimum flow restriction (pressure drop) when the valve is open full. Ball, gate, and plug valves have the lowest pressure drop, so it is extremely rare to use these types for flow restriction. Where this feature is important, the needle type of valve is used.
- The pressure rating should be suitable for the maximum pressure possible.
- The valve body and seat materials must be compatible with the expected trace gases and contaminants.
- There must be positive shutoff.
- There should be minimum or no leakage through the valve stem.

Flow Limit Shutoff Valve

A flow limit shutoff valve (see Figure 12-9) automatically shuts off the flow from a cylinder if the flow rate exceeds a predetermined limit, which is usually about 10 times the highest expected flow rate. This valve must be manually reset after operation.

Check Valves

Check valves (see Figure 12-9) are used to prevent the reverse flow of gas in the delivery piping system. If one gas at a higher pressure possibly may force its way into another piping system or if system failure is a possibility, a check valve shall be installed.

Relief Valves

Relief valves (see Figure 12-10) are used to protect a system from overpressure. A relief valve must be provided between the regulator and the first shutoff valve in the system, with the discharge independently piped outdoors. The discharges from a single gas service manifold or regulator may be connected, but no connection from any source to a relief discharge may be made from any other system. The discharge pipe should be a minimum of ¾ inch in diameter.

The relief valve shall be located at the first point in the system that could be subject to full cylinder pressure if the regulator failed. No valve should be located between the relief valve and the regulator. The relief valve release point should be set to 50 percent over working pressure.

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

Manifold and Regulator Purge Devices

The replacement of cylinders introduces unwanted room air into the piping manifold assembly and the connecting cylinder pigtails. When maintaining a high purity level of the gas is necessary, purge valves are installed to run system gas through the contaminated parts of the system to replace all such air. The purge valve outlet should be vented outside the building. If the gas is suitable and low enough in volume and the storage room is large enough and well ventilated, it could discharge into the room since the purge volume used is generally quite small. The regulator often requires special purging techniques recommended by the manufacturer. Purge gas shall be taken from a dedicated source used only for this purpose and as illustrated in Figure 12-11.

Flow Measurement

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

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

Gas Warmers

On occasion, the gas in cylinders is withdrawn so fast that the regulator could freeze because of the change in temperature. If this occurs, an electrically heated gas warmer is available to be installed inline, and this warmer heats the gas out of the cylinder before it reaches the regulator. The rule of thumb is to consider a warmer if the use of gas exceeds 35 acfm. The actual figure should be based on the specific type of gas being used, so consult with the supplier. Carbon dioxide, for example, presents a particular problem.

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

Alarms

Alarms are necessary to alert the user to immediate or potential trouble. They could be visible and/or audible. The typical alarms are high system pressure, low system pressure, and reserve in use. In some installations, a normal light is also requested. If a single cylinder is the sole source of supply, an alarm might be installed when the pressure in the tank reaches 400 psig (2,757.9 kPa). Other alarms could be provided that will indicate high pressure loss at filters, low gas temperature, purifiers at limit of capacity, and flow limit valve operation.

These alarms are usually installed in an alarm panel, which can be mounted in the room where the gases are stored, in a constantly occupied location such as a maintenance shop or receptionist area, or in the laboratory itself, depending on the availability and level of maintenance. Often, multiple locations are desirable if a continued supply of gas is critical. Various devices must be placed in the system for these alarms to function, such as pressure switches, transducers, and auxiliary contacts in a manifold assembly to transmit the alarm signal to the alarm panel.

Toxic and Flammable Gas Monitors

If a toxic and/or flammable gas might accumulate in an enclosed area or room, a gas monitor must be installed to signal an alarm if the gas percentage rises above a predetermined limit that is considered harmful or dangerous. This should be 50 percent of either the lower flammability limit (LFL) or the level of concentration that may cause ill effects or

Table 12-7 Typical Laboratory Branch Sizing Chart

No. of Connections	Pipe Diameter, in.						
	Cold water, hot water	Air	Gas	Vacuum	Oxygen	D.W.	Nitrogen
1	½	½	½	½	½	½	½
2	¾	½	½	½	½	½	½
3	¾	½	½	¾	½	½	½
4	¾	½	½	¾	½	½	½
5	¾	½	¾	¾	½	¾	½
6	¾	½	¾	1	½	¾	½
7	1	½	¾	1	½	¾	½
8	1	½	¾	1	½	1	½
9	1	½	¾	1	½	1	½
10	1	½	¾	1	½	1	½
11–20	1¼	¾	1	1¼	¾	1	¾
21 and over	1½	1	1¼	1½	1 (21–30) 1¼ (31–50) 1½ (51 and over)	1	1

Note: 1 in. = 25.4 mm

Table 12-8 Recommended Air Compressor Inlet Pipe Size

Maximum scfm Free Air Capacity	Minimum Size, in.
50	2½
110	3
210	4
400	5
800	6

Note: 1 cfm = 0.03 m3/min
Source: James Church

breathing problems. The oxygen concentration of ambient air should never be allowed to fall below 19.5 percent. In addition, much lower levels should also be alarmed to indicate that a problem exists well before the evacuation of an area is required because of a leak. Refer back to Table 12-4 for the flammability limits of some of the more common gases. Request the MSDS for gases not listed.

Gas Mixers

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

Vibration Isolation

Vibration isolation is achieved by the proper selection of resilient devices between the pump base and the building structure. This isolation is accomplished by placing isolators between the pump and the floor, flexible connections on all piping from the compressor, and spring-type hangers on the piping around the compressor.

DISTRIBUTION NETWORK

System Pressure

Unless otherwise instructed, it is generally accepted practice to use a pressure of 50–55 psig (344.7–379.2 kPa) in the normal centralized piping distribution system, with a nominal 5-psig (34.5-kPa) loss in the system. High-pressure systems, if specifically requested by the end user or required by the laboratory equipment manufacturer, use a different pressure. Accepted practice limits the allowable friction loss in the piping system to 10 percent of initial pressure. These figures are not set in stone and should be adjusted for specific conditions or special systems when necessary. The most important consideration is the actual pressure required by the equipment being used. The maximum pressure set by a regulator should be 10 psi (69 kPa) above the minimum recommended by the manufacturer or end user.

Pipe Material Selection

Consider the following when selecting the pipe material and type for a specialty gas system:

- Compatibility with the specific gas used
- Capability of delivering the desired gas purity for the anticipated usage
- Pressure rating of the pipe and joining methods
- Temperature rating and the ability to be cleaned or sterilized in place
- Joining method

If all elements are equal, the least expensive piping shall be selected

Refer to the manufacturer or supplier of the gas for pipe compatibility. The pipe most often used to maintain the highest purity is grade 304L or 316L stainless steel tubing conforming to ASTM A270: *Standard Specification for Seamless and Welded Austenitic Stainless Steel Sanitary Tubing*. The interior should be electro-polished, and the exterior could be mill finished in concealed spaces. In exposed locations and where the pipe exterior will be sterilized or cleaned, the pipe exterior should have a No. 4 finish. Stainless steel pipe is capable of withstanding repeated sterilization by steam and a variety of chemicals. The pipe is joined by orbital welding, so the tube should have a minimum wall thickness of 0.65 inch to be welded. When welding is not required, a tube wall thickness of 0.28 inch is commonly used, but the wall thickness must be able to handle the working pressure of the system. The total installed cost often is less than that of copper tube.

When hard pipe is not desired or used from a cylinder or system to a movable instrument, it is common practice to use -inch (6-mm) polyethylene (PE), stainless steel, or copper tubing of sufficient pressure rating and compatibility with the specific gas, with no joints between the cylinder and instrument.

In many laboratory applications, maintaining ultra-high purity of a gas from the storage tank to the outlet is not an absolute requirement. For this type of service, copper tube and fittings that have been cleaned for oxygen service and joined by brazing and properly purged often are inexpensive and the material of choice. The following grades of copper pipe have been used:

- ASTM B88: *Standard Specification for Seamless Copper Water Tube*
- ASTM B819: *Standard Specification for Seamless Copper Tube for Medical Gas Systems*
- ASTM B280: *Standard Specification for Seamless Copper Tube for Air Conditioning and Refrigeration Field Service*
- ASTM B75: *Standard Specification for Seamless Copper Tube*

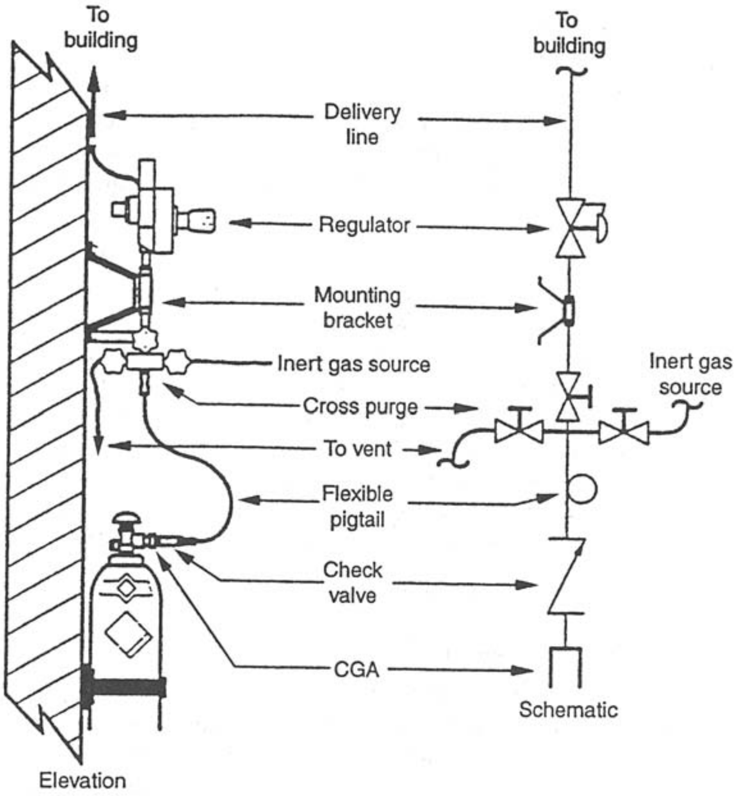


Figure 12-11 Typical Purging Arrangement

Another type of material for non-critical applications is aluminum tubing ASTM B210: *Standard Specification for Aluminum and Aluminum-Alloy Drawn Seamless Tubes,* alloy 6061, T4 or T6 temper. This pipe is commonly joined by patented flare joints.

The pipe pressure rating is selected to resist the highest system design pressure, which is usually in the range of 50–55 psig (344.7–379.2 kPa). Copper tubing type L is used for pressures up to 200 psig (1,379 kPa), and type K is used for pressures up to 300 psig (2,068.4 kPa). The pressures are lowered internally at the equipment if the supplied pressure is too great. Based on experience, the allowable pressure range is usually between 30 and 75 psig (206.8 and 517.1 kPa). Higher pressures in the 300 psig (2,068.4 kPa) range for special uses are well within the limits of piping with flared, orbital welded, and brazed joints. The allowable pressure ratings for the various piping materials at ambient temperatures based on wall thickness values are calculated from equations appearing in ASME B31.3: *Process Piping Design*.

The piping system also shall be capable of being cleaned and sterilized in place, often, if required. Cleaned in place (CIP) uses chemicals, so the pipe must be able to resist corrosion. Refer to the manufacturer's literature to establish compatibility. Steam in place (SIP) raises the distribution system to a high temperature that kills microbes. A drain for the system is often required. The piping system materials need to be steam compatible for the temperatures that may be experienced.

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

Experience has shown that reaming the ends of pipe or tubing to obtain a smooth interior has left pieces of shaved metal in the pipe. If this is a cause for concern, reaming methods and tools are available that eliminate this problem.

Joints

The joining method may be a criteria in the selection of pipe wall thickness or pipe material composition. The temper of the pipe may have to be carefully selected to use proprietary fittings.

The most often used joints for copper tubing are brazed. No flux is permitted, so only cast or wrought copper fittings should be used. The interior of the joint shall be purged with an inert gas, such as nitrogen type NF or argon. The reason for making up a joint in this manner is to eliminate any residue that may be produced as a by-product by the brazing process.

For stainless steel pipe, orbital welding leaves the smoothest interior surface, but it should be used only on tubing with a wall thickness of 0.65 inch or thicker. Another type of joint that can be used is the patented flared joint, which is preferable to solder or brazed joints that often leave a residue that contributes particulates into the gas stream. In addition, the flared joint is popular because it can be made up using only a saw and some wrenches. When copper tubing is used with flared joints, the pipe shall not have embossed identification stamped into the pipe because doing so causes leaks at the joint. There is no ASTM designation for patented flare joints, but they are acceptable for all applications as long as the allowable joint pressure ratings are not exceeded.

PIPE SIZING AND LAYOUT

Before laying out the piping system, the following information must be known:

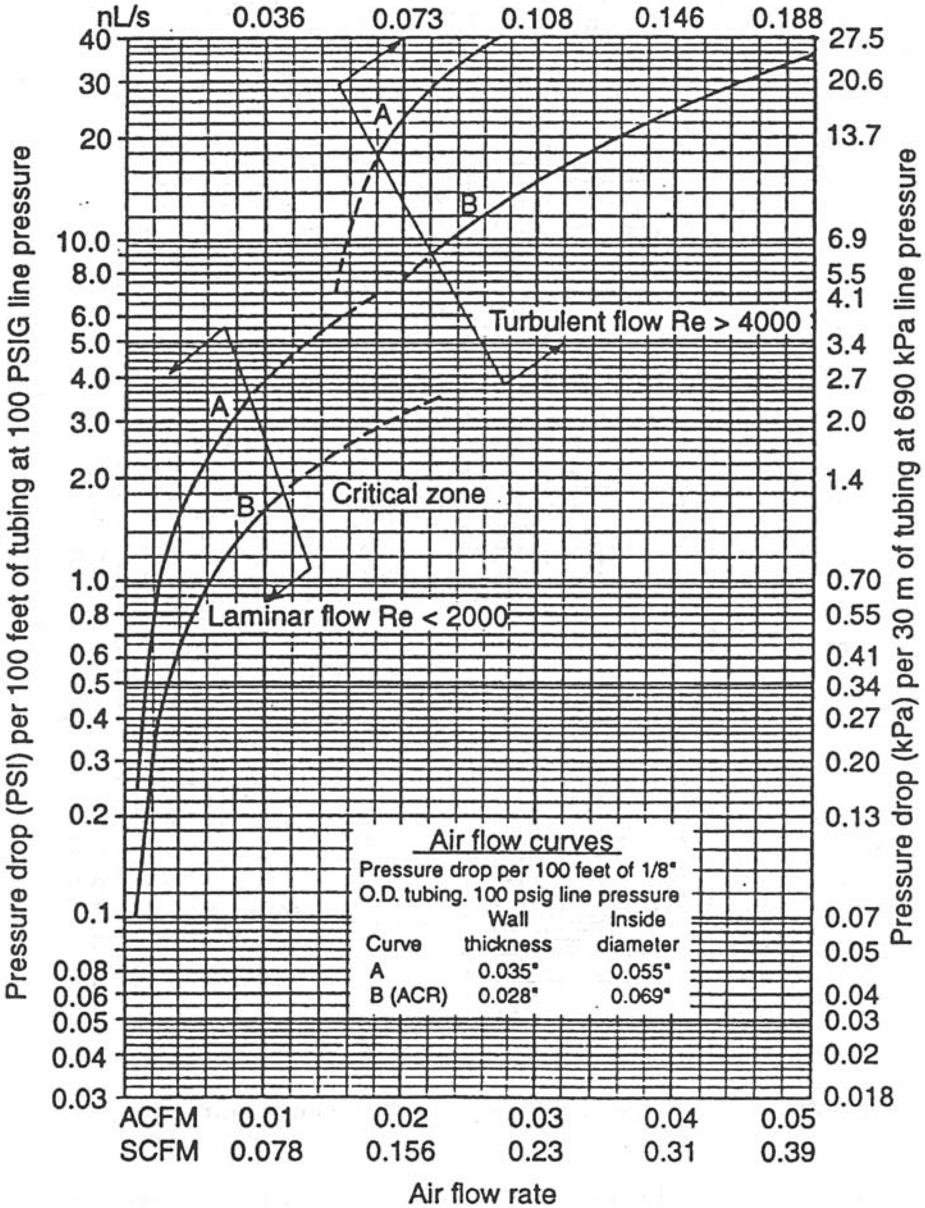


Figure 12-12 $^1/_8$-in. OD Tubing

- All air- or gas-consuming devices
- Minimum and maximum pressure requirements for each device
- Actual volume of air or gas used by each device
- Suggested duty cycle and diversity factor for equipment
- Special individual air or gas purification requirements

System Sizing Procedure

Following is a recommended system sizing procedure. It is not intended for compressed air in common laboratories. Refer to Chapter 9 for that information.

1. Locate the gas storage area and lay out the cylinders, manifolds, and so on.
2. Establish a general layout of the system from the storage area to the farthest outlet or use point. Measure the actual distance along the run of pipe to the most remote outlet. Next, add a fitting allowance. For ease of calculations, the addition of 50 percent of the actual measured run will give a conservative approximation of the entire system. Adding the measured length to the fitting allowance will result in the equivalent run of pipe.
3. Choose all of the filters, purifiers, and accessories necessary for system purity. This will establish a combined allowable pressure drop through each of them and the assembly as a whole.
4. Establish the actual pressure required at the farthest outlet.

5. Calculate the allowable total system friction loss.
   a. It is accepted practice for general use to have a minimum system pressure of 45 to 55 psig (310.3 to 379.2 kPa) and to allow 5 psig (34.5 kPa) as a pressure loss in the pipe. For high-pressure systems serving specific equipment or tools, start with the high end of the range for the actual pressure required. Accepted practice is to allow 10 percent of the proposed system pressure for pipe friction loss. So, for a 125-psig (861.8-kPa) system, a ±12-psig (82.7-kPa) friction loss will be allowed. This figure is variable. To that figure add the pressure required to overcome the drop through the filter-purifier-manifold assembly and other accessories.
   b. Divide the total equivalent run of pipe (in hundreds of feet) by the allowable friction loss to calculate the allowable friction loss in psig per 100 feet of pipe. This calculation is necessary to allow the use of the sizing chart provided in this chapter. If other methods are used to indicate friction loss in the piping system, calculate the loss in that specific method.
6. Calculate the connected flow rate for the piping to be sized. For general use, a figure of 1 scfm (30 nLpm) for each outlet unless the end user indicates otherwise. Calculate the scfm (nLpm) of gas through each branch, from the farthest outlet back to the source (or main). For specific equipment, use the flow rate recommended by the manufacturer.
7. Calculate the expected flow rate for all points using the appropriate diversity factor for all parts of the system. For specific equipment, the diversity factor must be obtained from the end user. The diversity (or simultaneous use) factor, which determines the maximum number of outlets in use at any one time, has a major influence on the sizing of the piping system. Specialty gas systems have no exact calculation method, so consultation with the end user is the best method and is strongly suggested.
8. The sizing chart, Table 12-5, has been calculated for a gas with a specific gravity of 1 (which is air), using type L copper pipe, and a pressure of 55 psig (379.2 kPa). This table also can be used for gases with a specific gravity ranging from 1.90 to 1.10. Slight differences are well within accepted accuracy. To find the specific gravity of many common gases, refer back to Table 12-4.

   With all the above information available, the pipe can now be sized. Starting from the most remote point on the branch and then proceeding to the main, calculate the actual flow rate using the appropriate diversity factor. Enter Table 12-5 with the actual flow rate and the allowable friction loss. Find the flow rate, and then read across to find a friction loss figure that is equal to or less than the allowable friction loss. Read up the column to find the size. In some cases, the diversity factor for the next highest range of outlets may result in a smaller-size pipe than the range calculated. If this occurs, do not reduce the size of the pipe; keep the larger size previously determined. For equipment using capillary piping and tubing, refer to Figure 12-12 for nominal -inch pipe.

   c. To calculate the specific gravity of any gas not covered in Table 12-4, divide the molecular weight of that gas by 29, which is the composite molecular weight of air.
   d. When any gas with a specific gravity other than 1 is used, an adjustment factor is provided in Table 12-6 that will convert scfm to the equivalent of any other gas or combination of gases for use in Table 12-5. Multiply the factor found in the table by the compressed air flow rate to obtain the new flow rate for the gas in question.
   e. For pressures other than 55 psig (379.2 kPa), use the following formula:

Equation 12-2

$$PD = \frac{P_1 + 14.7}{P_2 + 14.7} \times PD_r$$

For the flow of any compressed gas at temperatures other than 60°F (15.6°C), use the following formula to calculate a factor that, when multiplied by the flow rate, will give the flow rate at the new temperature:

Equation 12-3

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

where:

PD = New pressure drop, psig (kPa)
P_1 = 55 (referenced table pressure), psig (kPa)
P_2 = Actual service pressure, psig (kPa)
PD_r = Referenced pressure drop found in Table 12-5, psi/100 feet (kPa/30m)
t = Temperature under consideration, °F (°C)
f = Factor

Having calculated the scfm (nLpm) and the allowable friction loss in each section of the piping being sized, now size the piping using the charts for system pressure. Since all pipe sizing charts are formulated on the loss of pressure per some length of piping (usually 100 feet [30 m]), it will be necessary to arrive at the required value for the chart being used. A maximum velocity of 4,000 fpm (1,200 m/min) is recommended.

Another method, applicable only to branch lines with small numbers of laboratory outlets used for average purposes, is to use a prepared chart based on the number of outlets with the actual flow of gas not considered. The flow rate and diversity of use are taken into consideration in the sizing chart, which assumes that sufficient system pressure is available. With a small number of outlets on a branch, this method provides a sufficient degree of accuracy and speed of calculation. Table 12-7 is such a chart for various systems found in a typical laboratory.

COMPRESSOR INLET PIPING

Since air compressor performance depends on inlet conditions, this system deserves special care. The air intake should provide a supply of air to the compressor that is as clean, cool, and dry as possible. The proposed location should be studied for the presence of any type of airborne contamination and positioned to avoid the probability of a contaminated intake. Intake piping is discussed in Chapter 9. For sizing intake piping, refer to Table 12-8.

TESTS

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

Testing is done by pressurizing the system to the test pressure with an inert, oil-free, and dry gas. Nitrogen is often used because of its low cost and availability. The system test pressure for low-pressure systems is 150 percent over the working pressure. For systems with a working pressure up to 200 psig (1,379 kPa), the entire piping system, including the cylinder manifold, is tested to 300 psig (2,068.4 kPa) for one hour with no leakage permitted. If a working pressure higher than 200 psig (1,379 kPa) is required, the system is tested at 150 percent of the system pressure.

The pressure testing should be done in increments of 100 psig (689.5 kPa), starting with 100 psig. This is done to avoid damage due to a catastrophic failure. Leaks are repaired after each increment. After final testing, it is recommended that the piping be left pressurized at the system working pressure with system gas if practical.

FLUSHING, TESTING, AND PURGING THE DISTRIBUTION SYSTEM

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

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

To test for particulates, flow the gas into a clean white cloth at a minimum rate of 15 cfm (100 L/min) and inspect the cloth for contamination.

Finally, the system must be capable of providing the desired purity when actually placed in operation. Since flushing and testing may leave the piping system filled with inert or other gases, they must be removed, or purged. This is accomplished by allowing the system gas to flow through all parts of the piping system, opening all of the valves, and testing the gas purity at various points of the system until the desired purity level is reached. For high-purity gases, a laboratory specializing in testing for the purity level required shall be used unless the facility is capable of performing the test.

It is often best to use the system gas for testing purposes.

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