CHAPTER 13
FUEL GAS SYSTEMS

The fuel gas system delivers gas to provide light or heat energy in sufficient volume and pressure as required for the satisfactory operation of all connected devices and for all purposes. This chapter will discuss natural gas and propane only.

FUEL GAS DESCRIPTION

There are many gases used as a fuel gas. Where easily and cheaply available, two major fuel gases, natural gas (NG) and liquefied petroleum gas (LPG), are preferred. Other gases are used because of availability. Refer to Table 13.1 for the physical and combustion properties of the fuel gases most commonly available throughout the world.

NG and LPG are hydrocarbon compounds obtained from the separation of gas mixtures occurring naturally at the wellhead of crude oil or gas producing wells or as a by-product of the oil refining process. NG is primarily composed of methane with minor percentages of other gases that result in variations in heating content. *LPG* is a term applied to a group of hydrocarbons such as propane, butane, isobutane, and pentane or to various mixtures of each. Propane and butane are the principal constituents of LPG, with propane the most common. Table 13.2 lists the physical properties of NG and propane. Since NG and LPG are odorless, an odorant is added to make detection of the gas possible.

There are variations in the hydrocarbon mixtures that produce variations in specific gravities and British thermal unit contents of NG and LPG obtained from various suppliers. The values presented here are average values and sufficiently accurate for the design of these systems. It is recommended that an analysis of the products actually furnished by the supplier for each specific project be obtained if extreme precision is required.

CODES AND STANDARDS

There are a number of codes and standards governing the manufacture, design, installation, and testing of LPG and NG systems, piping, and components. The principal codes, standards, and regulations are as follows:

TABLE 13.1 Physical and Combustion Properties of Commonly Available Fuel Gases

Name of gas	Heating value: Btu/cu ft[1] Gross	Heating value: Btu/cu ft[1] Net	Heating value: Btu/lb[2] Gross	Heating value: Btu/lb[2] Net	Heat release, Btu[3] Per cu ft air	Heat release, Btu[3] Per lb air	Specific gravity	Density, lb per cu ft	Specific volume cu ft/lb
1. Acetylene	1498	1447	21,569	20,837	125.8	1677	0.91	.07	14.4
2. Blast Furnace Gas	92	92	1178	1178	135.3	1804	1.02	.078	12.8
3. Butane	3225	2977	21,640	19,976	105.8	1411	1.95	.149	6.71
4. Butylene (Butene)	3077	2876	20,780	19,420	107.6	1435	1.94	.148	6.74
5. Carbon Monoxide	323	323	4368	4368	135.7	1809	0.97	.074	13.5
6. Carburetted Water Gas	550	508	11,440	10,566	119.6	1595	0.63	.048	20.8
7. Coke Oven Gas	574	514	17,048	15,266	115.0	1533	0.44	.034	29.7
8. Digester (Sewage) Gas	690	621	11,316	10,184	107.6	1407	0.80	.062	16.3
9. Ethane	1783	1630	22,198	20,295	106.9	1425	1.06	.060	12.5
10. Hydrogen	325	275	61,084	51,628	136.6	1821	0.07	.0054	186.9
11. Methane	1011	910	23,811	21,433	106.1	1415	0.55	.042	23.8
12. Natural (Birmingham, AL)	1002	904	21,844	19,707	106.5	1420	0.60	.046	21.8
13. Natural (Pittsburgh, PA)	1129	1021	24,161	21,849	106.7	1423	0.61	.047	21.4
14. Natural (Los Angeles, CA)	1073	971	20,065	18,158	106.8	1424	0.70	.054	18.7
15. Natural (Kansas City, MO)	974	879	20,259	18,283	106.7	1423	0.63	.048	20.8
16. Natural (Groningen, Netherlands)	941	849	19,599	17,678	111.9	1492	0.64	.048	20.7
17. Natural (Midlands Grid, U.K.)	1035	902	22,500	19,609	105.6	1408	0.61	.046	21.8
18. Producer (Wellman-Galusha)	167	156	2650	2476	128.5	1713	0.84	.065	15.4
19. Propane	2572	2365	21,500	19,770	108	1440	1.52	.116	8.61
20. Propylene (Propene	2332	2181	20,990	19,630	108.8	1451	1.45	.111	9.02
21. Sasol (South Africa)	500	443	14,550	13,016	116.3	1551	0.42	.032	31.3
22. Water Gas (bituminous)	261	239	4881	4469	129.9	1732	0.71	.054	18.7

[1] 1 cu ft = 0.0283 m^3
[2] 1 lb = 0.453 kg
[3] 1 BTU = 0.252 kCal

TABLE 13.2 Average Physical Properties of Natural Gas and Propane

	Propane	Natural gas (methane)
Formula	C_3H_8	CH_4
Molecular weight	44.097	16.402
Melting (or freezing) point, °F	−305.84	−300.54
Boiling point, °F	−44	−258.70
Specific gravity of gas (air = 1.00)	1.52	0.60
Specific gravity of liquid 60°F/60°F (water = 1.00)	0.588	0.30
Latent heat of vaporization at normal boiling point, Btu/lb	183	245
Vapor pressure, lb/in^2, gauge at 60°F	92	
Pounds per gallon of liquid at 60°F	4.24	2.51
Gallons per pound of liquid at 60°F	0.237	
Btu per pound of gas (gross)	21591	23000
Btu per ft^3 gas at 60°F and 30 in mercury	2516	1050 ±
Btu per gallon of gas at 60°F	91547	
Cubic feet of gas (60°F, 30 in Hg)/gal of liquid	36.39	59.0
Cubic feet of gas (60°F, 30 in Hg)/lb of liquid	8.58	23.6
Cubic feet of air required to burn 1 ft^3 gas	23.87	9.53
Flame temperature, °F	3595	3416
Octane number (isooctane = 100)	125	
Flammability limit in air, upper	9.50	15.0
Flammability limit in air, lower	2.87	5.0

1 in. Hg = 3.37 kPa
60°F = 15.6°C
1 lb = 2.2 kg
1 L^3 = 4.5 L
1 cu ft = .03 m^3

ANSI/NFPA 30, Flammable and Combustible Liquids Code

ANSI/NFPA 54, National Gas Code

ANSI/NFPA 58, Standard for the Storage and Handling of Liquefied Petroleum Gases

ANSI Z83.3, Standard for Gas Utilization Equipment in Large Boilers

ANSI/UL 144, Pressure Regulating Valves for LP Gas

American Gas Association (AGA) codes and standards

Local utility company rules and regulations

Some insurance carriers, such as Factory Mutual and Industrial Risk Insurers, have standards that in many aspects may be more stringent than those listed above.

SYSTEM OPERATING PRESSURES

The maximum allowable system operating pressure of fuel gas when installed inside a building is governed by NFPA 54, unless local codes or insurance carriers have more stringent requirements. NG systems are not permitted to exceed 5 psig unless all of the following conditions are met:

1. Local authorities permit a higher pressure.

2. All piping is welded.

3. The pipe runs are enclosed for protection or located in a well-ventilated space that will not permit gas to accumulate.

4. The pipe is run inside buildings or areas used only for industrial processes or research or for warehouses or boiler and/or mechanical equipment rooms.

LPG pressures of up to 20 psig are permitted only if all of the following conditions are met:

1. The building is used exclusively for industrial or research purposes.

2. The building is constructed in accordance with NFPA 58, Chap. 7.

NATURAL GAS

GENERAL

Natural gas is usually obtained from a franchised public utility obligated to provide gas to every customer that requests this service. As part of this service, the utility company usually supplies and installs the service line free of charge from the utility main, in addition to providing a regulator-meter assembly in or adjacent to the building.

If the utility company has an existing main in the vicinity of the project—which is most often the case—then the initial start-up cost is fairly low. Sometimes, however, an installation fee is charged if the utility company regulations concerning the time of payback from expected revenue does not justify the cost of installing the service. The same might be true if the use of gas for a commercial or industrial facility is considered too little. It would then be the responsibility of the owner to pay for the design and installation of the complete site service and meter assembly in conformity with utility company regulations.

There are several different types of service that a utility company may provide, each with a different cost (or rate). Specific types of service may be unavailable or known by different names in various localities. They are:

1. *Firm service.* This type of service provides a constant supply of gas under all conditions without exception. This service has the highest rate.
2. *Interruptible service.* This type of service allows the utility company to stop the gas supply to the facility under predetermined conditions, and then to start it again when these conditions no longer exist. The most common condition usually occurs when the outside temperature falls below a certain point. The rate is lower than for firm gas, and users with this service will require a backup source of fuel, such as fuel oil or LPG.
3. *Light or heavy process service.* This type of service is provided for industrial or process use and is reserved for quantities of gas that the utility companies define for this class of service.
4. *Commercial or industrial service.* This type of service is provided for heating and cooling system loads for this class of building usage.
5. *Transportation gas service.* This service is purchased directly from a company other than the public utility, with the gas actually carried to the site by the utility company mains. In addition to the cost of the gas, the utility company will also charge an additional fee for this service. This type of service is always available.

The following criteria and information should be obtained in writing from the public utility company:

1. The British thermal unit content of the gas provided
2. The minimum pressure of the gas at the outlet of the meter
3. The extent of the installation work done by the utility company and the point of connection by the facility construction contractor
4. The location of the utility supply main and the proposed run of pipe on the site by the utility company

5. The acceptable location of the meter and/or regulator assembly and any work required by the owner to allow the assembly to be installed (such as having a meter pit dug or a slab installed on grade)
6. The types of service available and the cost of each

In order for the utility company to provide this data, they require that the following information be provided to them:

1. The total connected load. The utility will use their own diversity factor to calculate the size of the service line. If the design engineer is responsible for the installation, this information is not required since the diversity factor for the facility shall be used.
2. The minimum and maximum pressure requirements for the most demanding device.
3. The site plan indicating the location of the proposed building on the site and the specific area of the building where the proposed NG service will enter the building.
4. Preferred location of the meter-regulator assembly.
5. Expected date for the start of construction.

MAJOR NATURAL GAS SYSTEM COMPONENTS

Drip Pots

Drip pots are necessary to remove water that is in the mains from reaching the building. Modern technology has reduced, but not eliminated, the presence of moisture in the utility company mains. Each utility company has standard methods of installing drip pots depending upon pressure in the main.

Gas Line Filters

Filters for natural gas are installed on the site service to protect the regulator and meter from injury due to particulate clogging, which may damage the equipment inside the building. They should be considered when:

1. Line scale, dirt or rust is known to be present
2. Dirty gas is obtained from a transmission company
3. ‘‘Wet’’ gas is known to be present, such as after large PRVs

The filter consists of a housing and a cartage filter element. Selection of the housing is based on the highest flow rate and pressure expected and the size of the proposed building service. The housing should be capable of having interchangeable elements to allow replacing the original filter if desired. Having a filter oversized is considered good practice since this allows a longer service life if the cost of the larger size is not excessive.

The filter element is usually cellulose or synthetic fiber. Generally, the cellulose type is used for sizes 3 in and less and fiber 4 in and larger. Fiber is stronger and should be considered where the pressure differential may be excessive when recommended by the manufacturer. A filter rating of 10 microns is suggested as a starting point, with actual operating experience being the final criteria.

The size of the filter is based on ACFM and velocity across the filter. The pressure drop across the filter when dirty shall be considered in the actual pressure loss allowed for the service assembly. Since the filter should be changed when the pressure difference approaches 10 percent of the operating pressure, it is good practice to provide pressure gauges on both sides of the filter. If no filter is installed on the service, a spool piece should be provided if there is a possibility that one may be required. Most filters are mounted horizontally.

Gas Meters

Gas meters are part of a service assembly that may consist of filters, valves, regulators and relief valves. The complete assembly is usually supplied and installed by the utility company. For the rare instances where this is not the case, gas meters are selected using the local utility company standards with the size and arrangement of the entire meter assembly based on flow rate and pressure. Because steady pressure is necessary for accurate metering, a regulator is installed upstream of the meter. The utility company will provide sketches and details, with space requirements, of typical meter assemblies for various capacities and pressures. This will permit accurate determination of the dimensional and space requirements for the area where the complete assembly will be installed. Obtain from the utility company all requirements for the specific installation under design.

A contractor other than the utility company will be responsible for providing a pit for the assembly or a concrete slab under the complete meter assembly when installed outside the building. This will include meter slab size for outdoor meter installations and pit sizes and access openings for meters installed in pits. Additional requirements will usually be a weatherproof telephone outlet and a 120 V electrical outlet at the meter site. Facilities with large demands for boilers and other equipment, a meter assembly with dimensions of 6 ft (2 m) wide by 25 ft (8 m) long is not uncommon.

Generally, if the contractor is installing the site service, the utility company will either supply the meter or install the entire assembly at no charge. This must be confirmed.

Requirements of various utility companies differ regarding the placement of the meter assembly. It could be installed either in an underground, exterior meter pit, at an above ground exterior location exposed to the weather, or inside the building in a well ventilated area or mechanical equipment room.

Pressure Regulators

Gas pressure regulators are pressure reducing devices used to reduce a variable high inlet pressure to a constant lower outlet pressure. Two types of regulators are available: direct acting and pilot operated. The direct operated type uses the difference of pressure between the high and regulated side of the regulator to directly move a closure (adjusting) member inside the regulator to adjust the pressure. The pilot operated type uses a primary regulator to sense and magnify differences in pressure of the high and low pressure sides and a second, main valve with the closure member to achieve the desired pressure.

There are several categories of regulators, with the end use determining the nomenclature. The first is the line regulator, which is used to reduce high pressure, often in a range of between 25–50 psig (170–345 kPa), from the gas service provided by the utility company to a lower pressure used for the building service. An intermediate regulator is used to reduce the lower pressure, often in the range of 3–5 psig (21–35 kPa) to a pressure required to supply terminal equipment such as a boiler gas train. The third type is an appliance regulator used at the individual piece of equipment for final pressure.

The line regulator is usually pilot operated and provided with an internal or external relief valve. The regulator is pressure rated to withstand the highest pressure expected. The relief valve is installed downstream from the regulator and is set to trip at a pressure of about 10% higher than the highest set pressure. The line regulator is placed upstream from the meter in order to provide the meter with a constant pressure, allowing accurate measurement. This line pressure regulator is most often selected and installed by the utility company as part of the gas meter assembly.

An intermediate regulator is used within a facility where high pressure used for distribution purposes must be reduced to a lower pressure required by the terminal appliances. There are two types of intermediate regulators used, and the choice is determined by the accuracy desired and the ability to install a relief valve and associated gas vent discharge. One type of regulator has an internal relief valve set to discharge when the pressure rises above the set point. This has the least initial cost and least accuracy. Another type of intermediate regulation, called a monitor type, consists of two pilot operated regulators and does not require a relief valve. They can be installed in two configurations, both of which use regulators in series. The first uses the upstream regulator to initially reduce the inlet pressure to some intermediate value and the downstream regulator to further reduce the pressure to the final set point. This arrangement puts less stress on each of the regulators. The second configuration uses the upstream regulator wide open and the downstream regulator to do all of the pressure reducing. If the gas pressure goes above the set point, the upstream regulator closes to partially lower the pressure. This installation has a high initial cost but must be used where a relief valve cannot be installed. The intermediate type regulator arrangement is the most often used.

The appliance regulator is used to control the pressure of gas directly connected to the terminal appliance or equipment. The appliance regulator is most often provided by the manufacturer as part of the equipment gas train. The gas train is an assembly of piping, valves, regulators, relief vents, etc. used to directly connect the gas supply to the terminal equipment. For larger pieces of equipment such as boilers, etc., the gas train arrangement is dictated by insurance carrier requirements. An additional requirement of most gas trains are small relief vents from various devices. These vents must be piped outside the building to a point where they can be diluted by the outside air and will pose no threat to the public or create a fire hazard. This is usually above a roof or the highest point of the structure.

Another type of appliance regulator is called an atmospheric regulator or a zero governor. This type of regulator is a very sensitive type that works with a very low gas pressure and extremely small differentials.

A differential regulator is a multiple port type that is used to produce a single, uniform outlet pressure when supplied with multiple inlets of different pressures.

A backpressure regulator is a regulator arranged to provide accurate inlet pressure control. It is used as a relief valve where the application requires a higher degree of regulation and sensitivity than possible with a standard poppet type relief valve. When operating as a relief valve it limits inlet pressure to a set point. At pressures below this point, it remains closed. If the pressure rises above the set point, it begins to open and will bleed off only enough pressure to maintain the system set point.

A piped gas vent must be provided from regulators to a point several feet above the roof of any adjacent structure, and it must be properly sized to carry the amount of gas that will be discharged. This is to protect the system from overpressure in the event of a malfunction or failure to fully lockup. Each individual regulator vent must be separately carried to a non-hazardous location away from any potential source of ignition. Common vent lines are not permitted.

Regulator Selection Considerations

It is common practice to oversize the capacity of a regulator by about 15% to provide a margin for accurate regulation.

For large loads, regulators in parallel are often used to keep the pressure drop to a minimum.

The adjustment range of a regulator should be approximately 50% over the desired regulated pressure to 50% under that pressure.

The utility company may require that regulators be of the "lockout" type. This feature will stop regulator operation when the pressure falls below a predetermined set point.

SITE DISTRIBUTION

The site distribution portion of the system starts at the property line of the customer and usually ends above grade (or the concrete pad) at the valve after the meter. The connection to the utility company mains are done by the utility company.

The most often used piping material is High Density Polyethylene (HEPE). The rating for pipe 4 in and smaller should be SDR 11, and for 5 in and larger SDR 13.5. The pipe shall be buried a minimum of 3 ft below ground and a 14 AWG corrosion resistant tracer wire placed in the pipe trench in over the pipe. Another detection method is to put a warning tape containing metallic material with the words "Natural Gas" on it. This is to allow location by a metal detector and to warn of the gas line immediately below the tape if digging has taken place without trying to locate the pipe beforehand.

The pipe above ground shall be metal; therefore, a transition fitting is required if HDPE is used for the supply service. The transition fitting shall comply with ASTM D-2513. Refer to Fig. 13.4.

Testing and Purging

After installation of the pipe is complete, the site system shall be tested, purged of air and then filled with natural gas. The testing phase shall be done with compressed air at a gauge pressure 50% higher than the highest pressure expected in the main. The larger the total volume of the pipe, the longer the test shall last. No loss of pressure shall be allowed. The test period is based on the size of the line and the length of run. Table 13.3 gives the recommended test periods.

TABLE 13.3 Maximum Length Of Pipe Being Tested (ft) Mains To Operate At Less Than 125 PSIG
Test Duration (Hours)

Main size	2 hrs.	3 hrs.	4 hrs.	6 hrs.	8 hrs.	10 hrs.	12 hrs.	14 hrs.	16 hrs.	18 hrs.	20 hrs.	22 hrs.	24 hrs.
1″ or less	6590	11000	15400	24200									
2″													
3″	1700	2830	3960	6220	8490								
4″	743	1240	1730	2730	3720	4710	5700						
6″	439	732	1030	1610	2200	2780	3370	3960	4540	5130			
8″	189	315	442	694	947	1200	1450	1710	1960	2210	2460	2730	2970
12″	108	180	252	396	541	685	829	973	1120	1260	1410	1550	1700
14″	48	80	112	177	241	306	370	435	499	563	628	692	757
16″	41	68	96	151	206	261	316	371	426	482	537	592	647
20″	30	50	70	110	150	191	231	271	311	352	392	432	472
24″	19	31	44	69	95	120	146	171	197	222	247	273	298
	13	21	30	48	65	83	100	118	135	153	170	188	205

After successful testing, the line shall be purged of air with dry nitrogen. The reason for this is to prevent a flammable mixture of gas and air when the pipe is filled with natural gas for the first time. Calculate the volume of the piping and introduce an equal volume of nitrogen into the pipe. After the nitrogen purge, natural gas is then introduced until the nitrogen is displaced and left under pressure.

SITE SERVICE SIZING PROCEDURE

Pressure Required

The pressure in the main provided by the utility company and the flow rate is the basis for design. The line is sized using proprietary charts for the specific pressure in the gas main. If these charts are not available, compressed air friction loss tables, using a table having the actual pressure in the gas service main, can be use with adjustment to the flow rate calculated with eq. 1. This will provide sizing within a range acceptable for this system. The pressure drop selected is at the discretion of the design professional, but is generally kept to approximately 10% of the available pressure in psig. To use the pressure loss tables, calculate the pressure drop per 100 ft of pipe.

If the design engineer is responsible for sizing the meter and regulator, the following information must be calculated or established.

1. The adjusted maximum flow rate, in CFM, for all connected equipment in the facility. Typical BTU values for equipment are given in Table 13.8. CFH demand for multiple dwellings are given in Fig. 13.1 (for 50 pts and less) and Fig. 13.2 for more than 50 apts.

2. The highest pressure required for the most demanding equipment inside the building.

3. The pressure in the building service main upstream immediately downstream of the regulator. If a pressure loss through a filter is expected, this will reduce the pressure.

4. The allowable pressure loss for the piping system inside the facility.

5. The pressure differential between the service main pressure and the pressure required inside the building. This is the sum of items 2 and 4 subtracted from item 3.

6. The regulator and meter can now be sized using literature and catalog information from the manufacturers.

Maximum Probable Demand

For some types of buildings, such as multiple dwellings and laboratories, the total connected load is not used to size the piping system since not all of the connected devices will be used at the same time. For design purposes, it will be necessary to apply a diversity factor to reduce the total connected load when calculating the maximum probable demand.

This calculation first requires the listing of every device using gas in the building and the demand in BTU/h for each. The manufacturer of each device should be

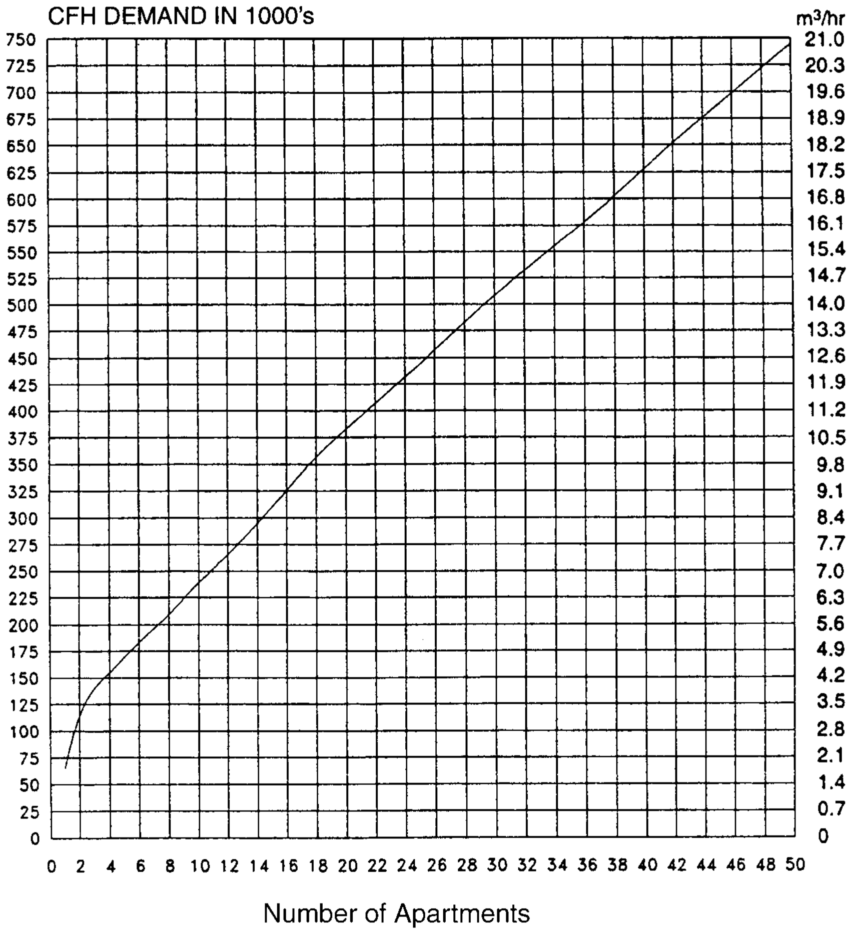


FIGURE 13.1 Gas demand for multiple-unit dwellings with less than 50 apartments.

consulted to find its actual input gas consumption. Average gas demand values for typical devices are listed in Table 13.8.

For multiple dwellings, a direct reading of the quantity of gas based on the number of apartments is presented in Fig. 13.1 for buildings up to 50 apartments and Fig. 13.2 for buildings with more than 50 apartments. A diversity factor has been included in creation of the chart. For laboratories, use a figure of 5 cfh based on the use of Bunsen burners. Refer to Table 13.9 for diversity factors. Where laboratories are part of a school, use no diversity for entire rooms, and consult with the school authorities to find the total number of rooms that might be in use at once. If there is no conclusive answer, use no diversity. Demand for trailer parks is given in Table 13.10.

For industrial or process installations, and for major gas using equipment such as boilers and water heaters in all building types, no diversity factor is used because

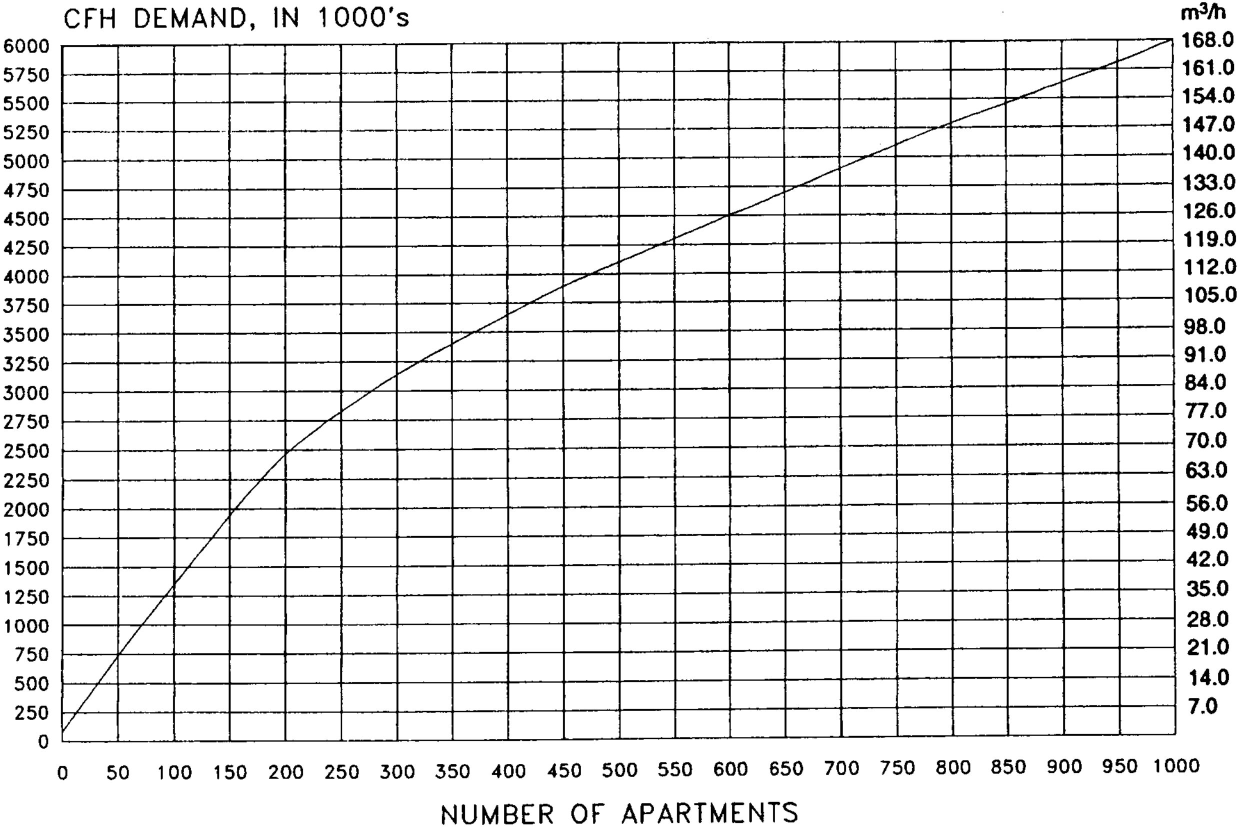


FIGURE 13.2 Gas demand for multiple-unit dwellings with more than 50 apartments.

it is possible for all connected equipment of this nature to be in use at the same time.

NG SITE SERVICE PIPE SIZING METHODS

The most conservative method for sizing NG piping systems is by the use of tables, such as those prepared by the American Society of Plumbing Engineers (ASPE). Calculators are also available. The calculators are considered more accurate than the prepared tables.

Tables are provided that will allow sizing for a majority of systems. Table 13.4 is for a pressure of 10 psig, Table 13.5 is for a pressure of 20 psig, and Table 13.6 is for a pressure of 50 psi. If higher pressure in encountered, the use of compressed air tables can be used for sizing, reducing the flow rate based on a factor found in Table 13.12 using the specific gravity of air, which is 1.00. Table 13.13 gives the conversion of various low gas pressure designations.

Using the correct chart with the system inlet pressure and the total system pressure drop, find the lowest SCFH figure that equals or exceeds the calculated CFH. Read the size in the correct column. Calculate the equivalent run of pipe from the outlet of the meter or regulator (or point of connection) to the furthest point of use. THIS IS THE ONLY DISTANCE USED. Find the pipe size at the intersection of the above distance column with a CFH figure that equals or exceeds the calculated CFH figure at each design point. Branches are sized using the same distance column but with the CFH figure from the branch to connection with the main.

PIPE AND SYSTEM MATERIALS FOR SITE INSTALLATION

All of the piping materials must be listed in NFPA 54 and other applicable codes. In addition to the codes, the recommendation of the utility company, which has experience in the area of the project, should be considered. The most often used material for underground lines is high density Polyethylene (PE). Larger lines and piping for high pressure (over 100 psig) are steel pipe protected against corrosion by wrapping with a plastic coating.

Codes do not permit plastic pipe to be run above ground. For above ground lines, the piping and jointing methods depend on pipe size and system pressure. For piping up to 3 psig (21 kPa), black steel, ASTM A-53 pipe is used with cast or malleable iron screwed fittings in sizes 3 in (75 mm) and smaller and butt welded joints 4 in (100 mm) and larger. Where natural gas is considered ‘‘dry gas,’’ type ‘‘L’’ copper pipe is finding widespread use. All piping for pressures over 3 psig (21 kPa) shall be steel with welded joints. Welded fittings shall conform to ANSI 16.9. Screwed fittings shall be black malleable iron, 150 lb class conforming to ANSI A-197. Check valves shall be cast iron, 316 SS trim, disk type, with a soft seat. In sizes 3 in and smaller use screwed joints. Larger sizes shall be flanged.

Joints for HDPE should be butt type, heat fused joints. Socket type joints have been found to introduce a stiffness in the joint area that is undesirable. Joints for steel pipe shall be screwed for pipe sizes 4 in (100 mm) and smaller. Sizes 5 in (125 mm) and larger should be welded. Where flanged connections are necessary to connect some devices, flanges are heat welded to the HDPE pipe end.

TABLE 13.4 Gas Pipe Sizing, Initial Gas Pressure 10 psig, 1 psig Pressure Loss Capacity of Horizontal Gas Piping (cfh)

Length (ft)	Nominal actual	0.50 0.622	0.75 0.824	1 1.049	1.25 1.380	1.5 1.610	2 2.067	2.5 2.469	3 3.068	3.5 3.548	4 4.026	5 5.047	6 6.065
10		1023	2164	4120	8561	12,914	25,256	40,388	72,079	106,206	148,773	271,820	443,686
20		723	1531	2913	6047	9131	17,780	28,559	50,967	75,164	105,198	191,580	313,733
25		647	1369	2606	5415	8168	15,902	25,543	45,586	67,171	94,093	171,915	280,605
30		590	1293	2379	4943	7456	14,517	23,318	41,615	61,318	85,894	156,936	256,162
35		546	1157	2202	4576	6903	13,440	21,588	38,528	56,770	79,523	145,294	237,411
40		511	1082	2060	4281	6457	12,572	20,194	36,040	53,103	74,386	135,910	221,843
45		482	1020	1942	4036	6088	11,853	19,039	33,978	50,066	70,132	128,137	209,156
50		457	968	1843	3829	5776	11,245	18,062	32,260	47,497	66,533	121,562	198,422
60		417	883	1682	3475	5272	10,265	16,488	29,426	43,358	60,736	110,970	181,133
70		387	818	1558	3236	4881	9503	15,265	27,243	40,142	56,231	102,739	167,698
80		362	765	1457	3027	4566	8889	14,279	25,483	37,550	52,599	96,103	156,868
90		341	721	1373	2854	4304	8381	13,462	24,026	35,401	49,590	90,607	147,895
100		323	684	1303	2707	4084	7952	12,772	22,793	33,585	47,542	85,957	140,306
125		289	612	1165	2422	3653	7112	11,423	20,387	30,040	42,080	76,882	125,493
150		264	559	1063	2210	3334	6492	10,428	18,611	27,422	38,413	70,184	114,559
200		228	484	921	1914	2888	5622	9031	16,117	23,746	33,266	60,780	99,211
300		187	395	752	1563	2358	4591	7374	13,160	19,390	27,162	49,628	81,006
400		162	342	652	1353	2042	3975	6348	11,397	16,793	23,523	42,979	70,153
500		145	306	583	1210	1826	3556	5712	10,193	15,020	21,039	38,441	62,747
1,000		102	216	412	856	1291	2514	4039	7208	10,620	14,877	27,182	44,368
1,500		82	177	336	699	1054	2053	3298	5885	8671	12,148	22,194	36,227
2,000		72	153	291	605	913	1778	2856	5160	7510	10,519	19,221	31,373

TABLE 13.5 Gas Pipe Sizing, Initial Gas Pressure 20 psig, 2 psig Pressure Loss Capacity of Horizontal Gas Piping (cfh)

	Pipe diameter (in.)												
Length (ft)	Nominal actual	0.50 0.622	0.75 0.824	1 1.049	1.25 1.380	1.5 1.610	2 2.067	2.5 2.469	3 3.068	3.5 3.548	4 4.026	5 5.047	6 6.065
10		2040	4329	8240	17,121	25,820	50,285	80,771	144,079	212,400	247,753	543,611	887,323
20		1446	3060	5826	12,332	18,262	35,556	57,113	101,929	150,190	210,385	384,391	629,684
25		1293	2738	5211	10,828	16,334	31,803	51,084	91,168	134,334	188,174	343,810	561,192
30		1180	2499	4757	9885	14,911	29,032	46,633	83,225	122,630	171,779	313,854	512,296
35		1093	2314	4404	9150	13,791	26,878	43,174	77,051	113,532	159,035	290,572	474,294
40		1022	2165	4120	8561	12,913	25,143	40,385	72,674	106,200	148,764	271,806	443,662
45		964	2040	3885	8071	12,175	23,705	38,075	67,953	100,127	140,257	256,260	418,288
50		915	1936	3685	7657	11,550	22,488	36,122	64,466	94,988	133,059	243,110	396,823
60		835	1767	3340	6990	10,544	20,529	32,974	58,848	86,712	121,466	221,928	362,248
70		773	1636	3114	6471	9761	19,006	30,528	54,483	80,276	112,455	205,466	335,377
80		723	1530	2913	6053	9131	17,779	28,556	50,964	75,095	105,193	192,196	313,716
90		682	1443	2746	5707	8609	16,761	26,924	48,050	70,794	99,176	182,750	294,774
100		646	1369	2606	5414	8167	15,902	25,670	45,584	67,167	94,087	171,905	280,596
125		578	1224	2331	4843	7305	14,223	22,845	40,770	60,076	84,153	153,756	250,973
150		528	1118	2128	4421	6668	12,110	20,855	37,219	54,842	76,822	140,360	229,106
200		457	968	1843	3828	5775	11,244	18,061	32,232	47,494	66,529	121,555	198,411
300		374	790	1504	3126	4715	9181	14,747	26,318	38,779	54,322	99,299	162,002
400		324	685	1303	2707	4083	7950	12,771	22,792	33,583	47,043	85,952	140,299
500		289	612	1141	2421	3653	7111	11,423	20,386	30,038	42,077	76,878	125,487
1,000		204	433	824	1712	2583	5028	8076	14,415	21,240	29,753	54,361	88,732
1,500		166	354	673	1398	2109	4106	6595	11,770	17,342	24,293	44,385	72,449
2,000		145	306	583	1210	1826	3557	5712	10,193	15,018	21,039	38,439	62,743

TABLE 13.6 Sizing, NG Pipe with Initial Pressure of 50 psig and 5 psig Pressure Drop

	Capacity of horizontal gas piping (CFH)											
	Pipe diameter (in.)											
Length (ft)	Nominal actual	0.5 0.622	0.75 0.824	1 1.049	1.25 1.380	1.5 1.610	2 2.067	2.5 2.469	3 3.068	3.5 3.548	4 4.026	5 5.047	6 6.065
10		5,850	12,384	23,575	48,984	73,889	143,864	231,083	412,407	607,670	851,220	1,555,251	2,538,598
20		4,137	8,757	16,670	34,637	52,248	101,727	163,400	291,616	429,688	601,903	1,099,729	1,795,060
25		3,700	7,832	14,910	30,980	46,732	90,988	146,150	260,829	384,324	538,359	983,627	1,465,660
30		3,377	7,150	13,611	28,281	42,660	83,060	133,416	238,103	350,839	491,452	897,925	1,356,938
35		3,127	6,619	12,601	26,183	39,495	76,899	123,519	220,441	324,813	454,996	831,317	1,356,938
40		2,925	6,192	11,787	24,492	36,945	71,932	115,541	206,203	303,835	425,610	777,626	1,269,299
45		2,758	5,838	11,113	23,091	34,832	67,818	108,934	194,411	286,459	401,269	733,152	1,196,706
50		2,616	5,538	10,543	21,906	33,044	64,338	103,343	184,434	271,758	380,677	695,529	1,135,295
60		2,388	5,056	9,624	19,998	30,165	58,732	94,339	168,364	248,080	347,509	634,929	1,036,378
70		2,211	4,681	8,910	18,514	27,927	54,376	87,341	155,875	229,678	321,731	587,830	959,500
80		2,068	4,378	8,335	17,319	26,124	50,864	81,700	145,808	214,844	300,952	549,864	897,530
90		1,950	4,128	7,858	16,328	24,630	47,955	77,028	137,469	202,557	283,740	518,417	846,199
100		1,850	3,916	7,456	15,490	23,366	45,494	73,075	130,415	192,162	269,179	491,814	802,775
125		1,655	3,503	6,668	13,855	20,899	40,691	65,360	116,646	171,875	240,761	439,891	718,024
150		1,510	3,197	6,087	12,648	19,078	37,146	59,665	106,483	156,900	219,784	401,564	655,463
200		1,308	2,769	5,271	10,953	16,522	32,169	51,672	92,217	135,879	190,339	347,765	567,648
300		1,068	2,261	4,304	8,943	13,490	26,266	42,190	75,295	110,945	155,411	283,949	463,482
400		925	1,958	3,727	7,745	11,683	22,747	36,537	65,207	96,081	134,590	245,907	401,388
500		827	1,751	3,334	6,927	10,450	20,345	32,680	58,323	85,938	120,381	219,946	359,012
1,000		585	1,238	2,357	41,898	7,389	14,386	23,108	41,241	60,767	85,122	155,525	253,860
1,500		478	11,011	1,925	4,000	6,033	11,746	18,868	33,673	49,616	69,502	126,986	207,276
2,000		414	876	1,667	3,464	5,225	10,173	16,340	29,162	42,969	60,190	109,973	179,506

INTERIOR PIPE SIZING PROCEDURE

In order to size the piping system inside of any facility, the following information must be calculated or established:

1. The minimum gas pressure available from the utility company
2. The allowable friction loss for gas flowing through the piping system
3. The equivalent length of the piping system
4. The maximum probable demand
5. The pipe sizing method acceptable to local codes

Discussion:

Pressure Available from the Utility Company

The minimum pressure that the utility company will guarantee after the meter assembly must be provided upon request, and it is based on the pressure available in the utility supply mains adjacent to the facility under design. In cases where the utility is not providing the meter, the minimum pressure will be given for the main at the tie-in point. If there is a specific requirement for equipment that needs a higher pressure, such as that for a boiler, the utility company must be advised of this requirement and guarantee this pressure in writing. If the higher pressure is not possible, a gas pressure booster will be necessary.

Allowable Friction Loss in the Piping System

The minimum guaranteed pressure supplied by the utility company after the meter-regulator assembly could be as low as 4 to 7 in of water column (WC). This amount of pressure is quite low and requires that the friction loss of NG through the piping system be kept low in order to have sufficient pressure to properly operate the terminal appliance or equipment. A range of values between 0.2 and 0.5 in WC are generally acceptable, depending on the actual range of pressure available. When the available pressure is higher than 7 in WC, a higher friction loss is allowed for economy of pipe sizing depending on the end use pressure requirements.

A pressure loss figure of up to approximately 10 percent of the pressure available is a generally accepted value for distribution main piping with high pressure, depending on the actual pressure in the system. A regulator will then be required at each terminal appliance requiring a lower gas pressure. High-pressure gas distribution may not be practical due to the added cost of regulators and relief vents.

Equivalent Length of Piping

The equivalent length of piping is required to calculate the friction loss in all portions of a piping network. It is common practice not to use the vertical length of piping when calculating the total run for NG systems. Since NG is lighter than air, it expands at the rate of 0.1 in WC for every 15 ft of elevation as the gas rises.

The additional pressure created as the gas rises approximates the pressure lost to friction inside the pipe. LNG is heavier than air; therefore, the entire length of run is used in calculating the pressure loss. Refer to Table 13.7 for equivalent lengths of fittings and valves for the flow of gas in a pipeline.

Maximum Probable Demand

For some types of buildings, such as multiple dwellings and laboratories, the total connected load is not used to size the piping system since not all of the connected devices will be used at the same time. For design purposes, it is necessary to apply a diversity factor to reduce the total connected load when calculating the maximum probable demand.

This calculation first requires the listing of every device using gas in the building and the demand in British thermal units per hour for each. The manufacturer of each device should be consulted to find the actual input gas consumption of each device. Average gas demand values for typical devices are listed in Table 13.12.

For multiple-unit dwellings, a direct reading of the quantity of gas based on the number of apartments is presented in Fig. 13.1 for buildings of up to 50 apartments and in Fig. 13.2 for buildings with more than 50 apartments. A diversity factor has been used to create the charts. For individual risers, refer to Fig. 13.3 for a direct reading of the pipe size by floor. For laboratories, refer to Table 13.9 for diversity factors. Where laboratories are part of a school, use no diversity for entire rooms, and consult with the school authorities to find the total number of rooms that might be in use at once. If there is no conclusive answer, use no diversity.

The maximum demand for trailer parks is given in Table 13.10. For industrial or process installations and for major gas-using equipment such as boilers and water heaters in all building types, a diversity factor is generally not used because it is possible that all connected equipment will be in use at the same time.

NG Pipe Sizing Methods

The most conservative method for sizing NG piping systems is by the use of tables, such as those prepared by the American Gas Association, which are included in App. C of the National Fuel Gas Code, NFPA 54. Other methods using proprietary tables and calculators are available. The calculators are considered more accurate than the prepared tables. Table 13.11 is provided to allow sizing for low pressure systems of up to ½ psi (3.5 kPa).

To use the low-pressure chart, first establish the acceptable friction loss in order to select the proper table. Then calculate the equivalent run of pipe from the outlet of the meter or regulator (or point of connection) to the farthest point of use. *This is the only distance used.* Find the pipe size at the intersection of the above distance column with a cfh figure that equals or exceeds the calculated cfh figure at each design point. Branches are sized using the same distance column but with the cfh figure from the branch to connection with the main.

If a gas fuel with a different specific gravity is being used, the multipliers found in Table 13.12 can be used to adjust the capacity found in Table 13.11.

Refer to Table 13.13 for conversion of gas pressure designations.

TABLE 13.7 Resistance of Valves and Fittings to the Flow of Gas

(Expressed in equivalent feet of pipe)

		Screwed fittings[b]				90° welding elbows and smooth bends[c]					
		45° ell	90° ell	180° close return bends	Tee	*R/d* = 1	*R/d* = 1⅓	*R/d* = 2	*R/d* = 4	*R/d* = 6	*R/d* = 8
k factor =		0.42	0.90	2.00	1.80	0.48	0.36	0.27	0.21	0.27	0.36
L/d′ ratio[e] *n* =		14	30	67	60	16	12	9	7	9	12
Nominal pipe size, in	Inside diam. *d*, in, Sched. 40[g]	*L* = equivalent length in feet of Schedule 40 (standard weight) straight pipe[g]									
½	0.622	0.73	1.55	3.47	3.10	0.83	0.62	0.47	0.36	0.47	0.62
¾	0.824	0.96	2.06	4.60	4.12	1.10	0.82	0.62	0.48	0.62	0.82
1	1.049	1.22	2.62	5.82	5.24	1.40	1.05	0.79	0.61	0.79	1.05
1¼	1.380	1.61	3.45	7.66	6.90	1.84	1.38	1.03	0.81	1.03	1.38
1½	1.610	1.88	4.02	8.95	8.04	2.14	1.61	1.21	0.94	1.21	1.61
2	2.067	2.41	5.17	11.5	10.3	2.76	2.07	1.55	1.21	1.55	2.07
2½	2.469	2.88	6.16	13.7	12.3	3.29	2.47	1.85	1.44	1.85	2.47
3	3.068	3.58	7.67	17.1	15.3	4.09	3.07	2.30	1.79	2.30	3.07
4	4.026	4.70	10.1	22.4	20.2	5.37	4.03	3.02	2.35	3.02	4.03
5	5.047	5.88	12.6	28.0	25.2	6.72	5.05	3.78	2.94	3.78	5.05
6	6.065	7.07	15.2	33.8	30.4	8.09	6.07	4.55	3.54	4.55	6.07
8	7.981	9.31	20.0	44.6	40.0	10.6	7.98	5.98	4.65	5.98	7.98
10	10.02	11.7	25.0	55.7	50.0	13.3	10.0	7.51	5.85	7.51	10.0
12	11.94	13.9	29.8	66.3	59.6	15.9	11.9	8.95	6.96	8.95	11.9
14	13.13	15.3	32.8	73.0	65.6	17.5	13.1	9.85	7.65	9.85	13.1
16	15.00	17.5	37.5	83.5	75.0	20.0	15.0	11.2	8.75	11.2	15.0
18	16.88	19.7	42.1	93.8	84.2	22.5	16.9	12.7	9.85	12.7	16.9
20	18.81	22.0	47.0	105	94.0	25.1	18.8	14.1	11.0	14.1	18.8
24	22.63	26.4	56.6	126	113	30.2	22.6	17.0	13.2	17.0	22.6

Note: For SI units, 1 ft = 0.305 m.

[a] Values for welded fittings are for conditions where bore is not obstructed by weld spatter or backing rings. If appreciably obstructed, use values for "Screwed Fittings."

[b] Flanged fittings have three-fourths the resistance of screwed elbows and tees.

[c] Tabular figures give the extra resistance due to curvature alone to which should be added the full length of travel.

Miter elbows[d] (no. of miters)					Welding tees		Valves (screwed, flanged, or welded)			
1–45 in	1–60 in	1–90 in	2–90 in	3–90 in	Forged	Miter[d]	Gate	Globe	Angle	Swing check
0.45	0.90	1.80	0.60	0.45	1.35	1.80	0.21	10	5.0	2.5
15	30	60	20	15	45	60	7	333	167	83
			f	f						
L = equivalent length in feet of Schedule 40 (standard weight) straight pipe[g]										
0.78	1.55	3.10	1.04	0.78	2.33	3.10	0.36	17.3	8.65	4.32
1.03	2.06	4.12	1.37	1.03	3.09	4.12	0.48	22.9	11.4	5.72
1.31	2.62	5.24	1.75	1.31	3.93	5.24	0.61	29.1	14.6	7.27
1.72	3.45	6.90	2.30	1.72	5.17	6.90	0.81	38.3	19.1	9.58
2.01	4.02	8.04	2.68	2.01	6.04	8.04	0.94	44.7	22.4	11.2
2.58	5.17	10.3	3.45	2.58	7.75	10.3	1.21	57.4	28.7	14.4
3.08	6.16	12.3	4.11	3.08	9.25	12.3	1.44	68.5	34.3	17.1
3.84	7.67	15.3	5.11	3.84	11.5	15.3	1.79	85.2	42.6	21.3
5.04	10.1	20.2	6.71	5.04	15.1	20.2	2.35	112	56.0	28.0
6.30	12.6	25.2	8.40	6.30	18.9	25.2	2.94	140	70.0	35.0
7.58	15.2	30.4	10.1	7.58	22.8	30.4	3.54	168	84.1	42.1
9.97	20.0	40.0	13.3	9.97	29.9	40.0	4.65	222	111	55.5
12.5	25.0	50.0	16.7	12.5	37.6	50.0	5.85	278	139	69.5
14.9	29.8	59.6	19.9	14.9	44.8	59.6	6.96	332	166	83.0
16.4	32.8	65.6	21.9	16.4	49.2	65.6	7.65	364	182	91.0
18.8	37.5	75.0	25.0	18.8	56.2	75.0	8.75	417	208	104
21.1	42.1	84.2	28.1	21.1	63.2	84.2	9.85	469	234	117
23.5	47.0	94.0	31.4	23.5	70.6	94.0	11.0	522	261	131
28.3	56.6	113	37.8	28.3	85.0	113	13.2	629	314	157

[d] Small-size socket-welding fittings are equivalent to miter elbows and miter tees.

[e] Equivalent resistance in number of diameters of straight pipe computed for a value of *f*—0.0075 from the relation *n*—*k*/4*f*.

[f] For condition of minimum resistance where the centerline length of each miter is between *d* and 2½*d*.

[g] For pipe having other inside diameters, the equivalent resistance may be computed from the above *n* values.

TABLE 13.8 Average Gas Demand Values for Typical Equipment (*In British thermal units per hour*)

Appliance	Input-BTU/h (MJ/h)
Commercial kitchen equipment:	
Small broiler	30,000 (31.7)
Large broiler	60,000 (63.3)
Combination broiler and roaster	66,000 (69.6)
Coffee maker, 3 burner	18,000 (19)
Coffee maker, 4 burner	24,000 (25.3)
Deep fat fryer, 45 pounds (20.4 kg) of fat	50,000 (52.8)
Deep fat fryer, 75 pounds (34.1 kg) of fat	75,000 (79.1)
Doughnut fryer, 200 pounds (90.8 kg) of fat	72,000 (76)
2 deck baking and roasting oven	100,000 (105.5)
3 deck baking oven	96,000 (101.3)
Revolving oven, 4 or 5 trays	210,000 (221.6)
Range with hot top and oven	90,000 (95)
Range with hot top	45,000 (47.5)
Range with fry top and oven	100,000 (105.5)
Range with fry top	50,000 (52.8)
Coffee urn, single, 5 gal. (18.9 L)	28,000 (29.5)
Coffee urn, twin, 10 gal. (37.9 L)	56,000 (59.1)
Coffee urn twin, 15 gal. (56.8 L)	84,000 (88.6)
Stackable convection oven, per section of oven	60,000 (63.3)
Residential equipment:	
Clothes dryer	35,000 (36.9)
Range	65,000 (68.6)
Stove top burners	40,000 (42.2)
Oven	25,000 (26.4)
30 gal. (113.6 L) water heater	30,000 (31.7)
40 to 50 gal. (151.4 to 189.3 L) water heater	50,000 (52.8)
Log lighter	25,000 (26.4)
Barbecue	50,000 (52.8)
Miscellaneous equipment	50,000 (52.8)
Commercial log lighter	50,000 (52.8)
Bunsen burner	5,000 (5.3)
Gas engine, per horsepower (745.7 W)	10,000 (10.6)
Steam boiler, per horsepower (745.7 W)	50,000 (52.8)

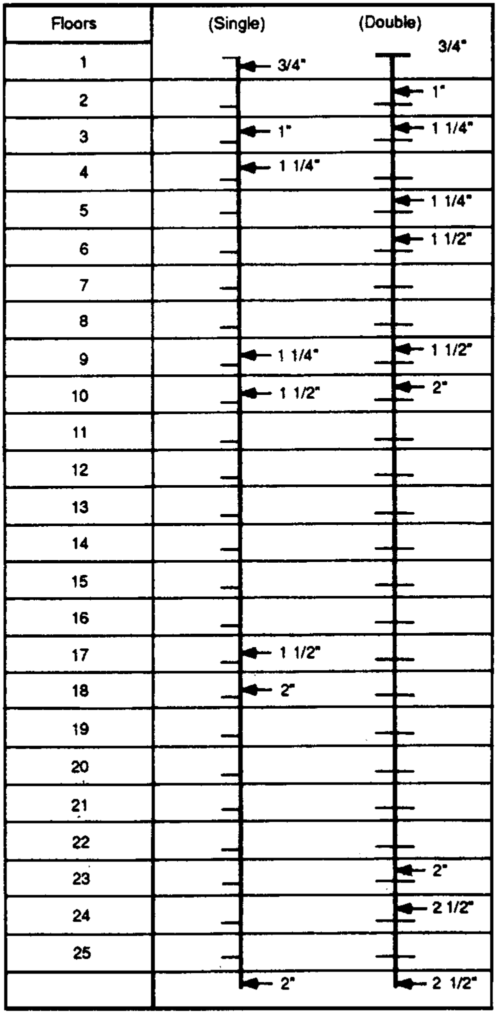


FIGURE 13.3 Gas riser pipe sizing for multiple dwellings.

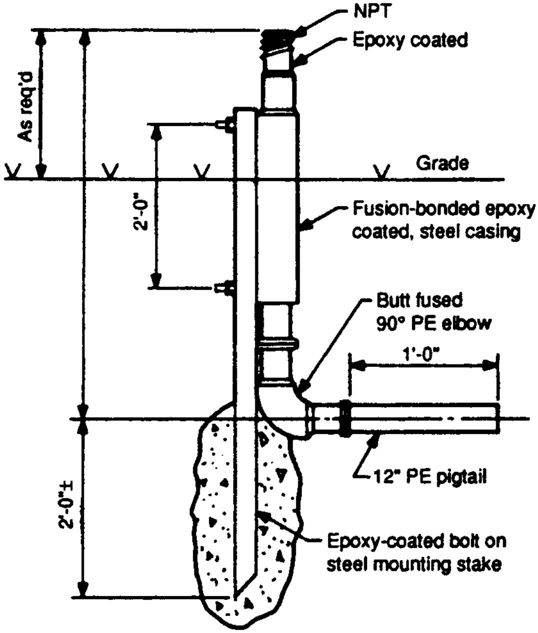


FIGURE 13.4 Transition fitting from underground to above-ground pipe.

TABLE 13.5 Laboratory Diversity Factors

Number of outlets	Average % use	Maximum
1–5	100	
6–10	75	90
11–20	60	75
21–70	40	60
71–150	30	50
Over	20	40

TABLE 13.10 Maximum Demands for Trailer Parks

Number of trailer sites	British thermal units per hour per trailer site	MJ/h
1	125,000	(132)
2	117,000	(123)
3	104,000	(109)
4	96,000	(101)
5	92,000	(97)
6	87,000	(92)
7	83,000	(88)
8	81,000	(86)
9	79,000	(85)
10	77,000	(81)
11–20	66,000	(69)
21–30	62,000	(65)
31–40	58,000	(61)
41–60	55,000	(58)
Over 60	50,000	(53)

Pipe and System Materials

All of the piping materials must be listed in NFPA 54 and other applicable codes. The most often used material for underground lines are high-density polyethylene (PE). For larger lines and high-pressure piping, the most often used material is steel pipe protected against corrosion by wrapping with a plastic coating.

Codes do not permit plastic pipe to be run above ground. For above-ground lines the piping and jointing methods depend on pipe size and system pressure. For piping up to 3 psig (21 kPa), black steel, ASTM A-53, pipe is used with cast or malleable iron screwed fittings in sizes of 3 in (75 mm) and smaller and butt-welded joints of 4 in (100 mm) and larger. Where natural gas is considered ‘‘dry gas,’’ type G (ASTM B-837) copper pipe is finding widespread use. It is available in sizes up to 1⅛ in. All piping for pressures over 3 psig (21 kPa) shall be made of steel with welded joints. Welded fittings shall conform to ANSI 16.9. Screwed fittings shall be made of black malleable iron, 150-lb class conforming to ANSI A-197. Check valves shall be cast iron, 316 SS trim, disk type, with a soft seat. In sizes of 3 in and smaller, use screwed joints. In larger sizes, use flanged joints.

Joints for PE should be butt, heat-fused joints. Socket joints have been found to introduce a stiffness in the joint area that is undesirable. Joints for steel pipe shall be screwed for pipe sizes of 4 in (100 mm) and smaller. Sizes of 5 in (125 mm) and larger should be welded.

TABLE 13.11 Low-Pressure Gas Pipe Sizing Schedule

(*Maximum capacity of pipe in cubic feet of gas per hour for gas pressures of 0.5 psig or less and a pressure drop of 0.3 in water column, based on a 0.60 specific gravity gas*)

Nominal iron pipe size, in	Internal diameter, in	Length of pipe, ft													
		10	20	30	40	50	60	70	80	90	100	125	150	175	200
1/4	0.364	32	22	18	15	14	12	11	11	10	9	8	8	7	6
3/8	0.493	72	49	40	34	30	27	25	23	22	21	18	17	15	14
1/2	0.622	132	92	73	63	56	50	46	43	40	38	34	31	28	26
3/4	0.824	278	190	152	130	115	105	96	90	84	79	72	64	59	55
1	1.049	520	350	285	245	215	195	180	170	160	150	130	120	110	100
1 1/4	1.380	1,050	730	590	500	440	400	370	350	320	305	275	250	225	210
1 1/2	1.610	1,600	1,100	890	760	670	610	560	530	490	460	410	380	350	320
2	2.067	3,050	2,100	1,650	1,450	1,270	1,150	1,050	990	930	870	780	710	650	610
2 1/2	2.469	4,800	3,300	2,700	2,300	2,000	1,850	1,700	1,600	1,500	1,400	1,250	1,130	1,050	980
3	3.068	8,500	5,900	4,700	4,100	3,600	3,250	3,000	2,800	2,600	2,500	2,200	2,000	1,850	1,700
4	4.026	17,500	12,000	9,700	8,300	7,400	6,800	6,200	5,800	5,400	5,100	4,500	4,100	3,800	3,500

TABLE 13.12 Multipliers to Be Used for Specific Gravities Different from 0.60

Specific gravity	Multiplier	Specific gravity	Multiplier
0.35	1.31	1.00	0.78
0.40	1.23	1.10	0.74
0.45	1.16	1.20	0.71
0.50	1.10	1.30	0.68
0.55	1.04	1.40	0.66
0.60	1.00	1.50	0.63
0.65	0.96	1.60	0.61
0.70	0.93	1.70	0.59
0.75	0.90	1.80	0.58
0.80	0.87	1.90	0.56
0.85	0.84	2.00	0.55
0.90	0.82	2.10	0.54

TABLE 13.13 Conversion of Gas Pressure to Various Designations

	Equivalent inches		Pressure per square inch		Equivalent inches		Pressure per square inch		
kP	Water	Mercury	Pounds	Ounces	Water	Mercury	Pounds	Ounces	kPa
0.002	0.01	0.007	0.0036	0.0577	8.0	0.588	0.289	4.62	2.0
0.05	0.20	0.015	0.0072	0.115	9.0	0.662	0.325	5.20	2.2
0.07	0.30	0.022	0.0108	0.173					
0.10	0.40	0.029	0.0145	0.231	10.0	0.74	0.361	5.77	2.5
					11.0	0.81	0.397	6.34	2.7
0.12	0.50	0.037	0.0181	0.239	12.0	0.88	0.433		3.0
0.15	0.60	0.044	0.0217	0.346	13.0	0.96	0.469	7.50	3.2
0.17	0.70	0.051	0.0253	0.404					
0.19	0.80	0.059	0.0289	0.462	13.6	1.00	0.491	7.86	3.37
0.22	0.90	0.066	0.0325	0.520	13.9	1.02	0.500	8.00	3.4
					14.0	1.06	0.505	8.08	3.5
0.25	1.00	0.074	0.036	0.577					
0.3	1.36	0.100	0.049	0.785	15.0	1.10	0.542	8.7	3.7
0.4	1.74	0.128	0.067	1.00	16.0	1.18	0.578	9.2	4.0
0.5	2.00	0.147	0.072	1.15	17.0	1.25	0.614	9.8	4.2
0.72	2.77	0.203	0.100	1.60	18.0	1.33	0.650	10.4	4.5
0.76	3.00	0.221	0.109	1.73	19.0	1.40	0.686	10.9	4.7
1.0	4.00	0.294	0.144	2.31					
					20.0	1.47	0.722	11.5	5.0
1.2	5.0	0.368	0.181	2.89			0.903	14.4	6.2
1.5	6.0	0.442	0.217	3.46	25.0	1.84	0.975	15.7	6.7
1.7	7.0	0.515	0.253	4.04	27.2	2.00	1.00	16.0	6.9
					27.7	2.03			

LIQUEFIED PETROLEUM GAS

LPG is supplied to facilities from a tank truck (or railroad tank car if the storage tank is large enough) and is stored on-site as a liquid. Where usage is large, permanent, large tanks are installed on the facility property and refilled directly from a tanker truck. If the usage requirements are small, small propane tanks containing liquid may be installed and the tanks replaced after they are emptied.

The liquid must be vaporized to produce a gas. Depending on the actual installation and flow rate, the liquid can be vaporized in the storage tank (using heat gained through the storage tank wall) or in an auxiliary vaporizer that uses an outside source of heat. The gas may be used as vaporized, or, if it is a substitute supply for natural gas, it may have to be mixed with air to provide a lower British thermal unit content suitable for the specific application and equipment.

STORAGE TANKS

Tanks used for the storage of propane are made of steel. They can be installed either above or below grade. Although underground tanks have an advantage of a more constant environment, most tanks are placed above ground because of the lower initial cost and EPA requirements. Because of the relatively high pressure developed by the propane vapor, all tanks must be designed in conformance with the ASME code for unfired pressure vessels. The vapor pressure developed in above-ground tanks is based on the ambient outside air and can be found from Fig. 13.5. For underground tanks, a figure of 50°F (10°C) is used. Typical capacities of large, standard tanks are shown in Fig. 13.6. The dimensions and capacity of smaller, standard tanks are summarized in Table 13.14. The dimensions vary slightly from manufacturer to manufacturer. For nonstandard tanks, Fig. 13.7 contains a simplified method for calculating the areas of tanks with various configurations.

Although it is common practice to classify containers as either portable or stationary, there are too many exceptions to make these classifications practical. Containers and storage tanks are referred to as either *Department of Transportation* (DOT) *cylinders* (generally portable) or *ASME tanks* (generally stationary). In the following discussions, all capacities referring to gallons are gallons of water, and all weights are of liquid propane, unless indicated otherwise.

DOT cylinders range in size from 1- to 420-lb capacity. Cylinders built in 1966 or earlier may bear the Interstate Commerce Commission (ICC) designation. ASME tanks range in size from 500- to 60,000-gal capacity.

The advantages of an underground tank are:

1. The tank is not visible if aesthetics are a consideration.
2. There is greater vaporization of liquid in the winter due to the constant temperature, which is about 50°F.

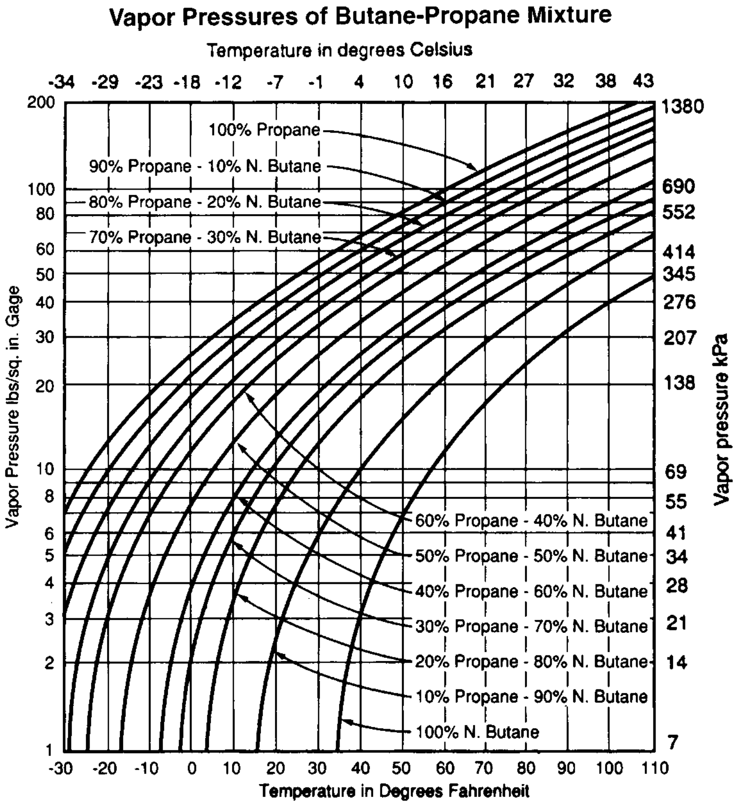


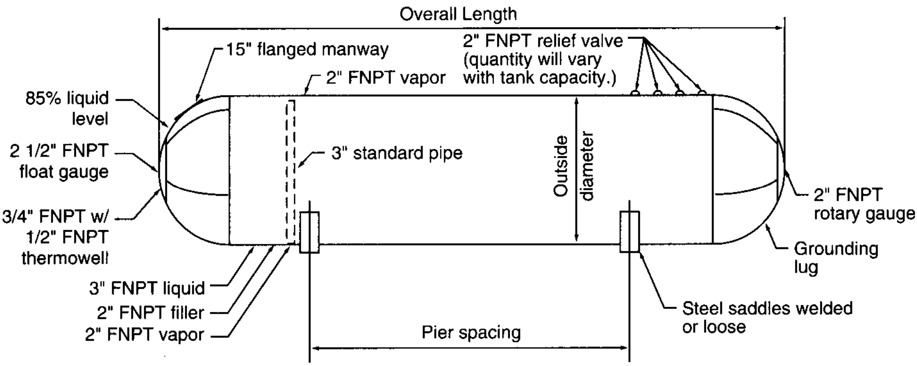
FIGURE 13.5 Vapor pressure of butane-propane mixtures. (*Courtesy Fisher Regulator.*)

The disadvantages are:

1. The tank may have to be anchored to prevent floating in areas of high water tables.
2. The initial cost is higher.
3. Inspection and maintenance are more difficult to perform.

If the underground tank is subject to traffic or potential damage, the top should be a minimum of 2 ft below grade. In remote locations, 6 in of cover is considered adequate. A manhole giving access to the valves, gauges, connections, and so on must be provided for maintenance and inspection.

New tanks must be purged of both air and water prior to being placed in service. A concentration of 6 percent air is the maximum limit acceptable. Water should be removed from the tank by the manufacturer, and the tank should be shipped to the site sealed.



Dimensions and Capacities of Larger Tanks				
Capacity, in gallons	Dia, inches	Length	Pier spacing	Estimated weight, lbs
6,565	84	25' – 10"	8' – 0"	11,260
9,200	84	35' – 4"	17' – 6"	15,920
12,000	84	44' – 10"	27' – 0"	20,035
14,500	84	54' – 4"	36' – 6"	25,230
18,000	109	40' – 11"	21' – 0"	30,502
20,000	109	46' – 11"	27' – 0'	35,300
25,000	109	56' – 5"	36' – 6"	43,100
30,000	109	65' – 11"	46' – 0"	50,900
30,000	121	53' – 3"	32' – 4"	50,000
30,000	121	46' – 9"	24' – 11"	50,100

FIGURE 13.6 Dimensions and capacities of larger propane tanks. (*Courtesy Fisher Regulator.*)

TABLE 13.14 Dimensions and Capacities of Small Propane Tanks

		Dimensions		Surface area, ft^2				
					Wetted surface			
Tank size, gal	Net propane capacity, gal, 60°F	Outside diameter, in	Overall length	Total surface	15% full	25% full	33% full	50% full
120	99	24	5 ft 7 in	35.1	7.0	8.75	14.0	17.5
150	124	24	6 ft 11 in	43.5	8.7	10.8	17.4	21.7
250	207	30	7 ft 5 in	58.3	11.6	14.8	23.3	29.1
325	269	30	9 ft 6 in	74.6	14.8	17.6	29.8	37.3
500	414	37	10 ft 0 in	96.9	19.4	24.2	38.1	42.4
1000	827	41	16 ft 1 in	172.6	34.8	43.1	69.1	86.3

1 Gal = 4.5 L
1 Ft = 0.3 m
1 In = 25.4 mm
1 Sq Ft. = 0.092 m^2

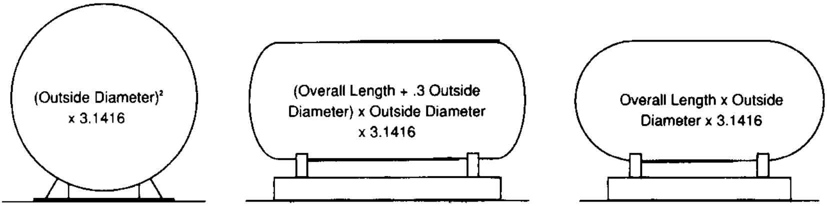


FIGURE 13.7 Areas of nonstandard tanks. (*Courtesy Trinity Industries.*)

MAXIMUM CONTENT OF LIQUID IN TANKS

The maximum allowable quantity of LPG permitted in a container is limited by NFPA 58 to a filling density based on tables and formulas provided in that code. In future discussions of tank sizing, this maximum allowable quantity must be compared to that calculated by other methods to make sure that the maximum is not exceeded.

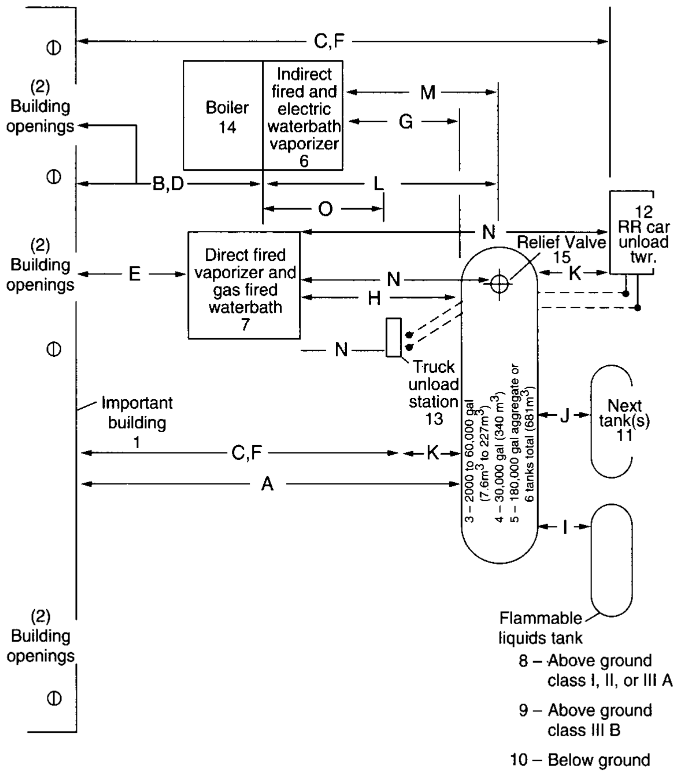
LOCATION OF EQUIPMENT ON THE SITE

The factors to be considered in locating the equipment are:

1. Code required clearance from other buildings, property lines, and any other equipment. These clearances also depend on insurance carrier requirements and client preferences. Factory Mutual requirements, indicated in Fig. 13.8, are considered conservative. Distances specified in NFPA 54 and other insurance carrier codes vary but are not longer.
2. Accessibility for fuel delivery.
3. Location of underground utilities.
4. Site elevations. Avoid placing the equipment at low points.
5. Client preferences.

TANK FOUNDATIONS AND SUPPORT

Tank foundations must provide a stable means of support. Uneven settlement will lead to errors in fuel gauging and stresses leading to broken lines. The weight of the tank should be calculated using water since there may be a requirement for hydrostatic testing during the life of the system. An approximation of the gross weight of a steel tank can be obtained by multiplying the capacity in gallons by 11 for water and 6 for propane. Some larger tanks may require a temporary, intermediate center support during the time they are filled with water for hydrostatic testing.



Minimum Recommended Distance			
Dimension	Point to point	Distance, ft	Distance, m
A	1 to 3a	75	23
	4a	150	46
	5b	200	60
	5c	350	105
B	6	20	6
C	12	200	60
	13	50	15
D	2 to 6	20	6
E	7	50	15
F	12	200	60
	13	75	23
G	3,4,5 to 6	5	1.5
H	7	15	4.5
I	8	100	30
	9	50	15
	10	20	6
J	11	75	23
K	12	75	23
	13	50	15
L	14	75	23
M	6 to 15	50	15
N	7 to 12,13,15	75	23
O	13 to 14	75	23

Notes:

a. For single tanks only. Treat multiple tanks as No. 5.
b. For buildings with hydrant protection.
c. For buldings without hydrant protection.
d. 5 ft (1.5 m) for tanks within a group.
e. For tanks smaller than 2000 gal (7.6 m^3), 25 ft (7.6 m).

FIGURE 13.8 Clearances from propane tank to buildings or other structures.

REGULATORS

The regulator for LPG is different from that used for natural gas service. The purpose of an LPG regulator is to reduce a variable inlet pressure to a constant outlet pressure under variable flow conditions. The following information is required to size a regulator:

1. Minimum significant and maximum flow rate possible
2. Maximum and minimum container pressure
3. Required outlet pressure desired
4. Manufacturer's rating curves for the regulator

The pressure developed inside the storage tank is produced by the vaporization of product inside the storage tank. This pressure is called the *vapor pressure.* This figure varies, depending on the ambient temperature. Figure 13.6 is a direct reading chart to determine the vapor pressure for various mixtures of propane and butane that might be provided by suppliers. Outside temperatures can be found by requesting this information from the National Oceanographic and Atmospheric Administration (NOAA).

Regulators are manufactured in single- and double-stage models and are selected using the capacity and rating curves supplied by the manufacturer. If a relief valve is provided as part of the regulator assembly, refer to Table 13.15 for pressure settings.

Experience has shown that when regulators are kept in service longer than 15 years, the probability of malfunction increases. This figure is only a generalization, with actual climate and service conditions playing an important factor in the service life of a regulator.

PRESSURE RELIEF DEVICES

The purpose of a pressure relief device is to automatically vent propane vapor to the atmosphere upon reaching a predetermined high pressure. It can be an integral part of a pressure regulator, separately installed on the storage tank, part of vaporizers and mixers, or in the piping system itself.

The relief valve flow capacity is calculated on the basis of a full tank and the resultant vaporization of that volume of propane. For an underground tank, the

TABLE 13.15 Final-Stage Relief Valve Settings

Regular delivery pressure	Relief valve start-to-discharge pressure setting (percent of regulator delivery pressure)	
	Minimum, %	Maximum, %
1 psig or less	200	300
Above 1 psig but not over 3 psig	140	200
Above 3 psig	125	200

capacity will be 30 percent of the above-ground value. Refer to Table 13.16 to determine the required flow of propane based on the square foot area of the storage tank or use Fig. 13.7. All larger tanks must have a separate relief valve installed directly on the tank. If a single relief valve does not have the required flow capacity, it will be necessary to have multiple relief valves mounted on the top of the tank to provide the necessary flow rate. A typical tank relief valve is illustrated in Fig. 13.9. The final pressure setting of the relief valve is nominally 88 to 100 percent of the design pressure of the tank, with a permitted error of +10 percent.

TABLE 13.16 Relieving Capacity for Relief Valves on Tanks and Vaporizers

(*Minimum required rate of discharge in cubic feet per minute of gas at 120 percent of the maximum permitted start-to-discharge pressure for relief valves to be used on containers other than those constructed in accordance with Department of Transportation specifications*)

Surface area, ft^2	Flow rate, cfm air	Surface area, ft^2	Flow rate, cfm air	Surface area, ft^2	Flow rate, cfm air
20	626	170	3,620	600	10,170
25	751	175	3,700	650	10,860
30	872	180	3,790	700	11,550
35	990	185	3,880	750	12,220
40	1,100	190	3,960	800	12,880
45	1,220	195	4,050	850	13,540
50	1,330	200	4,130	900	14,190
55	1,430	210	4,300	950	14,830
60	1,540	220	4,470	1,000	15,470
65	1,640	230	4,630	1,050	16,100
70	1,750	240	4,800	1,100	16,720
75	1,850	250	4,960	1,150	17,350
80	1,950	260	5,130	1,200	17,960
85	2,050	270	5,290	1,250	18,570
90	2,150	280	5,450	1,300	19,180
95	2,240	290	5,610	1,350	19,780
100	2,340	300	5,760	1,400	20,380
105	2,440	310	5,920	1,450	20,980
110	2,530	320	6,080	1,500	21,570
115	2,630	330	6,230	1,550	22,160
120	2,720	340	6,390	1,600	22,740
125	2,810	350	6,540	1,650	23,320
130	2,900	360	6,690	1,700	23,900
135	2,990	370	6,840	1,750	24,470
140	3,080	380	7,000	1,800	25,050
145	3,170	390	7,150	1,850	25,620
150	3,260	400	7,300	1,900	26,180
155	3,350	450	8,040	1,950	26,750
160	3,440	500	8,760	2,000	27,310
165	3,530	550	9,470		

Note: Buried tanks require only 30 percent of the vent capacity shown.

Source: Factory Mutual.

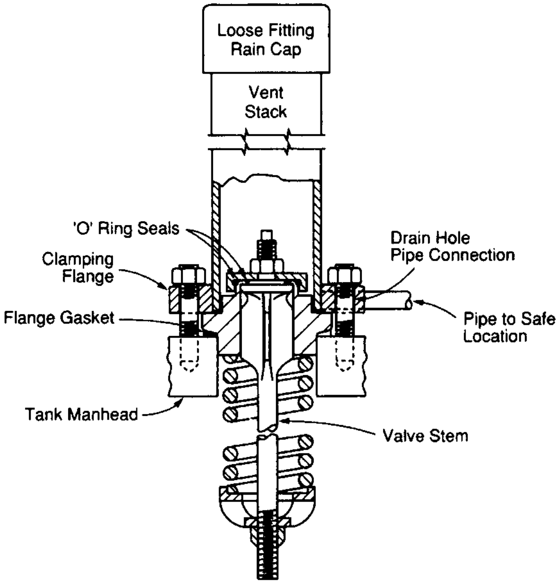


FIGURE 13.9 Tank relief valve. (*Courtesy Factory Mutual.*)

Another pressure relief device within the piping system is the external bypass valve, which relieves excessive pressure in an LPG pumping system upon reaching a high-pressure set point and returns the discharge back to the storage tank instead of to the atmosphere as is done by a relief valve. All LPG pumps require an external bypass valve. Different types of bypass valves are manufactured for different applications.

EXCESS FLOW VALVE

An excess flow valve permits the flow of vapor or liquid in both directions but shuts off the flow of liquid or vapor in only one direction when the flow exceeds a predetermined limit. It is recommended that an excess flow device be placed on all connections to a larger tank except for the safety relief valve. The filler connection should have an integral valve. The capacity is calculated from the largest expected flow and its mounting position (horizontal or vertical). Valves are selected to open at between 150 and 200 percent of the expected maximum flow.

SERVICE LINE VALVES

A service line valve controls the flow of propane from a DOT cylinder. This is a multipurpose valve that could contain a shutoff valve, relief valve, gauge, and filler valve all in one body.

FILLER VALVES

A filler valve permits the flow of liquid in one direction only and is used for filling larger tanks with liquid. This valve contains an integral back pressure check valve that will prevent the loss of vapor or liquid from the tank if the fill hose or a fitting ruptures. A preferred location is at the filling connection used by the delivery truck hose.

VAPOR EQUALIZING VALVES

When large tanks are filled, the liquid propane added to the storage tank compresses the vapor in the tank. A vapor equalizing line is connected between the vapor area of the receiving tank and the vapor area of the delivery truck during propane deliveries to equalize pressure in both containers and to lessen the head requirements of the supply pump. The vapor equalizing valve is mounted in the equalizing line tank truck hose connection and permits the flow of vapor both ways.

LIQUID LEVEL GAUGES

When a larger tank is filled on the basis of volume, it is important that a liquid level gauge be installed on the tank to indicate the exact liquid level inside. There are several types available.

The slip tube gauge is mounted on top of a tank and consists of a vertical rod extending from the liquid level inside to a point outside the tank for measurement. There is a float on one end of the tube that rides on the liquid, automatically rising and falling with the level.

A magnetic float gauge consists of a gauge faceplate mounted on the side of a tank and a connecting rod with a float at the end that rides on the liquid level. As the float rises and falls with the liquid, it automatically moves a magnetic device on the faceplate indicating the level inside. Because there is no direct opening to the tank outside, this is the most widely used gauge. Since it is a mechanical device, it is recommended that this type be used with the slip tube as a backup.

A rotary liquid level gauge is a manually operated gauge that uses an angled dip tube inside the tank connected to a bleeder valve on a calibrated faceplate on the outside of the tank. The bleeder valve is opened, and the dip tube is manually turned until the vapor escaping changes to a liquid. The level is then read from calibrated markings on the faceplate.

The fixed level gauge is an external needle valve connected to a short length of tubing extending inside the tank. There may be a number of these gauges installed at various calibrated levels on the tank. As the filling proceeds, the valve is cracked open until the vapor changes to liquid. When the desired level is reached, the filling operation stops.

MISCELLANEOUS EQUIPMENT

In addition to the devices indicated, it is often desirable to install a liquid temperature gauge and a pressure gauge on a tank to aid in diagnosing any potential problem.

VAPORIZER

A vaporizer is a device that converts liquid propane into a vapor in larger quantities than would be possible from ambient heat alone. It is required when sufficient quantities of liquid propane inside the storage tank cannot be vaporized quickly enough to satisfy the maximum demand.

There are two basic types of vaporizers: direct fired and indirect fired. The direct-fired vaporizer uses the propane itself as fuel for the direct flame. It has the lowest initial cost and no ancillary power requirements. Disadvantages include the problem of pilot light extinguishment in high winds, production of sludge in the propane being vaporized, and a useful life expectancy of only 5 years. Optional accessories to be considered would be an automatic ignition, manual drain, liquid strainer, and propane-air mixer. An indirect type of vaporizer is available that uses steam, glycol-water bath, or the lesser-used electric resistance heaters as a heat source.

PROPANE MIXERS

A *mixer,* also called a *blender* or *proportioner,* is a device used to combine pure propane and air together into a mixture of both gases. It is required when propane will be used as a direct substitute for natural gas because the much higher British thermal unit content of 100 percent propane will not allow the use of the same burner orifices and gas train as natural gas. Experience has shown that a mixed gas content of 1450 Btu/cf with a specific gravity of 1.30 provides the best burning characteristics. Refer to Table 13.17 for properties of various mixtures of propane and air.

Several methods can be used to accomplish mixing. The simplest is the use of a venturi. Intended for exterior installation, it consists of a nozzle inside of a larger body. Propane passing through the nozzle creates a partial vacuum that pulls air from around the opening, thereby creating a mixed gas. Because the venturi principle is accurate only within a very limited flow range, this type of unit is either on or off. If the demand pressure is higher than 5 psi (35 kPa), the use of an air compressor will be required to raise the mixed gas pressure. Generally, this system has the least initial cost. Four conditions have a strong bearing on the accuracy and composition of the mixture:

1. Venturi tube dimensions and throat diameter
2. Nozzle or orifice size and location of venturi in throat
3. Pressure of both gases at the venturi
4. Desired discharge pressure

Another and more costly device is the modulating proportional blender. Suitable only for interior installation, these units are generally used for larger quantities and higher pressures than available from a venturi unit. They use regulators to stabilize both the air and propane in separate supply lines. A proportioning valve is then used to meter both supplies into a common discharge line. An air compressor is often used to supply air at the higher pressure required. The vaporizer and mixer are also available as a factory-assembled package on a single skid, ready for installation.

TABLE 13.17 Properties of Various Propane/Air Mixtures

British thermal unit per cubic foot of mixture	Propane/air mixtures			
	Percentage of propane by volume	Percentage of air by volume	Percentage of oxygen by volume	Specific gravity of the mixture
2550	100.00	0.00	0.000	1.523
2500	98.04	1.96	0.409	1.513
2450	96.08	3.92	0.819	1.502
2400	94.12	5.88	1.288	1.492
2350	92.16	7.84	1.639	1.482
2300	90.19	9.81	2.050	1.472
2250	88.24	11.76	2.458	1.461
2200	86.27	13.73	2.869	1.451
2150	84.31	15.69	3.279	1.441
2100	82.35	17.65	3.688	1.431
2050	80.39	19.61	4.098	1.420
2000	78.43	21.56	4.506	1.410
1950	76.47	23.53	4.918	1.400
1900	74.51	25.49	5.317	1.390
1850	72.55	27.45	5.737	1.379
1800	70.58	29.42	6.149	1.369
1750	68.62	31.38	6.558	1.359
1700	66.67	33.33	6.964	1.349
1650	64.70	35.30	7.378	1.338
1600	62.74	37.26	7.787	1.328
1550	60.78	39.22	8.197	1.318
1500	58.82	41.18	8.606	1.308
1450	56.86	43.14	9.016	1.297
1400	54.90	45.10	9.246	1.287
1350	52.94	47.06	9.835	1.277
1300	50.98	49.02	10.245	1.267
1250	49.02	50.98	10.654	1.256
1200	47.06	52.94	11.064	1.246
1150	45.09	54.91	11.476	1.236
1100	43.13	56.87	11.886	1.226
1050	41.17	58.83	12.295	1.215
1000	39.21	60.79	12.705	1.205
950	37.25	62.75	13.115	1.195
900	35.29	64.71	13.524	1.185
850	33.33	66.67	13.934	1.174
800	31.37	68.63	14.344	1.164
750	29.41	70.59	14.753	1.154
700	27.45	72.55	15.163	1.144
650	25.49	74.51	15.573	1.133
600	23.53	76.47	15.982	1.123
550	21.56	78.44	16.394	1.113
500	19.61	80.39	16.892	1.103

(*Continued*)

TABLE 13.17 Properties of Various Propane/Air Mixtures (*Continued*)

British thermal unit per cubic foot of mixture	Propane/air mixtures			
	Percentage of propane by volume	Percentage of air by volume	Percentage of oxygen by volume	Specific gravity of the mixture
450	17.65	82.35	17.211	1.092
400	15.69	84.31	17.621	1.082
350	13.73	86.27	18.031	1.072
300	11.76	88.24	18.442	1.062
250	9.80	90.20	18.852	1.051
200	7.84	92.16	19.261	1.041
150	5.88	94.12	19.670	1.031
100	3.92	96.08	20.081	1.021

LPG SYSTEM DESIGN

Prior to sizing components, initially decide what equipment (such as pumps or vaporizers) may be required and if the tank is to be above or below ground, and select the proposed location of the tank and other required equipment on the site. Determine if the propane system will be in constant use or used only periodically, such as for emergency operation or as an occasional substitute for interrupted natural gas. Calculate the maximum hourly and daily fuel gas demand, and determine if this demand is continuous, such as that for a process used all day, or intermittent, such as that used for heating purposes. If only a small part of the demand is continuous, the entire load should be considered continuous.

Storage Tank Sizing and Selection

The storage tank volume is based on one of two factors: a reasonable return schedule for the local supplier or the amount of liquid propane that has to be vaporized by the ambient air in order to satisfy the maximum demand.

Vaporization directly from a tank, if economically feasible, is used to avoid having to add another mechanical device (a vaporizer) that requires constant maintenance. If a single tank sized to optimum criteria will not provide the required vaporization rate, a single oversized tank or two smaller, separate tanks are often installed if space conditions and initial cost are acceptable.

Tank Size Based on Return Schedule. Using the return schedule, a preliminary starting point for determining actual capacity is a 10-day usable supply for continuous demand and between 3 to 5 days usable supply for intermittent or standby purposes. With the maximum propane level based on the maximum quantity for the allowed filling density and the minimum level between 10 and 15 percent of the capacity, the usable tank capacity is about 75 percent of the total tank capacity.

Tank Size Based on Vaporization Rate of Propane. When using the vaporization rate as the critical factor in selecting the size of the storage tank, the tank must be large enough to vaporize the maximum flow rate of propane required by the facility when the outside air temperature and liquid level are at their lowest. For above-ground tanks, the rate of vaporization is calculated using the wetted area of liquid propane in the tank. For underground tanks, the entire area of the tank is used even if the tank is partially full.

There are two methods that will be discussed. The first, and most accurate, will use various formulas to calculate the wetted area of a tank that will vaporize the required amount of propane. The second, although slightly less accurate, is the direct reading of the vaporization rate from prepared charts. This is a more conservative method and by far the easier.

Formula Method. Using this method, the wetted area of the proposed above-ground tank necessary to vaporize the required amount of propane will be calculated. If an underground tank is proposed, the area calculated shall be that of the entire tank. The basic formulas are as follows.

TOTAL HEAT OF VAPORIZATION FROM AN ABOVE-GROUND TANK

$$Q = U \times A \times TD \tag{13.1}$$

TOTAL HEAT OF VAPORIZATION FROM A BELOW-GROUND TANK

$$Q = U \times A \times 15 \tag{13.2}$$

Equation (13.1) transposed to find the wetted area is:

$$A = \frac{Q}{U \times (TD \text{ or } 15)} \tag{13.3}$$

ACTUAL AMOUNT OF PROPANE VAPORIZED

$$V = \frac{\text{A}Q}{L} \tag{13.4}$$

where Q = the total amount of heat required to vaporize a quantity of liquid propane, Btu.

U = rate of heat transfer through the walls of a steel tank, per square foot of wetted area/temperature difference in °F. Generally accepted figures are 2 Btu/sf/°F for above-ground tanks based on severe conditions and 0.5 Btu/sf/°F for underground tanks.

A = the wetted surface area of the above-ground tank containing liquid propane, or the entire surface area of an underground tank, ft^2.

TD = the intended difference in temperature between ambient outside air reached during the coldest part of the day and the temperature of propane in the tank reached during the warmest part of the day, in °F. One factor that must be taken into consideration is the formation of frost on the outside of the storage tank. Since frost acts as an insulation, its formation must be avoided. Table 13.18 gives the minimum temperature difference to avoid frost formation. When predicted conditions are outside the figures required to enter the table, use the true temperature difference.

15 = 15°F, which is the generally accepted temperature difference for underground tanks.

V = propane vaporized under design conditions, gal.

TABLE 13.18 Difference between Air Temperature of Frost Formation

°C	Lowest air temp. °F	Relative humidity 20	30	40	50	60	70	80	90
−34.4	−30	—	—	—	—	8.0*	5.0*	2.5*	1.0*
−28.9	−20	—	20.0*	15.0*	11.5*	8.5	5.0	3.0	1.5
−23.3	−10	27.5*	20.5	16.0	12.0	9.0	6.0	3.0	1.5
−17.8	0	29.0	21.5	16.5	12.5	9.0	6.0	4.0	2.0
−12.2	10	30.0	22.5	17.0	13.0	9.5	6.5	4.0	2.0
−6.7	20	31.5	24.0	18.0	14.0	10.0	7.0	4.0	2.0
−1.1	30	33.0	25.0	19.5	15.0	11.0	8.0	5.0	3.0
4.1	40	35.0	27.0	21.0	16.5	12.0	9.0	8.0	8.0

* If the full temperature difference is used in these cases, the minimum tank pressure may be too low for satisfactory performance.

1°F = 0.55°C.

L = latent heat of vaporization of propane, Btu/gal. This is the amount of heat required to change liquid propane to a vapor (Table 13.19). Interpolate to find intermediate values when necessary.

The following methodology is used to select a tank with propane vaporization rate as criteria, solving for Eq. (13.3):

Step 1. Establish the lowest predicted ambient air temperature, highest predicted relative humidity, and the required propane gas demand in Btu/h/gal.

Step 2. Convert the British thermal unit per hour demand into gallons per hour. Refer to Table 13.2.

Step 3. Transpose Eq. (13.4) to find Q. Refer to Table 13.19 to find L.

Step 4. Substitute all figures into Eq. (13.3), and solve for the wetted area. After calculating the required minimum area, consult manufacturers' catalogs for a

TABLE 13.19 Latent Heat of Vaporization for Propane

°C	Ambient air temp, °F	Propane Btu/lb	Propane Btu/gal
−40	−40	180.8	765
−34.4	−30	178.7	755
−28.9	−20	176.2	745
−23.3	−10	173.9	735
−17.8	0	171.5	725
−12.2	10	169.0	715
−6.7	20	166.3	704
−1.1	30	163.4	691
4.4	40	160.3	678
10.0	50	156.5	662
15.6	60	152.6	645

size tank providing that figure with the minimum level of propane in the storage tank.

As an example, calculate the selection of a tank using the minimum area of a tank as the criteria. The following project conditions exist:

1. *Lowest predicted temperature:* 30°F
2. *Highest predicted humidity:* 60 percent
3. *Required propane demand:* 132,000 Btu/h
4. *Type of use:* Continuous

First, convert Btu demand per hour into gallons per hour using the figure obtained from Table 13.2:

$$\frac{132{,}000}{91{,}547} = 1.44 \text{ gal/h}$$

Second, find L using Table 13.19. Entering the table with 30°F, find 163.4 Btu.
Third, calculate Q using transposed Eq. (13.4) to read $Q = L \times V$:
Fourth, find TD using Table 13.18.
Fifth, substitute the above figures in Eq. (13.3):

$$A = \frac{235.2}{2 \times 11} = \frac{235.2}{22}$$

$$= 10.69 \text{ ft}^2 \text{ of wetted area of tank}$$

The result of the previous calculation is a tank area that will contain the absolute lowest volume of propane that will adequately supply facility needs. A higher volume should be used as an actual "low level." The additional capacity will be required to allow enough time for a delivery before the volume in the tank falls below the level needed to supply the facility. This low level will be a percent of the total capacity of the tank that will be used to select the actual, total capacity of the storage tank in conjunction with the proposed schedule of the supplier. Select a "standard" tank with a slightly greater volume than that calculated. If a single tank selected for adequate vaporization results in a size that is impractical, two tanks can be used. If the tanks are still too large or have too high an initial cost, the only other solution is to provide a vaporizer.

Direct-Reading Method. Table 13.20 provides a nomogram for determining a direct reading of propane vaporization from small tanks. Figure 13.10 provides a table for a direct reading of propane vaporization from larger tanks. Both Table 13.20 and Fig. 13.10 are based on a tank 25 percent full. Reduce the figures by 10 percent to approximate tanks 15 percent full.

LPG Gas Pipe Sizing Methods

A widely used pipe sizing method for low-pressure, 100 percent propane gas systems relies upon the tables used for NG in NFPA 54, such as that appearing in Table 13.7. Proprietary charts are available that are less conservative and more accurate. For use with propane, a conversion factor of 0.63 to reduce the indicated flow rate must be used.

TABLE 13.20 Propane Vaporization Chart for Small Tanks (*Cubic feet per hour of propane*)

Atmos. temp		Cylinder capacity, lb LP gas				
°C	°F	20	100	150	300	420
15.6	60	16	31	50	60	95
−1.1	30	10	20	33	46	63
−12.2	10	7	13	21	30	41
−17.0	0	5	10	15	22	30
−23.3	−10	3	6	10	15	19

Note: The above capacities are based on the assumption that the cylinder is 25 percent filled. It does not include effect of sensible heat. These figures are on the conservative side and should be used as a guide only. They are based on the cylinder being in the shade in still air and on continuous withdrawal. Due to beneficial effect of drafts, sunlight, radiation, and intermittent operations, most actual installations will have a greater capacity than shown in the table.

1 CFH = 0.03 m^3/h.

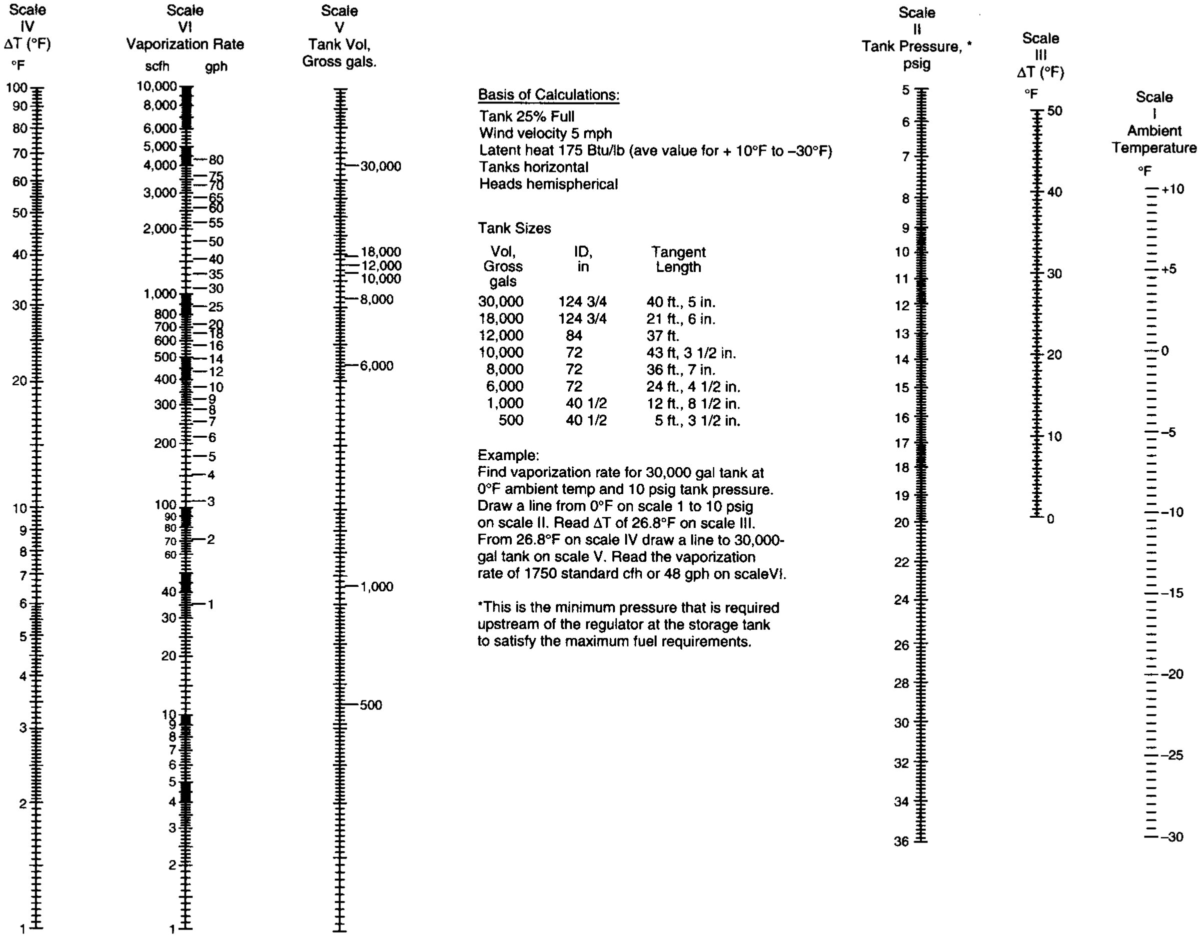
Propane is often mixed with air to provide a direct substitute for natural gas. Field experience has found that if mixed gas with the same British thermal unit value (1050 Btu/cf) as natural gas is used, the mixture will not burn properly. As a result, it is common practice to provide a mixed gas with a value of 1450 Btu/cf. This mixture has a specific gravity of 1.30. Since gas flow varies inversely as the square root of the specific gravity, a conversion factor can be used with readily available natural gas charts to size the mixed gas–natural gas piping system. The conversion factor for 1450 Btu/cf mixed gas is 0.69, which is used to multiply the capacity found in NG tables in order to convert the chart figure to the actual mixed gas capacity value. The method of using the charts is discussed previously for NG sizing.

LPG Pumps

There are two commonly used pumps in LPG service: sliding vane positive displacement and turbine regenerative centrifugal. In general, the sliding vane positive displacement pump is generally used for flow of from 40 to 350 gpm. The turbine regenerative pump is generally used for constant flows and pressure when the flow is less than 40 gpm, such as those used to fill propane tanks for home use. Either type of pump could be used for any pressure for which it is rated.

To calculate the pump head, add the following:

1. The vapor pressure of the storage tank into which the liquid propane will be pumped. If there is a vapor return line, this will not be a factor.
2. The friction loss of the liquid through the piping network. Refer to Table 13.21 for the friction loss of liquid propane through steel piping. Table 13.22 provides the losses through fittings in equivalent feet of steel pipe.
3. The friction losses of liquid propane through delivery hose in pounds per square inch. Refer to Table 13.23.
4. Static head difference between the supply and receiving points.
5. The resistance to flow from meters, filler valves, and so on. Obtain this information from manufacturers.



Basis of Calculations:

Tank 25% Full
Wind velocity 5 mph
Latent heat 175 Btu/lb (ave value for + 10°F to −30°F)
Tanks horizontal
Heads hemispherical

Tank Sizes

Vol, Gross gals	ID, in	Tangent Length
30,000	124 3/4	40 ft., 5 in.
18,000	124 3/4	21 ft., 6 in.
12,000	84	37 ft.
10,000	72	43 ft, 3 1/2 in.
8,000	72	36 ft., 7 in.
6,000	72	24 ft., 4 1/2 in.
1,000	40 1/2	12 ft., 8 1/2 in.
500	40 1/2	5 ft., 3 1/2 in.

Example:
Find vaporization rate for 30,000 gal tank at 0°F ambient temp and 10 psig tank pressure. Draw a line from 0°F on scale 1 to 10 psig on scale II. Read ΔT of 26.8°F on scale III. From 26.8°F on scale IV draw a line to 30,000-gal tank on scale V. Read the vaporization rate of 1750 standard cfh or 48 gph on scaleVI.

*This is the minimum pressure that is required upstream of the regulator at the storage tank to satisfy the maximum fuel requirements.

FIGURE 13.10 Propane vaporization of large propane tanks. (*Courtesy Phillips Petroleum Co.*)

TABLE 13.21 Resistance of Steel Pipe to the Flow of Liquid Propane (*Expressed in feet of head of liquid LP gas*)

Flow rate, U.S. gpm	Pipe size, schedule 40 steel						
	1 in	2 in	2½ in	3 in	4 in	5 in	6 in
10	0.007						
20	0.028	0.008					
30	0.060	0.017	0.007				
40		0.031	0.012				
50		0.048	0.020	0.004			
60		0.070	0.028	0.009			
70		0.095	0.038	0.013			
80			0.050	0.017			
90			0.063	0.021			
100			0.078	0.025	0.006	0.002	0.001
125				0.036	0.008	0.003	0.001
150				0.051	0.012	0.004	0.002
175				0.088	0.016	0.005	0.002
200				0.088	0.020	0.007	0.003
225					0.025	0.009	0.003
250					0.031	0.010	0.004
275					0.037	0.012	0.005
300					0.043	0.014	0.006

TABLE 13.22 Resistance of Valves and Fittings to Flow of Liquid Propane

(Expressed in equivalent feet of pipe)

Type valves and fittings	Resistance in equivalent feet of pipe of these sizes						
	1½ in	2 in	2½ in	3 in	4 in	5 in	6 in
Straight-through ball, and plug valves, same size as pipe	5	6	8	10	14	17	20
Globe valves, wide open, same size as pipe	40	50	60	80	110	130	160
Angle valves, wide open, same size as pipe	20	25	30	40	55	70	80
Swing check valves, same size as pipe	10	13	16	19	25	31	38
90° elbow, same size as pipe	4	5	6	8	11	13	16
45° elbow, same size as pipe	2	2½	3	3½	5	6	7
Tee, flow-through side outlet, same size as pipe	8	10	13	16	21	27	33
Tee, flow straight through, same size as pipe	2½	3	4	5	7	8½	11
Strainer, same size as pipe	25	60	42	42	50	50	50
Strainer, next larger size than pipe	16	17	14	20	30	30	
Bushing or reducer, to one size larger or smaller	2	2½	3	4	5	6	7

Note: Figures shown represent average resistance-to-flow values.

TABLE 13.23 Resistance of Delivery Host to the Flow of Liquid Propane, 60°F

Delivery rate		Pressure drop, psi					
L/S	GPM	½ in size	¾ in size	1 in size	1¼ in size	1½ in size	2 in size
0.375	5	8.1	1.1	0.2	0.1	0	0
0.75	10	30.0	4.0	0.9	0.3	0.1	0
1.12	15	64.6	8.5	2.0	0.7	0.3	0
1.5	20	Too high	14.4	3.4	1.0	0.5	0.1
1.9	25	Too high	22.1	5.2	1.7	0.7	0.2
2.25	30	Too high	31.0	7.4	2.4	0.9	0.3
3.0	40	Too high	54.0	12.6	4.2	1.6	0.4
3.75	50	Too high	Too high	19.0	6.4	2.5	0.6
4.5	60	Too high	Too high	26.4	.90	3.5	0.8
5.25	70	Too high	Too high	35.4	11.9	4.6	1.1
6.0	80	Too high	Too high	46.2	15.5	5.9	1.4
6.75	90	Too high	Too high	46.6	19.0	7.4	1.7
7.5	100	Too high	Too high	69.7	23.4	8.9	2.1

1 psi = 7 kPa.

6. Add all pressure obtained from steps 1 through 5 and add 10 psi to have some additional pressure available. This figure is the total head requirement for the pump.
7. The flow rate is determined from the specific application.

PIPING MATERIALS

The piping materials are the same as for the NG system.

FUEL GAS PRESSURE BOOSTER SYSTEM

Occasionally the pressure available in a utility company or site main may not be high enough to supply the required pressure for equipment intended to be installed in a facility. For these conditions, a gas pressure boosting system is required.

SYSTEM DESCRIPTION

The purpose of a gas booster pump system is to raise the pressure of fuel gas supplying equipment or devices that require a higher than available pressure. The gas booster is a low-pressure compressor that has been adapted for flammable gases, and it shall not exceed the 5-psi requirement established in NFPA 54.

CODES AND STANDARDS

In addition to the previously listed codes and standards associated with the fuel gas piping system, there are usually standards that originate with the local utility company in whose jurisdiction the project is located. These standards relate to protecting both the utility company's and the facility's low-pressure piping system from back pressure or suction resulting from the booster pump operation. The utility company will review proposed plans and require the installation of any protective devices they believe are necessary. When starting, the booster may develop a suction pressure of −15 in WC or more on a gas meter. If this situation is possible, protection is required.

SYSTEM COMPONENTS

The components of the gas booster system are the booster pump, heat exchanger (if required), protective components, and the piping, valves, and so on in the distribution network.

Booster Pump

Booster pumps are available in positive displacement, piston, and centrifugal fan types. For general use in facilities, the centrifugal fan is the type most often selected.

The booster pump shall be UL approved and hermetically sealed. The fan is directly coupled to the motor and completely enclosed in an airtight housing that does not require external shaft seals. Access to the fan is made from a gasketed cover plate assembly. The fan shall be manufactured of spark-resistant materials, with the most often used material being aluminum. The design of the pump shall provide different mounting positions that allow easy connection of the distribution piping to the booster outlet.

The booster pump shall be installed in an unconfined area that provides sufficient air to circulate about the unit to provide cooling. The unit shall be mounted so that vibration is minimized.

Heat Exchangers

The purpose of a heat exchanger is to lower the temperature of the fuel gas. This may be necessary for several reasons.

The flow of gas through the booster pump cools the motor. If the flow is too low, the small volume is not capable of removing sufficient heat for proper operation. To relieve this condition, a bypass arrangement that provides partial recirculation of the gas discharge through a heat exchanger to cool it will provide the necessary flow of cool gas.

The passage of gas through the booster pump heats the gas as it passes through the pump. As a general rule, each stage of a booster pump raises the gas temperature 20°F (6°C). If the ambient temperature of the room where the booster is located is hot, the gas temperature downstream of a multistage booster could exceed 140°F. Since most valves, diaphragms, controls, and other equipment are usually rated at 150°F (60°C), it may be necessary to install a heat exchanger to cool the gas.

Heat exchangers can be either air cooled, water cooled, or refrigerated. For general use in facilities, single-pass, modular, air-cooled units are the most common. The most often used material of construction is corrosion-resistant aluminum. This type of unit uses a self-contained, temperature-controlled auxiliary fan to increase the flow of ambient air across the exchange fins. It is considered good practice to have all the gas discharged flow through the exchanger and to use a temperature switch in the discharge gas line to turn on the fan only as required by the temperature of the gas. When the heat exchanger is used to cool the main supply to a facility, it is good practice to install a soft seat check valve in the discharge downstream of the heat exchanger.

The criteria needed to size the heat exchanger are the highest anticipated ambient air temperature and the maximum flow of gas in cubic feet per minute (cubic meters per minute). Each manufacturer has selection criteria based on this information.

Because of the hazardous nature of this system, it is a requirement that the control panels be in an NEMA-7 enclosure.

System Protection

When using a booster pump to increase gas pressure, safety devices and techniques are necessary to protect both the utility company's piping and the facility system from a number of possible accidents and equipment malfunctions. The following is a general discussion of potential failures and methods used to prevent damage to the system. Since not all of these failures are possible for every installation, judgment is required in their application for any specific project.

1. When using pressurized air, oxygen, or another gas for burner nozzles or other similar equipment in conjunction with NG, check valves must be installed on all of the lower-pressure lines to prevent high-pressure gas from entering the lower-pressure system.
2. Burner systems using pressurized air, oxygen, or another gas may cause a suction on the NG line if the NG supply is interrupted. A low-pressure electrically

operated switch shall be installed to stop the operation of the higher-pressure gas system if this situation occurs.

3. Excessive suction may be produced when starting the booster. If starting results in a suction pressure of more than −15 in WC at the utility company's piping, a pressure switch shall be installed to stop the booster.
4. There are usually two independent low-pressure protection devices installed on a burner system to prevent operation if the supply pressure falls too low. The first is a low-pressure switch, usually supplied by burner manufacturers on their gas train, that shuts off the burner under low gas pressure conditions. If this switch proves insensitive, another switch should be installed upstream from the train regulator. The second pressure switch is installed on the utility company's line to prevent booster operation if the pressure in the utility company supply line falls below 3 in WC.
5. Unit heater systems using booster pumps must be rated for the highest pressure capable of being generated by the pump plus the "lock-up pressure." If this arrangement is not possible, a pressure relief must be installed between the pump and the first unit heater. In addition, a low gas pressure switch shall be installed to prevent heater operation in the event that the gas pressure falls too low. The relief valve outlet must be piped outside the building to a safe location.
6. Some utility companies require 20 ft (6.3 m), of piping to be provided between a burner and a check valve when using an alternative fuel with a higher pressure than the booster pump is capable of providing.
7. All of the above may have to be approved by the local utility and building department authorities.

SYSTEM DESIGN CONSIDERATIONS

Gas booster starters should be wired directly to the equipment they are serving, so that if the equipment is not operating, the booster will not run. If multiple pieces of equipment are wired to a booster, isolating relays are required.

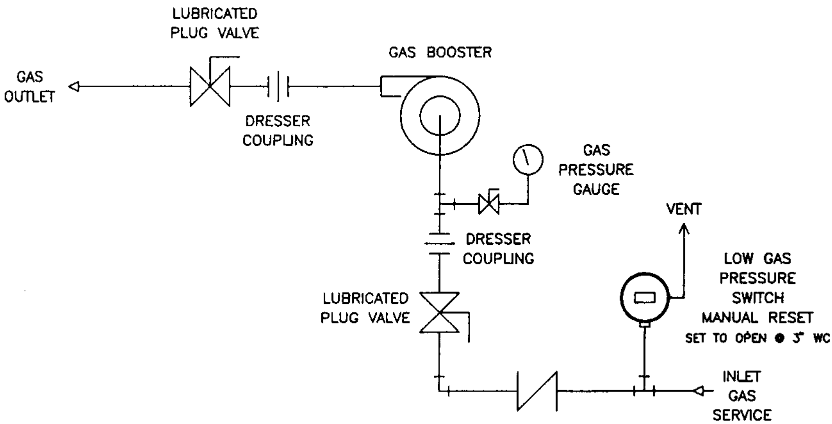


FIGURE 13.11 Schematic piping diagram of a typical booster pump.

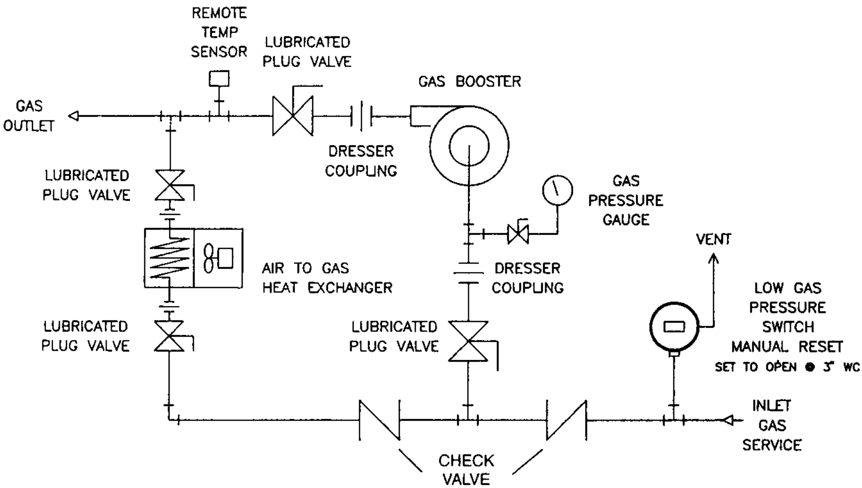


FIGURE 13.12 Schematic piping diagram of a typical booster pump with heat exchanger.

If other gases, such as LPG, are used as an alternate fuel, a three-way valve shall be installed to limit the gas supply to only one source.

If higher pressures are available from the alternate fuel sources, a regulator shall be installed on the higher-pressure sources so that the actual delivery pressure is the same as that supplied by the utility company.

Some utility companies do not permit a large-size booster to be connected to a low-pressure NG service. Contact the utility company to determine any restrictions.

In general, electronic ignition rather than pilot lights should be used. If pilot lights are the only alternative, they are not permitted to be supplied with a pressure higher than approximately 7 in WC.

A schematic detail of a typical simplex booster pump installation without a heat exchanger is illustrated in Fig. 13.11, and a schematic detail of a typical booster pump installation with a heat exchanger is illustrated in Fig. 13.12.

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