
CHAPTER 8

CRYOGENIC STORAGE SYSTEMS

Cryogenic gas, as used in this handbook, is defined as any gas in a liquid state at or below -20°F . This chapter describes the bulk storage of cryogenic liquids used for laboratory and light industrial purposes and the piping of cryogenic liquids from storage tanks. There are two applications of cryogenic storage. The first is for a facility that uses a large volume of gas and needs storage on site for practical and economical reasons. The second is for cold liquids required for research, cooling, and other purposes.

Cryogenic storage systems for gases in health care facilities and distribution of gases created from cryogenic storage are discussed in Chap. 14, Compressed Gas Systems.

SYSTEM COMPONENTS

The major components of a cryogenic storage system include the bulk storage tank containing gas in liquid form, a vaporizer (if a gas is desired), and the piping network conveying either gas or liquid to the point of use. The vaporizer is directly connected to the storage tank and is used to convert the liquid gas into its gaseous state (see Fig. 8.1).

CODES AND STANDARDS

The following are codes used for the design and fabrication of cryogenic systems:

1. Underwriters Laboratories, UL-644
2. ASME Code for Unfired Pressure Vessels
3. NFPA 50, 50A, and SOB
4. NFPA 99 Health Care Facilities (often used as a standard for laboratory piping)
5. ASTM G-88
6. ASME/ASTM B3 1.3 Code for Pressure Piping

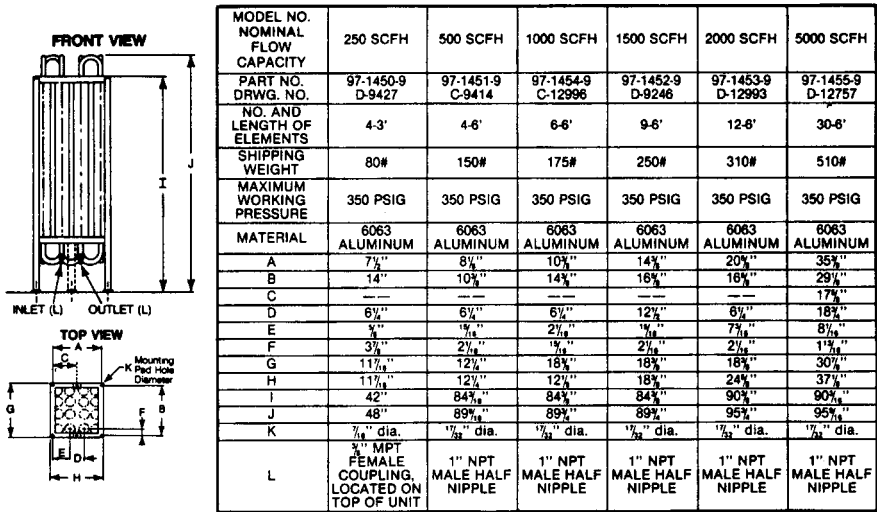


FIGURE 8.1 Ambient air vaporizers.

BULK STORAGE

Gas is often stored as a cryogenic liquid when the anticipated volume of gas usage is large enough to make cryogenic storage economical and practical. The reason for this is volume. The cold liquid occupies considerably less volume than a comparable quantity of compressed gas. The gases most commonly stored as cryogenics are nitrogen, argon, and oxygen. Also available but less common are carbon dioxide, hydrogen, and helium. The storage tanks can be generally categorized as either large bulk tanks or smaller dewers.

Large Bulk Tanks

Refer to Table 8.1 for standard large tank sizes. These tanks are highly insulated, generally with Pearlite or other proprietary high efficiency insulation in a vacuum, and can be installed either horizontally or vertically. Vertical installation is most common because a vertical tank occupies less site area than a horizontal one. Another reason is that the vertical tank presents less wetted area for the liquid to vaporize, and it is desirable to keep the stored liquid in that state as long as possible. The dimensions of the tanks vary slightly if installed horizontally or vertically, but the greatest difference is only about 6 in in length for the largest tanks. The horizontal tank is slightly smaller and lighter. All capacities are given in gallons of water. Manufacturers have similar tanks models, with some standard sizes having a capacity as low as 300 gallons. All tanks are ASME rated as unfired pressure vessels.

When locating the tanks on a facility site, there must be enough room for the delivery truck to approach close to the tank. Access to the tank must be easy because the operator must vent gas from the hose connection of the truck to the storage tank by means of the manual vent before filling can start. Two connections

TABLE 8.1 Typical Bulk Cryogenic Storage Tank Dimensions

Nominal capacity, gal	Diameter	Height	Working pressure, psig	Nominal tare weight, lb	Normal evaporation rate, %/day LOx
315	4'	8'1"	250	2,600	.90
525	4'	11'1"	250	3,600	.55
900	5'	11'7"	250	5,500	.40
1,500	5'6"	15'0"	250	9,100	.35
1,500	5'6"	15'8"	150	10,800	1.5
1,500	5'6"	6'6"	150	11,000	1.5
3,000	8'	16'7"	50	14,900	.17
3,000	8'	16'7"	250	20,360	.50
3,000	8'	16'4"	250	17,340	.17
6,000	8'	9'0"	250	34,500	.30
6,000	8'	27'0"	50	19,900	.15
9,000	9'6"	30'9"	250	53,500	.26
9,000	9'6"	30'9"	250	51,300	.10
11,000	9'6"	35'7"	75	34,900	.10
11,000	9'6"	35'7"	250	65,900	.25
11,000	9'6"	35'7"	250	60,000	.10
13,000	10'	36'7"	72	41,000	.10
13,000	10'	36'7"	250	68,300	.10
13,000	10'	36'7"	250	74,100	.25

Source: Minnesota Valley Engineering, Inc.

to the storage tank are desirable, one to the top of the tank (in the vapor space) and one to the bottom (in the liquid). This allows the operator to adjust the pressure in the tank during filling. Filling from the bottom will compress the vapor on top, increasing pressure. Filling from the vapor space on top will lower the pressure because some of the vapor will condense and turn back to liquid thereby reducing the volume of vapor. If filling to a set level is required, a level gauge must be installed on the tank.

There will be leakage of gaseous product from the cryogenic tank if there is no withdrawal of liquid product for a period of time. Each tank is insulated and not intended to have a high internal pressure. The rising of pressure inside the tank resulting from internal vaporization of product will raise the pressure higher than the allowable tank working pressure and will have to be vented to atmosphere from the relief vent. For the actual losses from specific tanks and gas products, consult the manufacturer of the tank or supplier of the gas. For comparison, refer to Table 8.1 for vaporization of oxygen in terms of percent loss of gases.

Dewers

Dewers are smaller insulated tanks used to store smaller quantities of cryogenic gases in individual laboratories or outdoors if required by space conditions. They

can be manifolded together for larger storage capacities, if desired. Standard size dewers are illustrated in Fig. 8.2.

SIZING THE LARGE BULK TANK

The amount of liquid to be stored is based on the anticipated volume of gas to be used between deliveries. The delivery schedule represents a compromise on the length of time between deliveries preferred by the supplier and those preferred by the client. The period of time most often suggested between deliveries ranges between once or twice a month. Proceed with the sizing as follows:

1. Determine the proposed usage of each gas per day, shift, or week as closely as possible. This is best done based on past experience. If the installation is new or past information is not available, calculate the expected usage based on the total number of outlets and connected equipment, the quantity of gas used by each, and amount of time each day they are expected to be used.

2. Contact the intended supplier (or interview several if one supplier is not being used at the present time) to obtain the intended delivery schedule and price. Agree on a tank size based on keeping the tank as small as possible and yet having a reasonable supply between deliveries. A minimum of two weeks between supply is a good starting point. Once a month is also common.

3. Calculate the actual usable capacity of the storage tank(s) based on the proposed usage per day multiplied by the number of days between deliveries. Use Table 8.2 to convert gallons of liquid to cubic feet of gas.

4. Add 25 percent to the actual usable capacity found in step 3. This figure will allow 15 percent for the additional empty volume used as vaporization space above the high allowable liquid level when full, and 10 percent additional volume actually occupied by the liquid gas present but not intended to be used, since this is a reserve capacity. This 10 percent should allow a two-day reserve supply of liquid in the tank when the actual low level alarm point is reached in order to allow enough time for the supplier to send more product. An absolute low-level point, which would trigger an emergency call to the supplier, should be 5 percent of capacity. In summary, select a total storage tank volume based on actual usage plus 25 percent.

5. When filling a tank, consider the fact that the density of cryogenic gases varies with pressure. The higher the storage pressure the more liquid will be in the tank. For nitrogen, refer to Fig. 8.3 for the density-pressure relationship.

6. Install vertical tanks on a concrete pad. The strength of the concrete should be a minimum of 3000 psi. The size of the pad should be a minimum of 6 in larger than the diameter of the tank, and if there is additional equipment (like a vaporizer), the pad should be enlarged accordingly. Recommendations of the manufacturers indicate that the minimum soil-bearing strength of the soil should be 2000 psi. In addition, the concrete should be poured over a 6-in layer of crushed stone or gravel. The thickness of the pad depends on the capacity of the tank and the pad should be reinforced. The reinforcement should be wire mesh for small pads and rebar each way (top and bottom) for large pads. Since the tanks may be required to be tested with water some time, use water weight to determine the tank foundation requirements. To estimate the total weight to be supported, find the tare (empty)

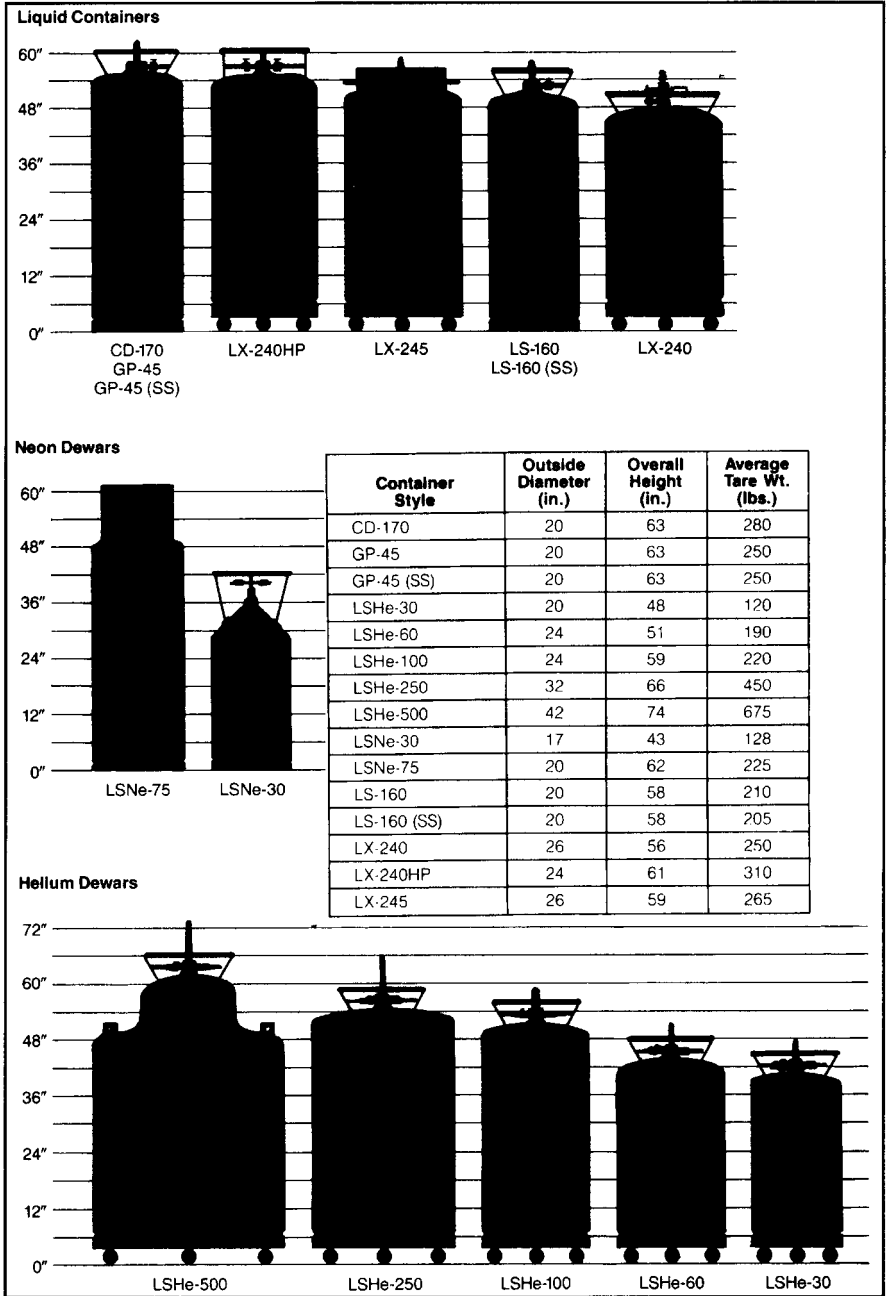


FIGURE 8.2 Cryogenic containers.

TABLE 8.2 Physical Properties of Gases

Gas		Argon	Carbon dioxide	Helium	Neon	Nitrogen	Oxygen
Atomic or Molecular Weight		39.948	44.010	4.0026	20.183	28.013	31.999
Normal Boiling Point (nbp)		°F -302.6	-109.3	-452.1	-410.9	-320.4	-297.3
Freezing Point		°F -308.9	-109.3	—	-415.5	-346.0	-361.8
Triple Point (tp)		°F -308.9	-69.8	—	-415.5	-346.0	-361.8
		psia 10.0	75.2	—	6.3	1.8	0.022
Critical Point		°F -188.1	87.9	-450.3	-380.0	-232.5	-181.1
		psia 710.0	1071.0	33.2	395.0	493.0	737.0
Density	Gas, NTP	lbs/ft ³ 0.1034	0.1144	0.01034	0.05215	0.07245	0.08281
	Gas, STP	lbs/ft ³ 0.1114	0.1234	0.01114	0.05618	0.07805	0.08921
	Vapor, nbp	lbs/ft ³ 0.363	—	1.04	0.596	0.287	0.279
	Liquid, nbp	lbs/ft ³ 86.98	63.36	7.798	75.35	50.46	71.27
Specific Heat, Cp, Gas, NTP Btu/lb, °F		0.125	0.20	1.25	0.246	0.247	0.220
Specific Heat Ratio, Cp/Cv, Gas, NTP		1.67	1.31	1.66	1.66	1.41	1.40
Heat of Vaporization, nbp		Btu/lb 70.2	246.6	8.72	37.0	85.7	91.7
Heat of Fusion, tp		Btu/lb 12.7	85.6	—	7.1	11.1	6.0
1 Gallon Liquid to cu. Ft Gas, NTP		112	92	100	95	93	115

NTP = Normal Temperature and Pressure

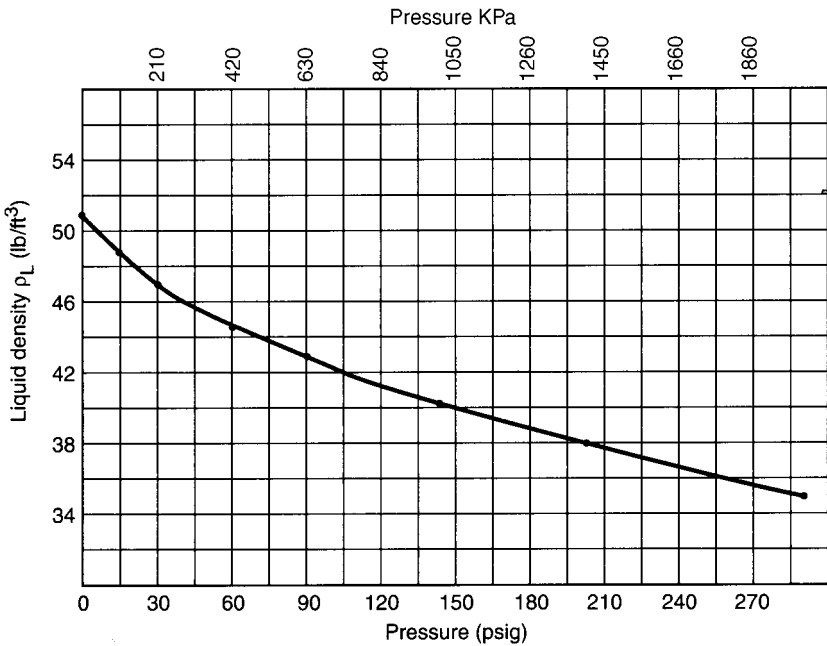


FIGURE 8.3 Density-pressure relationship for nitrogen.

weight of the tank and use the capacity as if filled with water. For a quick estimate, multiply the capacity in gallons by 15.

Tank pad thickness should conform to these minimums:

Capacity, gallons	Thickness	
	inches	mm
Less than 900	12	300
1500 to 3000	15	375
6000 to 9000	18	450
11,000	21	525
13,000 and larger	24	300

Large horizontal tanks usually have piers located 8 ft from each end of the tank. Smaller tanks have supports located one-quarter of the distance from each end. It is then necessary to design foundations based on the weight of the tank and its contents spread out between the two piers. The foundations for the piers shall extend below the frost level.

Vertical tanks are attached to the foundations by bolts connecting legs on the tanks to the concrete pad. The bolts are supplied by the manufacturer and installed by the contractor supplying the pad. The specifications should require the contractor to install the tanks based strictly on manufacturers' requirements and under their supervision.

7. Cryogenic storage tanks are actually two tanks, one inside the other. The annulus is filled with insulation and a vacuum in order to provide a high degree of insulation. Storage tanks used only for gas supply are normally constructed for a working pressure range of between 150 and 250 psig, with the pressure relief valve set to 10 percent over the working pressure. If the low temperature were not maintained, the liquid gas introduced into the tank during filling would vaporize instantly and the pressure inside the tank would quickly rise above the working pressure. If a filled tank is not used for a period of time, usually about two days, approximately 0.5 percent of the contents of the tank per day will be lost through the relief valve in order to maintain the set pressure. This is called the normal evaporation rate. For the approximate normal vaporization rate of oxygen from storage tanks, refer to Table 8.1. Other gases are approximately equal except hydrogen, where experience has shown that the evaporation rate is approximately 3 percent per day because of the ability of the atoms of the gas to slip through the molecules of the metallic tanks and piping.

Another option for storage tank system installation is to allow the supplier to size, design, and install the tank based on a performance specification. It is then the responsibility of the supplier to accurately size the storage system based on the provided usage criteria. In many cases, it is also possible for the installation of the storage tank and equipment to be paid for by the supplier and the cost paid out over 7 to 10 years along with the cost of the gases.

The information required by suppliers is as follows:

1. *Location of the facility (to determine outside air conditions).* If site temperature ranges are available, provide this also.
2. *Peak quantity of gas to be used in cfm and cfh (Lpm or Lph).* Indicate peak usage per day and week if possible. If this quantity is not obtainable, then state how the gas will be used and the total number of outlets or stations in the facility.
3. *Constant or intermittent use of gas.* If only a portion of the use is constant, the use is considered constant. This information is used to determine if a vaporizer is necessary, and to size it based on usage.
4. *Required pressure range of the gas.*
5. *The proposed location of the tank on the site.* Consider easy road access to the location by the supply truck.
6. *Flammable or reactive gas.* If the gas is either one, then separate the tank and any other material storage as required by NFPA and local codes.

SIZING THE VAPORIZER

Bulk gases are stored as liquid, and must be converted to gas prior to being used. If a large volume is used by the facility, neither the storage tank nor the pipeline gain sufficient heat to convert liquid into enough gas to satisfy demand. To convert the necessary volume of liquid into gas, a device called a vaporizer is required.

The most popular vaporizer has no moving parts and uses ambient air to warm the cryogenic liquid as it passes through a long length of finned tubing. The vaporizer is installed close to the storage tank, usually on the same pad. Each man-

ufacturer has standard size units that are selected based on the SCFH, type of cryogenic liquid to be vaporized, and the lowest expected outdoor temperature. For typical sizes of atmospheric vaporizers, refer to Fig. 8.1. If a large volume is expected, a vaporizer using an additional source of heat obtained from steam, electricity, or fuel gas may be required.

A common material for the vaporizer is aluminum. If high purity is required, stainless steel is used. For preliminary sizing based on a temperature of 70°F and 70 percent relative humidity, an approximate figure is that each 8-ft length of 8-in diameter aluminum tube with 8 fins per foot will vaporize 500 cfh.

Manufacturers have proprietary methods for sizing vaporizers. Two factors are necessary for sizing: the lowest mean ambient air temperature for 72 h and the flow rate of the gas. The flow rate is given in cubic feet of gas per hour. For example, if there is a requirement for 100 ft³ of gas in only 10 min, the flow rate of vaporization must be 600 cfh. Aluminum vaporizers are generally rated at 400 psig, with Monel, Inconel, and stainless steel inserts inside the fin tube available for higher pressures.

The area under the vaporizer is constantly wet. This is due to the ice melting and condensing on the fins and dripping to the ground when the ambient temperature becomes warm. Because of this, the immediate area must have good slope drainage or be provided with a drainage inlet.

PRESSURE FROM LIQUID GASES

The vapor pressure inside of a dewar or tank depends on the outside ambient temperature. Figure 8.4 is the vapor pressure curve for nitrogen and 8.5 for carbon dioxide.

NOTE: TYPICAL SERVICE CONDITIONS 87 PSIG & -320°F

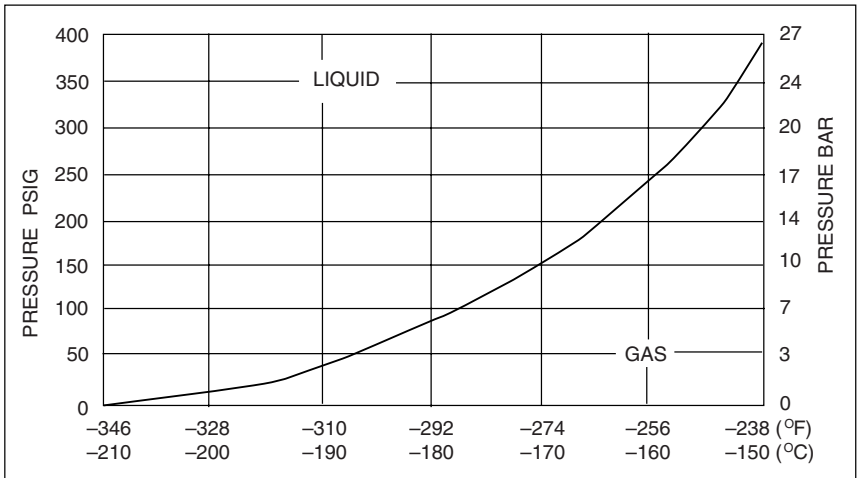


FIGURE 8.4 Vapor pressure curve for nitrogen.

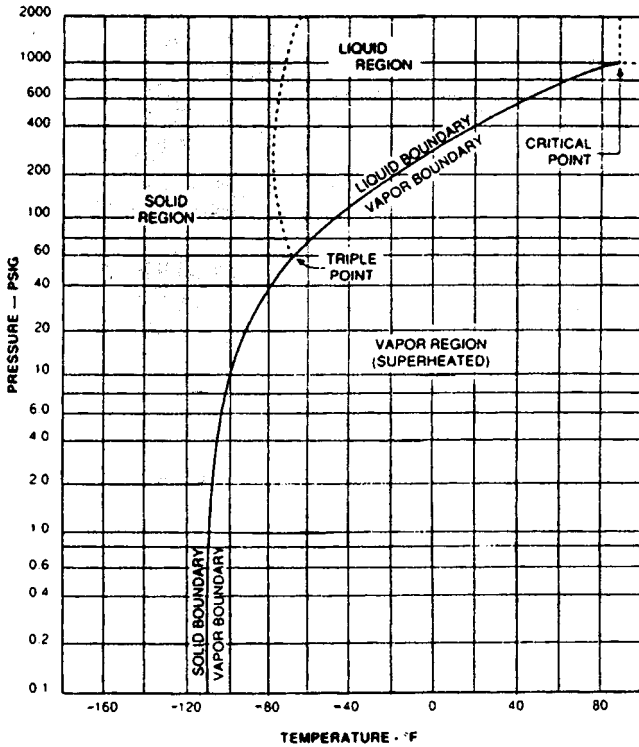


FIGURE 8.5 The pressures and temperatures in all CO₂-storage vessels and transfer piping must be closely monitored, to keep the substance from changing phase. Source: Airco Gases.

PRESSURE RELIEF VALVES

Pressure relief valves for overpressure protection must be provided in all cases where some gases or cryogenic liquids can become trapped between valves. In oxygen service (and other gases supporting combustion), a condition known as *adiabatic compression* can occur. When a gas at high pressure escapes into a lower pressure pipeline and encounters an obstruction, the temperature of the gas is greatly raised. This may cause autoignition of the metal used for the pipeline (see Fig. 8.6). For noncombustible or nonflammable gases, the rise in pressure of liquid turned to gas by adsorbing heat could exceed the design pressure of the pipe.

Pressure relief valves must be installed on a thermal standoff. They must be sized to vent the required amount of gas needed to lower the pressure inside the tank or piping system. A pressure release valve must be installed between any two valves. When the pressure relief valve goes off, it does not reseal at the set pressure but instead at a pressure about 20 psig lower. This may cause excessive loss of gas if allowed to happen regularly. Another type of relief used on tanks is a *rupture disk*. This is a nonresettable device set to break at a predetermined pressure and is considered an emergency vent that automatically operates when all other pressure

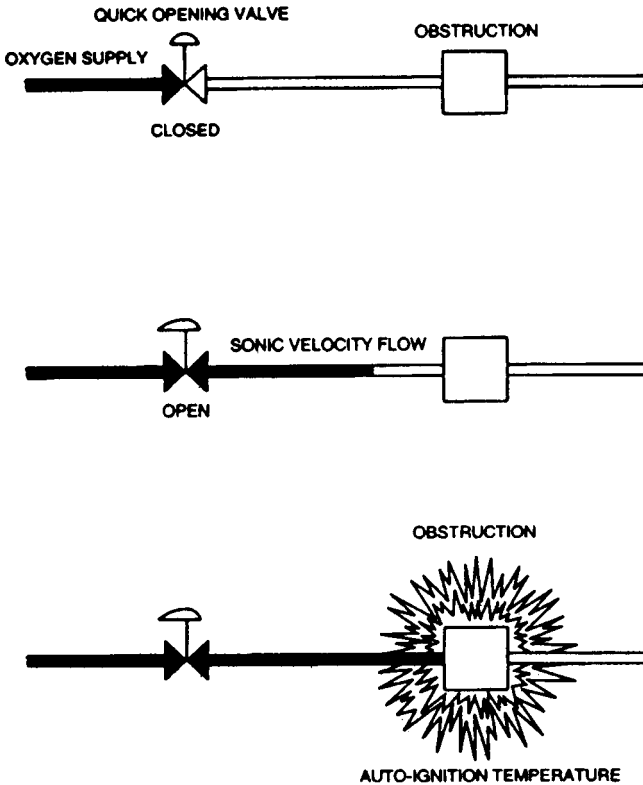


FIGURE 8.6 Adiabatic compression.

relief devices have failed to relieve pressure. All contents of the tank will be lost if the rupture disk is used.

PIPE MATERIALS AND INSULATION

General

Liquid gas piped directly from storage is often needed for laboratory and industrial purposes. It often requires a relatively long run of pipe. When a cryogenic liquid is piped from the storage tank to its point of use, a heavily insulated pipe must be used to avoid having product lost through flashing into a gas due to the high temperature of the pipe and absorbing heat from the ambient air. Most flashing occurs during the initial cooling of the pipe by the cryogenic liquid after a period of nonuse.

For cryogenic work, major consideration must be given to the material of the piping system and the insulation used to keep the heat loss to a minimum. It is

impossible to separate the piping material from insulation because, in most cases, the insulation is an integral part of the pipe itself or is factory applied.

Selection of Pipe and Insulation

The criteria for selecting pipe and insulation depend on the extent of the pipe run and the use of the piping.

When only gas is to be produced from cryogenic liquids, no insulation is used so that the product can absorb as much heat as possible. The type of piping on the tank is chosen by the manufacturer. For runs of piping carrying cryogenic liquid, the piping system is selected based on the amount of product allowed to be lost by flashing and adsorption of heat and whether the piping will be in continuous or intermittent use.

There are two general classes of insulated piping: double-wall piping with the annulus vacuum insulated and single-wall piping with the pipe exterior thermally insulated. Vacuum-insulated piping is double walled. It could be either a static vacuum system, where the annulus vacuum is factory assembled during manufacture, or a dynamic vacuum system, where a vacuum is applied to the annulus by continuous vacuum pumping.

Double-Wall Piping with Annulus under Static Vacuum. This double-wall system is usually manufactured from schedule 40, 304 SS, with nonmetallic spacers used to keep the piping apart. The pipe is manufactured in sections with the vacuum applied to the annulus during manufacture and sealed. Pipe joints are assembled using a mechanical “bayonet” joint with an O ring to connect the sections, which consists of a long male section being inserted into a female section and physically connected with a bolted flange. This provides a long heat leakage path.

Double-Wall Piping with Annulus under Dynamic Vacuum. This double-wall system is often manufactured from corrugated copper tube with nonmetallic spacers used to keep the piping apart. Pipe joints are assembled using a bayonet joint as previously discussed or brazed joints using a silver brazing alloy. A connection to the outer double-wall pipe provides the inlet to a vacuum pump which is used to produce the vacuum-insulating pressure.

Single-Wall Pipe with Exterior Thermal Insulation. Typical pipe could be made of copper water tube (hard drawn type K or L) or stainless steel (type 304 or 316 SS preinsulated with PE having a density of 2 lb/ft³), either 1½, 2 or 3 in thick. Fittings are usually wrought copper. The pipe is jacketed with PVC, .06 in thick. The pipes and fittings are preinsulated, with the ends bare to allow jointing. Additional insulation is installed after the pipe is tested. Copper pipe is jointed by using a silver brazing alloy. SS pipe is usually welded.

PIPE SIZING METHODS

The cryogenic lines are sized on flow rate and head loss. Because the specific gravity of the liquid is almost, but always less, than that of water, the same charts can be used for velocity and friction loss with the assurance of a safety factor. As

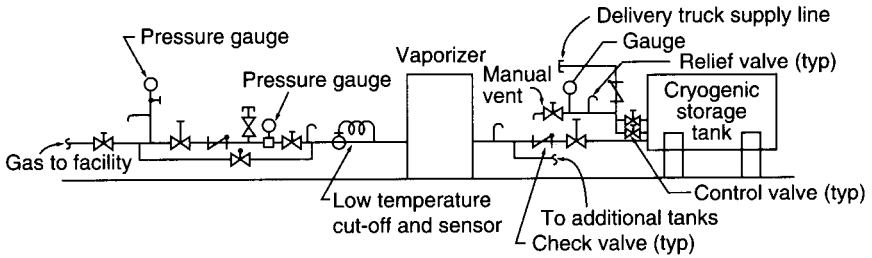


FIGURE 8.7 Detail of large-scale storage tank.

an example, the specific gravity of liquid nitrogen is 0.81. The pressure in the storage tank can be adjusted to produce the pressure necessary to overcome the static lift and friction loss through the lines.

A combination of vapor and liquid in the same line is called *two-phase flow*. This flow is less than that of liquid alone. For laboratories that use small amounts of cryogenic liquid for freezer cooling, or to fill dewers, two-phase flow is not important because only a small amount of liquid discharge, from the line is desired after the gas is eliminated. It is important for facilities that use an open discharge port to fill dewers, that the room or area where this is done be very well ventilated to avoid the accumulation of gas that invariably is discharged along with the liquid.

SYSTEM DESIGN CONSIDERATIONS

For a detail of a typical large-scale storage tank, refer to Fig. 8.7.

REFERENCES

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