Davis, Linda S

From: Davis, Linda S
Sent: Tuesday, March 16, 2010 5:04 PM
To: chme@ecn.purdue.edu; chmegrad@ecn.purdue.edu
Subject: Safety Update #14: Compressed Gas Cylinder Safety
Attachments: Chemical Engineering_116_52-58Oct_2009.pdf

ChE Faculty, Staff and Students,

If you use compressed gas cylinders in your laboratory, please read the attached article "Compressed Gases: Managing Cylinders Safely." The article is authored by Richard Palluzi, a distinguished engineering associate at ExxonMobil, and provides recommendations for safe handling, storage and use of gas cylinders.

Two videos illustrate the energy that is released when a compressed gas cylinder valve is broken:

- Myth Busters: Air Cylinder Rocket at http://www.youtube.com/watch?v=ejEJGNLTo84
- Compressed Gas Training Video: Missile Hazard at http://www.youtube.com/watch?v=pe9gYRXQTTY

Linda

Linda S. Davis
Industrial Education Director
Chair, ChE Safety Committee (https://engineering.purdue.edu/ChE/AboutUs/Safety.html)
School of Chemical Engineering
Purdue University
480 Stadium Mall Dr.
West Lafayette, IN 47907-2100
Phone: (765)496-1710
lsdavis@purdue.edu

COMPRESSED GASES: Managing Cylinders Safely

Richard Palluzi
ExxonMobil Research & Engineering

Follow these recommendations to ensure the safe handling, storage and use of gas cylinders

Compressed gas cylinders are widely used in research, pilot plant, laboratory and small-scale manufacturing and processing operations as a way to provide a convenient, economical and safe source of high-pressure gases for various applications. These gases can be inert, flammable, toxic or oxidizing (or mixtures of any or all), and are typically supplied at pressures from 800 to 6,000 psig, with 2,250 psig being common. A compressed gas is defined by the U.S. Department of Transportation (DOT) as any materials or mixtures in containers having an absolute pressure in excess of 40 psi at 70°F, or in excess of 104 psi at 130°F.

Cylinder basics

Gas cylinders have several major components, including the cylinder body, a steel or aluminum cylinder with a strengthened, threaded neck, a flat bottom rim for standing level, the valve assembly to control the gas flow, and a protective cap. Each cylinder is stamped with its design information, as shown in Figure 1. Items of particular interest include the cylinder size (which is required for calculating the content volume), the cylinder maximum design pressure, and the cylinder test date.

If it is past the test date indicated on the cylinder, the cylinder can be transported and the contents can still be used, but the unit cannot be refilled. Nearly all manufacturers label their cylinders with a stick-on label that provides the type of information shown in Figure 2.

Different manufacturers refer to their cylinders by a variety of different terms, and not all manufacturers provide all sizes. The most common sizes are shown in Table 1.

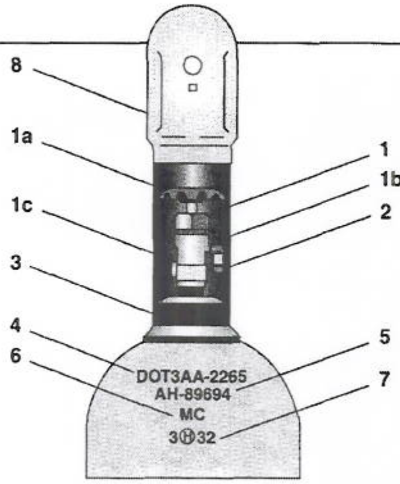
In the U.S., gas cylinder design and construction is governed by DOT codes. Rarely does a user need to worry about how a given cylinder is designed. One exception, however, is when the user is asking for a specialty cylinder for a non-standard application, such as a specialty gas made specifically for a one-time application, a sample of a new mixture, or similar one-of-a-kind uses. Specialty cylinders that are significantly past their date (by two years or more), should not be used; rather, they should returned to the supplier as soon as this fact has been discovered. Cylinders provided by specialty suppliers for non-standard sources should be confirmed to be adequately designed before being accepted.

Gas cylinders are designed to be transportation vessels — not pressure vessels. As such, they are not usually intended to replace a well-designed pressure vessel. In particular, DOT design standards are not intended to adequately cover pressure cycling. Most DOT vessels will only be rated for ~60% of the comparable American Society of Mechanical Engineers (ASME) rating. Hence, before using any gas cylinder as a pressure vessel (such as an accumulator), the design should be reviewed by both a pressure vessel expert and the vessel manufacturer. In most cases, using the cylinder will not prove to be the best course. For these applications, a properly designed and constructed ASME-code vessel is the proper choice.

Pressure relief

Gas cylinders are protected from overpressure in several ways. A pressure-relief device is always installed in the neck of the cylinder (Figure 1). A variety of such devices may be used, depending on the supplier and the gas:

- ***A rupture disk (CGA code CG-1).*** This device consists of a thin piece of metal that is designed to burst and release the cylinder contents to the atmosphere. The rupture disk setting may not exceed the minimum-DOT-required test pressure of the cylinder, which is usually 167% (5/3) of the cylinder service pressure. It may not exceed 4,500 psig for the DOT-3E or CTC-3E specification cylinders, nor be less than 105% of the cylinder test pressure, or greater than 80% of the minimum burst pressure for DOT-39 cylinders.
- ***A fusible link (CGA code CG2 or 3).*** This device relies on a metal link that is designed to melt at a given temperature and release the cylinder contents to the atmosphere. Fusible links are generally set between 165 and 220°F.
- ***A combination rupture disk and fusible link (CGA code CG 4 or 5).*** In this design, a fusible plug is provided on the atmospheric side of the rupture disk. The burst pressure of the disk may not exceed the minimum DOT-required test pressure of the cylinder, and the fusible link must melt or extrude between 157 and 220°F. Such an assembly is designed to prevent a release in the event of a small external fire (in which case the fusible link may fail but the pressure not rise sufficiently to burst the rupture disk), or a premature failure of the rupture disk (in which case the fusible link will remain intact).
- ***A spring-loaded relief device (CGA code CG7).*** This device is designed to open when the pressure exceeds a set value and to close again once the excess pressure is relieved. These are relatively uncommon in most gas cylinders due



1 Cylinder shut-off valve packing nut
1a Cylinder shut-off valve
1b CGA outlet connection
1c Cylinder pressure-relief device (relief valve, rupture disk or fusible link)
2 CGA outlet cap to protect threads and keep clean
3 Threaded cylinder collar to accept protective metal cap
4 DOT specification (3AA) and service pressure (2,265 psig)
5 Manufacturer's serial number
6 Manufacturer's symbol (MC)
7 Test date (3/89)
8 Cylinder cap

FIGURE 1. Key components of an appropriately appointed compressed-gas cylinder are shown here

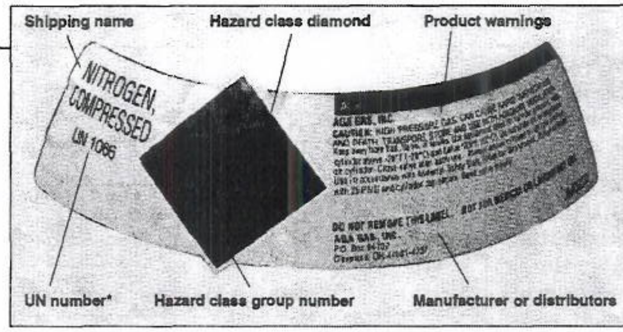


FIGURE 2. The manufacturer's label provides critical information to assist the end user

to their larger size, higher cost and greater complexity. The relief device setting must be greater than 75% and less than 100% of the cylinder's minimum test pressure with a reseating pressure greater than the pressure in a normally charged cylinder at 130°F. The relief device on DOT-39 cylinders must not exceed 80% of the minimum burst pressure of the cylinder nor be less than 105% of the cylinder test pressure.

Meanwhile, heating is often required for calibration gases (to prevent condensation) and liquefied petroleum gases (to vaporize the liquid or increase the delivery pressure). No matter which type of device is used, the potential for cylinder overheating remains a concern. In all cases, gas cylinder heating should be carried out by indirect methods using steam, hot water, hot air enclosures or similar heated enclosures.

While some manufacturers supply electric heating blankets, these should be considered a higher-risk alternative. The electric heating elements often operate well above the fusible-

TABLE 1. COMMON CYLINDER DIMENSIONS AND CAPACITIES

Size	DOT specifications	Nominal dimensions* (Excluding valve & cap), in.	Average tare weight, lb	Average internal volume, ft³
High pressure				
A	3AA2400	9 x 55	137	1.76
B	3AA2265	9 x 51	119	1.55
C	3A2015	7 x 33	57	0.56
D-1	3A2015	7 x 19	26	0.26
D	3AA2015	4 x 17	9	0.10
4X	3AA2015	4 x 13	6.6	0.075
L.B.I.	3E1800	2 x 12	2	0.015
L.B.	3E1800	2 x 12	2	0.015
Medical E	3AA2015	4 x 26	14	0.16
BX	3AA6000	10 x 51	300	1.49
BY	3AA3500	9 x 51	187	1.53
Low pressure				
A	3A480	10 x 49	85	1.93
B	3A480	10 x 36	90	1.28
C	3A480	8 x 22	33	0.53
AA	4AA480	15 x 52	160	4.46
A1	4BW240	16 x 50	75	3.83
A-2	4BW240	22 x 48	167	7.64
C_2H_2				
A	8/8AL	12 x 41	185	2.36
HCl and bulk electronic gases				
Y	3A1800	24 x 90	1,108	15.83
H_2S				
T	106A800X	30 x 82	2,254	25.82
SO_2, C_2H_5Cl, Cl_2, CH_3Cl				
T	106A500X	30 x 82	1,400	25.64
Aluminum				
A(Al)	3AL2216	10 x 52	90	1.64
B(Al)	3AL2015	8 x 48	48	1.04
C(Al)	3AL2216	7 x 33	32	0.56
D-1(Al)	3AL2216	7 x 16	15	0.21
4X(Al)	3AL1800	4 x 10	3.3	0.057
Nickel				
B	3BN400	7 x 45	88	0.65
D-1	3BN400	7 x 22	48	0.28
D-2	3BN400	5 x 15	10	0.10
Stainless steel				
55 gal	UN1A1	24 x 45	175	7.35
10 gal	UN1A1	14 x 29	50	1.34
5 gal	UN1A1	9 x 24	25	0.67

*These dimensions are not exact. They should not be used for engineering drawings or equipment specifications.

link, relief-valve or rupture-disk setting (800–1,100°F is common) even when operating at lower temperatures. Hence the heating elements rely on the control system (whether automatic or manual) to limit the cylinder temperature to a value below that required to initiate the relief device. The Box on p. 58 shares some simple guidelines for safe hot-box design.

Regulations and codes

In the U.S., specific requirements from the Occupational Safety and Health Administration (OSHA) for gas cylinders are rather minimal:

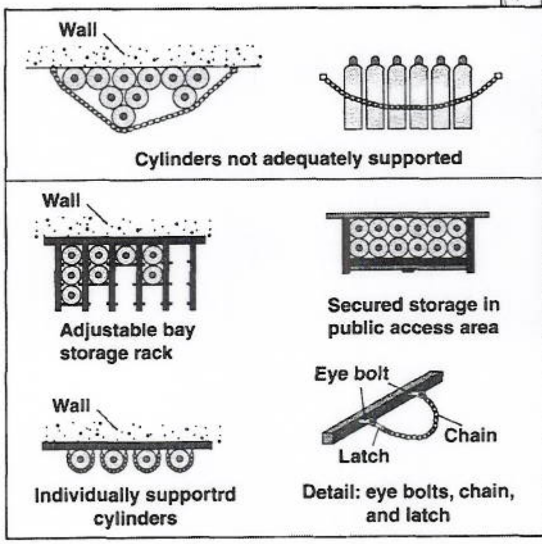
- OSHA 1910.101 (a) requires routine inspections per DOT regulations [49CFR parts 171–179, and 14CFR part 103]
- OSHA 1910.101 (b) requires that in-plant handling, storage and utilization shall be per Compressed Gas Association CGA P-1-1965
- OSHA 1910.101 (c) requires all cylinders to have safety-relief devices

Similarly, in several other parts, OSHA 29CFR provides some more-specific requirements for larger-size installations that are typical of full-scale industrial plants:

- 1910.253 Oxygen-Fuel Gas Welding and Cutting
- 1910.102 (Acetylene)
- 1910.103 (Hydrogen)
- 1910.104 (Oxygen)
- 1910.105 (Nitrous Oxide)

These are generally for larger site-wide or plant-wide installations.

Meanwhile, DOT addresses cylinders in depth in several regulations (namely, 49CFR parts 171–179 and 14CFR part 103), but these are generally restricted to the transportation aspects and do not affect laboratory research or other end-use applications except with regard to receiving cylinders or shipping out materials in cylinders. DOT regulations do prohibit refilling of any cylinder without the manufacturer's permission (although obtaining the manufacturer's permission in this litigious age can prove to be challenging). Fortunately, such applications, while rare, may need additional time and effort to be addressed.



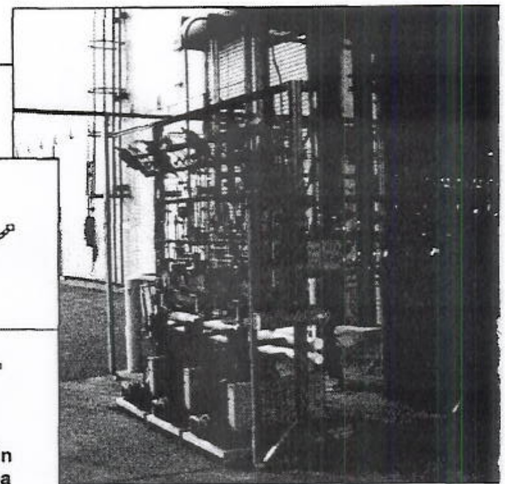


FIGURE 3. Unless they are properly secured, compressed-gas cylinders can fall and present a hazard in the workplace. Examples of proper procedures for securing gas cylinders are shown here

Meanwhile, the National Fire Protection Association (NFPA) addresses gas cylinder usage in several codes. The the two most prominent are NFPA-55: Storage, Use and Handling of Compressed and Liquefied Gases in Portable Cylinders, and NFPA-45: Fire Protection for Laboratories Using Chemicals. NFPA-55 is intended more for industrial applications, focusing on larger volumes and manufacturing applications. In fact, NFPA-55 specifically excludes laboratory applications and storage in 1.1.2 (0) from the scope of the standard. NFPA-45 addresses cylinders in detail in Chapter 11 but explicitly excludes pilot plants in 1.1.2 (2). Where pilot plants are covered remains somewhat uncertain. Some organizations apply NFPA-45 (despite the specific exclusion), others apply NFPA-55 despite what seems to not be the intent, and some apply neither.

Proper storage

Storage areas should be located away from sources of excessive heat and potential ignition. Care is required to ensure that all cylinders are protected against heating above 52°C (125°F). Storage areas should also be secured against unauthorized personnel and must be properly ventilated. They should be located at least 30 ft from any air intakes at the facility.

Exterior storage areas should always have a roof to keep cylinders out of direct sunlight. Even cooler climates can result in cylinders reaching 52°C (125°F) or above on hot summer days.

Exterior storage areas should be kept clear of weeds, grass and similar combustible vegetation for at least 15 ft around the perimeter of the cylinder storage area. Flash ground fires can easily span this distance in a matter of minutes — far too fast for emergency responders to intervene effectively.

All storage areas should also be clearly marked as "No Smoking" areas. Protection against vehicular collision is also necessary. Remember that the delivery vehicle may well be the most likely source of the collision so facilities should plan accordingly for positive protection that is designed to withstand the strongest anticipated collision.

Regardless of where the gas cylinders are stored, they should all be properly secured from falling (Figure 3). Except when stored in a properly designed central storage facility with their metal protective caps on, gas cylinders should not be secured in large groupings. When the chain or rope is removed, it is possible for a group of cylinders to fall, creating a hazard. Cylinders should be secured in smaller groups of not more than 4–6 cylinders, as an added precaution.

When installed for use, all gas cylinders should be individually secured at 1/2 to 3/4 of their height to a fixed support. Movable benches, rolling tables and similar objects should never be used as supports. A cylinder-transport cart, while very useful for transporting cylinders safely, should never be used

TABLE 2. NFPA-55 MAXIMUM ALLOWABLE QUANTITY OF GASES PER CONTROL AREA (QUANTITY THRESHOLDS FOR GASES REQUIRING SPECIAL PROVISIONS)

Material	Unsprinklered areas		Sprinklered areas	
	No gas cabinet, gas room, or exhausted enclosure	Gas cabinet, gas room, or exhausted enclosure	No gas cabinet, gas room, or exhausted enclosure	Gas cabinet, gas room, or exhausted enclosure
Corrosive gas				
Liquefied	68 kg (150 lb)	136 kg (300 lb)	136 kg (300 lb)	272 kg (600 lb)
Non-liquefied	23 m^3 (810 ft^3)	46 m^3 (1,620 ft^3)	46 m^3 (1,620 ft^3)	92 m^3 (3,240 ft^3)
Cryogenic fluid				
Flammable	0 L (0 gal)	170 L (45 gal)	170 L (45 gal)	170 L (45 gal)*
Oxidizing	170 L (45 gal)	340 L (90 gal)	340 L (90 gal)	681 L (180 gal)
Flammable gas				
Liquefied	114 L (30 gal)	227 L (60 gal)	227 L (60 gal)	454 L (120 gal)
Non-liquefied	28 m^3 (1,000 ft^3)	56 m3 (2,000 ft^3)	56 m^3 (2,000 ft^3)	112 m^3 (4,000 ft^3)
Highly toxic gas				
Liquefied	0 kg (0 lb)	2.3 kg (5 lb	0 kg (0 lb)	4.5 kg (10 lb)
Non-liquefied	0 m^3 (0 ft^3)	0.6 m^3 (20 ft^3)	0 m^3 (0 ft^3)	1.1 m^3 (40 ft^3)
Nonflammable gas				
Liquefied	No limit	No limit	No limit	No limit
Non-liquefied	No limit	No limit	No limit	No limit
Oxidizing gas				
Liquefied	57 L (15 gal)	114 L (30 gal)	114 L (30 gal)	227 L (60 gal)
Non-liquefied	43 m^3 (1,500 ft^3)	85 m^3 (3,000 ft^3)	85 m^3 (3,000 ft^3)	170 m^3 (6,000 ft^3)
Pyrophoric gas				
Liquefied	0 kg (0 lb)	0 kg (0 lb)	1.8 kg (4 lb)	3.6 kg (8 lb)
Non-liquefied	0 m^3 (0 ft^3)	0 m^3 (0 ft^3)	1.4 m^3 (50 ft^3)	2.8 m^3 (100 ft^3)
Toxic gas				
Liquefied	68 kg (150 lb)	136 kg (300 lb)	136 kg (300 lb)	272 kg (600 lb)
Non-liquefied	23 m^3 (810 ft^3)	46 m^3 (1,620 ft^3)	46 m^3 (1,620 ft^3)	92 m^3 (3,240 ft^3)
Unstable reactive (Detonable) gas, Class 3 or Class 4				
Liquefied	0 kg (0 lb)	0 kg (0 lb)	0.5 kg (1 lb)	1 kg (2 lb)
Non-liquefied	0 m^3 (0 ft^3)	0 m^3 (0 ft^3)	0.3 m^3 (10 ft^3)	0.6 m^3 (20 ft^3)
Unstable reactive (Non-detonable) gas, Class 3				
Liquefied	1 kg (2 lb)	2 kg (4 lb)	2 kg (4 lb)	4 kg (8 lb)
Non-liquefied	1.4 m^3 (50 ft^3)	3 m^3 (100 ft3)	3 m^3 (100 ft^3)	6 m^3 (200 ft^3)
Unstable reactive gas, Class 2				
Liquefied	114 L (30 gal)	227 L (60 gal)	227 L (60 gal)	454 L (120 gal)
Non-liquefied	21 m^3 (750 ft^3)	43 m^3 (1,500 ft^3)	43 m^3 (1,500 ft^3)	85 m^3 (3,000 ft^3)
Unstable reactive gas, Class 1				
Liquefied	No limit	No limit	No limit	No limit
Non-liquefied	No limit	No limit	No limit	No limit

Note: The maximum quantity indicated is the aggregate quantity of materials in storage and use combined.
*A gas cabinet or exhausted enclosure is required. Pressure-relief devices or stationary or portable containers shall be vented directly outdoors or to an exhaust hood.

as a support for a cylinder without its protective cap in place.

All storage areas should also be well-ventilated. While laboratories usually have high exhaust rates that are capable of handling routine leaks from gas cylinders, some may be inadequate to handle significant releases, particularly for toxic or liquefied gases. Enclosed interior storage spaces are a particular concern as the modest exhaust capacity provided is often overwhelmed by even a small leakage (and would be unable to safely evacuate a full cylinder release). Accidental releases, while rare in properly designed systems, do occur. As such, exterior storage areas should not be overly enclosed. The best designs are open on all four sides. When this is not practical, then no more than two sides should be enclosed, or special provisions for cross-ventilation should be provided, as shown in Figure 4.

The area electrical classification of cylinder storage areas is a function of the gases stored and the ventilation

TABLE 3. NFPA-45 GAS CYLINDER LIMITATIONS

Gas	For a laboratory work area of 500 ft² or less internal cylinder volume	For a laboratory work area > 500 ft² internal cylinder volume per ft² area
Flammable	6 scf	0.012 ft³
Oxidizing	6 scf	0.012 ft³
Liquefied flammable gas	1.2 scf	0.0018 ft³
NFPA health hazard 3 or 4 gas	0.3 scf	0.0006 ft³
Lecture bottles	25 total	

rate. If the flammable gas storage is significant or the ventilation rate low, it may be prudent to classify the area as Class I Division 2. If only a small quantity of flammable materials is involved, if the ventilation rate is high or in an unenclosed exterior location then General Purpose (ordinary) classification is usually adequate. Note that in many cases, cylinder storage areas have only minimal electrical equipment and fixtures, typically lighting. Hence, electrically classifying the area as Class I Division 2, while conservative, may be an appropriate and very low-cost solution.

All storage areas should also have easy access that is free of extended ramps and enclosed spaces. Consider that a release of even an inert gas in an elevator, for example, could be enough to cause asphyxiation.

Cylinder placement

How many cylinders can be used in a laboratory? Table 2 provides the NFPA-55 requirements. Table 3 provides NFPA-45 requirements. Local building codes may mandate even more stringent levels.

NFPA-45 provides some additional guidance. For instance, it specifies that cylinders "not required for current operations" shall be stored outside the laboratory work area. High-hazard gases shall be kept in a hood or other continuously ventilated enclosure. (A high-hazard gas is one that has an NFPA health hazard rating of 3 or 4 or 2 with no physiological warning properties.)

So what is the best location for gas cylinders used in laboratory and research applications? While it has been common practice for years to place cylinders directly in labs, this may not necessarily be the best approach. For instance, it is difficult to maintain the required separation of flammable and oxidizing materials required in a standard laboratory. Hazardous gas cylinders are often placed outside hoods. All cylinders have a tendency to end up in escape paths or along major traffic corridors. Gas cabinets are expensive, and are both space- and exhaust-intensive. They also are not foolproof in preventing a fire or explosion in the (admittedly unlikely) event of a major cylinder leak.

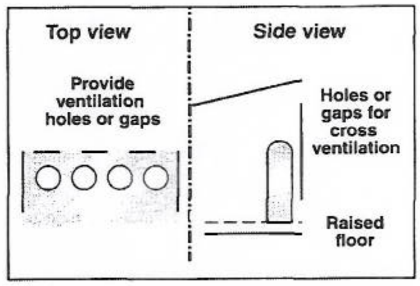


FIGURE 4. Proper ventilation is an important design consideration when storing gas cylinders, even in exterior storage areas

Even worse, cylinders are often moved around to obscure corners, alcoves, cabinets and closets with minimal ventilation or inadequately designed and constructed, ventilated cabinets and boxes that do not meet the safety requirements of a bona fide gas cabinet.

The preferred placement for cylinders used in a research or laboratory setting should be as follows:

- Outside the laboratory or pilot plant area with the gas piped to its final use location
- In a specially designed, gas-cylinder -storage area in the facility, with the gas piped in to its final use. This may be adjacent to the area served, or some distance away, depending on what makes most sense safety wise and economically
- Inside a specially designed gas cabinet that meets the requirements of NFPA-55

Inert gas cylinders, while posing significantly fewer dangers than those containing flammables, toxics or oxidizing agents still pose some risks and should follow these same guidelines. The argument that a lone cylinder of helium for a gas chromatograph poses a trivial or acceptable risk may be valid, but even a single cylinder improperly piped or secured can pose a hazard. And, since this lone cylinder often tends to accumulate additional, more-hazardous brothers and sisters over time, sound engineering design precedent should be established and maintained from the beginning.

Gas cabinets are commonly used for those desiring to keep their cylinders in the laboratory. NFPA-55 provides prudent requirements for such a setup:

- Such cabinets must be at negative pressure with respect to the laboratory, and have an average face velocity across the open doors of 200 ft/min, with a 150 ft/min minimum at any point
- Self-closing access doors and noncombustible windows are required
- The interior must be equipped with sprinkler systems
- The cabinet must be labeled as to its contents

NFPA-55 requires that toxic gases shall be treated to neutralize or dilute the effluent to below toxic levels that are considered to be life-threatening. Many organizations rely on the dilution effect of the exhaust and dispersion from the exhaust stack well above grade to achieve this effect. However, this may not be possible with very toxic gases or larger cylinder volumes.

Cylinder piping

Cylinders need to be properly piped to their final use location to ensure safe operation. A suggested minimum piping schematic is shown in Figure 5. No system should ever be supplied from a gas cylinder without a regulator to set the feed pressure. However, it is not safe to rely on a regulator alone to prevent a system from overpressure. Operator error and regulator failure can lead to a failure of the downstream equipment — with dangerous or even fatal consequences.

Instead, a relief device of some type should be used. It may be a spring-loaded device (Figure 5) or a rupture disk (for higher-purity or lower-maintenance applications), or a similar relief device. The relief device needs to be properly sized to handle a regulator failure, which produces flows as much

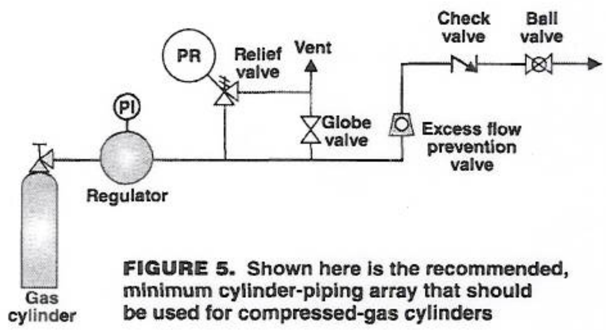


FIGURE 5. Shown here is the recommended, minimum cylinder-piping array that should be used for compressed-gas cylinders

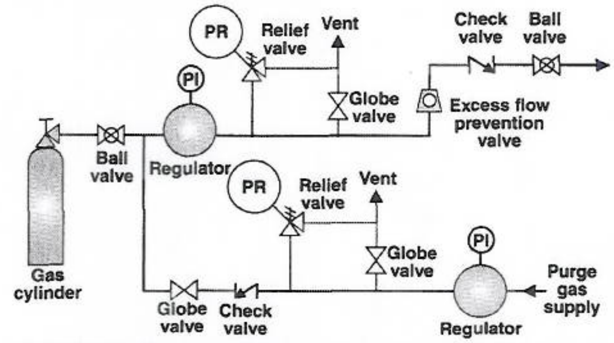


FIGURE 6. The recommended, minimum cylinder-piping array with purge capabilities is provided here

as an order-of-magnitude higher than the maximum regulator-design flow. The relief device vent should be piped to a safe location, typically an exhaust duct or vent stack. Both will need to have their sizing confirmed as adequate.

The purpose of a manual globe valve around the relief device (as shown in Figure 5) is to allow manual venting and purging during cylinder changes and system maintenance. It also allows the system pressure to be lowered through venting, in the event that the supply pressures are inadvertently set too high. This valve should always be a slow-opening, multiple-turn globe type to prevent a sudden depressurization.

The excess-flow-prevention valve should be mandatory on all piping systems involving flammable and toxic systems. It is intended to shut off (or at least limit the flow to an acceptable smaller rate) in the event of a system or component failure. Some facilities allow a manual bypass around this device, to allow initial filling at a higher rate without tripping the device, or to allow the excess-flow-prevention valve to be reset if tripped.

However, this is not the most appropriate approach. Too often, the manual bypass is left open, defeating the capabilities and intent of the excess-flow-prevention valve. If a bypass is required, it should be of the deadman type (requiring the operator to hold it open), or be on a timer that closes the bypass automatically after a minute or two.

The check valve is intended to prevent backflow into the gas cylinder from a source of higher pressure. If such a source is not present, then one might naturally consider eliminating the check valve; however, it should be a standard part of all gas cylinder installations, as higher-pressure sources often appear down the road and create problems if the check valve is not installed.

The manual ball valve is intended to provide a fast means to shut off the gas cylinder in an emergency situation, and also allows the system to be easily locked out and tagged for maintenance. In this case, both the gas cylinder shutoff valve and the ball valve should be closed, and the manual vent valve should be opened to vent the system, completing the double block-and-bleed setup.

Many organizations like to add a second block valve immediately downstream of the gas cylinder and before the regulator, to enable the isolation of the system for change out and maintenance. In this case, the valve must be rated for the full cylinder pressure.

Purge streams are also common on higher-purity systems (Figure 6). Since purge systems are usually lower-pressure gas supplies, it is important to provide the back flow and relief protection shown. The purge-system vent should also be treated as a potentially hazardous stream and piped to the same vent location as the purged hazardous gas.

Piping should be run in areas where it is to be expected. Routing pipe above offices, personnel corridors and supply rooms can lead to unfortunate incidents later, in the event that the piping is assumed to be something innocuous. At best it can lead to service interruptions; at worst to accidents. Similarly, piping should not be run above suspended ceilings unless the space is ventilated as part of the laboratory. Small leaks can develop into very hazardous situations over extended periods in unventilated areas. Even if ventilated, all welded systems should be strongly considered above suspended ceilings particularly for flammable or toxic gases. All valves above the ceiling should be of the packless or bellow-type seal. Better yet, no valve should be allowed in these areas.

Open all cylinder valves slowly. Pressurizing a system, particularly for the first time or following maintenance always presents a high potential risk. If the valve does not open by hand or with the manufacturer-supplied wrench, do not attempt to force it with a pipe wrench or similar tool that might be capable of transmitting too much force. Such efforts can result in unscrewing — or at least loosening — the entire valve assembly, with results ranging from leaks to catastrophic failure.

Stand clear of all outlet piping while opening the cylinder until the pressure has equalized. If there is going to be a failure, it usually happens in the first moments of pressurizing. While such an occurrence is extremely rare, this is still a prudent and essentially no-cost safety measure.

Cylinder connections

All cylinders come with special threads on the outlet. In the U.S., these threads follow standards that are developed by the Compressed Gas Association (CGA), and are often called CGA fittings. CGA fittings should never be modified or changed, as they are designed to minimize the chance of unsafe connections.

CGA fittings should never be forced if they do not fit properly. They are very effective for pure gases, but are less foolproof with mixtures since different vendors have different practices for assigning thread types to a particular gas mixture. Care must be taken before connecting a new cylinder to ensure compatibility.

Adaptors are available to ensure a proper fit between a CGA fitting and the existing pipe thread. However, these must be used with extreme care as they essentially allow the bypassing of safeguards.

Labeling

Gas cylinder piping should be clearly labeled as to its contents. The location of the feed cylinder should be posted at the point of final use to allow emergency responders to know where to go in order to shut off the cylinder. Similarly, the location should be posted at the cylinder unless it is obvious (for instance, strapped to the device), so the user knows what impact the shutoff of a specific cylinder may have.

Never rely on the vendor's color coding as it typically vary between vendors. Make sure each gas cylinder is carefully checked to confirm its contents from the label affixed to the cylinder before placing it in service.

Empty cylinders

Empty cylinders should be kept separately from full cylinders. Mark empty cylinders as soon as possible; as a rule-of-thumb (until the situation can be verified), always assume a cylinder is full and act accordingly to ensure safety, even when it is marked empty.

Cylinders should not be used at pressures below ~25 psi, to prevent gases from being drawn from the system into the cylinder and creating an inadvertent hazard for the vendor when refilling the cylinder. The remaining useable volume in a cylinder can be found from the following formula:

Actual volume = [(*Actual pressure*) (*Initial volume*)]/*Initial pressure*

Emergency response

All organizations using gas cylinders should have procedures in place for how to deal with leaking cylinders. The type of gas (inert, flammable or toxic) will obviously be a major factor, as will the cylinder location, rate of leakage, ventilation and numerous other incident-specific factors. Waiting to develop a plan once a leaking cylinder has been found, with no basis from which to work, is a recipe for a very poor and usually ill-conceived, response.

GUIDELINES FOR SAFE HOT-BOX DESIGN

These tips will ensure safe hot-box design for gas cylinders that require heating.

Ensure the enclosure has adequate over-temperature protection that is independent of the control system. A separate sensor, alarm and shutoff are the minimum required. The alarm should be latching (for instance, requiring a person to manually reset it), and should require someone to deliberately reset the alarm before heating can resume. Ensure that the temperature control and alarm systems are interconnected and enabled to allow the hot box to heat.

Confirm the placement of the over-temperature sensor carefully to ensure it monitors the hottest area. All too frequently, the device can be placed out of the way in a significantly cooler corner. Confirm the enclosure does not have such substantial temperature differentials to create a problem.

Provide adequate audible and visual alarms to signal a problem to the operating personnel. Take immediate automatic action to shut down all heat sources in the event of a high temperature.

Ensure the enclosure has adequate ventilation to prevent small leaks from building up to become a major hazard. Typical ventilation rates are 1 ft^3/min per square foot of floor area, with 150 ft^3/min as a suggested minimum. In general, exhaust ventilation should be provided at floor level. In larger installations (over 100 ft^2), both high- and low-point exhaust should be provided.

Make sure all heating elements are protected against direct impingement on the cylinder. Particular care should be paid to ensuring that a heavy cylinder cannot be pushed against a heater. Many mechanical guards to prevent this accident are clearly inadequate when compared to the forces they need to withstand when struck by a 300-lb cylinder in motion.

Ensure the hot box is completely constructed of non-combustible materials. Fire-retardant materials are not adequate. This includes doors, ramps and racks. ❑

Managing the inventory

All organizations should inventory their cylinders at least annually. This allows the user to identify unused cylinders, spot potential problems with older cylinders, and reduce demurrage charges (the rental fee the supplier charges on the cylinders). Return any damaged, suspect or unneeded cylinders immediately to the supplier.

Consider establishing retention times on cylinders with corrosive gases. Six to twelve months are common but each case needs to be individually evaluated. In general, no cylinder should be kept for more than 36 months. If it has not been used in that time, either it is not required or the amount of gas has been oversized.

Develop procedures to force individuals to dispose of cylinders before personnel transfer to other sites, to avoid accumulating un-owned cylinders around the facility. Failure to do so is not only costly in terms of continued demurrage charges, but is potentially very dangerous. Most organizations have their own horror stories of aged gas cylinders that were found in unexpected locations.

Cylinders cannot be tossed in the garbage, but must be returned to the supplier. Note, however, that some new small calibration-gas and mixed-gas cylinders are designed for single use, and are intended to be disposed of when empty.

Gas cylinders are common and very safe if installed and operated properly. However, despite their widespread use in research, they always hold the potential for accidents and injuries if not properly handled. ■

Edited by Suzanne Shelley

Author

Richard Palluzi is a distinguished engineering associate at ExxonMobil Research & Engineering Co. (1545 Route 22 East, Annandale, NJ 08801; Phone: 908-730-2323), responsible for the design, construction and support of pilot plants and laboratories for the firm's research site in Clinton, N.J., and consulting on pilot-plant issues throughout ExxonMobil worldwide. The author of two books, 30 articles and 40 presentations on all phases of pilot plant and laboratory safety and operations, he is a member of AIChE, ISA, the American Soc. of Safety Engineers and the National Fire Protection Assn., and was recently elected to the last-named organization's committee on NFPA-45 Fire Protection for Laboratories Using Chemicals. He teaches three pilot-plant training courses for AIChE, and is a past chair of the AIChE Pilot Plant Committee, as well as of the Clinton site's Safe Operations Team. Also, he currently chairs ExxonMobil's Pilot Plant and Laboratory Safety Standards Committee. Palluzi has consulted for both the U.S. Dept. of Energy and Dept. of Defense on research-related issues. He holds B.S.Ch.E. (1974) and an M.S.Ch.E. (1976) from Stevens Institute of Technology.