AIR PRODUCTS

Safetygram #46

A Practical Guide to Restrictive Flow Orifices

Restrictive flow orifices (RFOs) installed in cylinder valve outlets provide a significant safety benefit for users of hazardous gases, especially highly toxic or pyrophoric gases. An RFO is a simple, effective, inexpensive safety device that limits gas flow to a greatly reduced discharge rate during an accidental release. In keeping with Air Products' commitment to Product Stewardship and Responsible Care,® Air Products supplies a 0.010 inch (0.25 mm) RFO in cylinders smaller than 85 liters containing the products shown in Table 1 and mixtures that are classified as highly toxic ($LC_{50} \leq 200$ ppm). CGA pamphlet P-20, *Standard for Classification of Toxic Gas Mixtures,* contains methods to calculate the LC_{50} for toxic gas mixtures. Cylinders with an RFO installed have a label that indicates the size of the orifice diameter.

RFOs have been in use for over 20 years and are a proven, prudent safety technology. The orifice will reduce the flow of gas if an unconnected valve is inadvertently opened or if there is a failure of the downstream piping system when a cylinder is connected to that system. An RFO has no moving parts, and for the maximum benefit, the orifice is installed into the cylinder valve outlet as shown in Figure 1. A gasket is used to create a seal between the restrictor and the valve body. The RFO is about 3/8 inch (10 mm) in length and is typically constructed of 316L stainless steel.

Figure 1

Restrictive Flow Orifice Placement

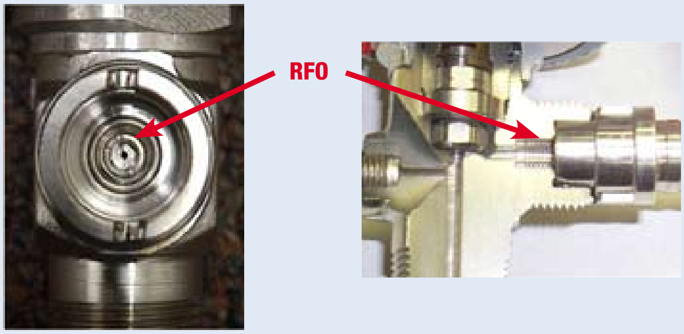


Table 1

Air Products Gases Offered with RFOs

Gas Name	Hazards	Specific Gravity [70°F, 1 atm]
Arsine (AsH_3)	Highly Toxic	2.7
Diborane (B_2H_6)	Toxic, Flammable	0.95
Disilane (SiH_6)[1]	Pyrophoric	2.3
Germane (GeH_4)	Toxic, Flammable	2.7
Hydrogen selenide (H_2Se)	Highly Toxic	2.8
Nitric oxide (NO)	Highly Toxic	1.0
Phosphine (PH_3)	Highly Toxic	1.2
Silane[1] (SiH_4)	Pyrophoric	1.1

[1]Per CGA G-13, silane is required to have an RFO not exceeding 0.010 inch in diameter.

Risk Reduction

A properly positioned RFO limits the gases' hazardous effects if there is a leak during cylinder connection and use. Effects that can be reduced include vapor cloud mass, jet fire size and downwind dispersion distances. The capacity of control systems associated with the gas delivery and distribution may be reduced accordingly, such as room or enclosure ventilation rates and treatment systems sized for emergency releases.

The potential risks from a cylinder that contains hazardous gas or liquefied compressed gas is not solely dependent on the existence of an RFO. The entire system must be evaluated to understand all the safeguards or layers of protection to ensure risk is properly managed. Issues to understand before making a decision regarding the use and sizing of an RFO in the cylinder valve include:

- Local code, standard or guideline requirements (see **References in Codes, Standards and Guidelines**)
- Indoor or outdoor system location
- System mechanical integrity—number of leak points, leak point isolation capability
- Operating and maintenance procedures
- Operator training
- Local ventilation effectiveness
- Local monitoring (i.e., gas leak, smoke, heat, flame detection systems)
- Automated shutdown capability
- Cylinder separation from other hazardous exposures
- Cylinder separation from sensitive receptors (on-site personnel, property lines, third parties)

In general, an RFO does not provide significant risk reduction during cylinder transportation, on-site handling or storage. This is because cylinders containing highly hazardous gases are required to have their valves tightly closed and leak-tight outlet seals installed while in transportation and storage. However, an RFO installed in a valve outlet does provide additional risk mitigation when the outlet seal is removed for valve inspection, cylinder connection and product use. During this time, personnel and equipment may be exposed to an accidental release of product via equipment malfunction and/or operator error. The RFO significantly limits the flow rate achievable from the cylinder as compared to the flow from a valve without an RFO in place.

The hazard reduction benefit of an RFO installed in a cylinder valve outlet is illustrated by a silane cylinder containing 31 lb (14 kg) of product at a pressure of 1,440 psig at 70°F (101.5 kg/cm^2-g at 21°C). The silane release from a fully open cylinder valve (Cv = 0.25) with no RFO is calculated to be 414 scfm (11,700 slpm) producing a jet fire length in still air of 20 ft (6.1 m). The silane release from the same cylinder incorporating a 0.010 inch (0.25 mm) diameter RFO is calculated to be 2.4 scfm (68 slpm) producing a jet fire length in still air of 1.9 ft (0.58 m).

References in Codes, Standards and Guidelines

Several codes, standards and guidelines allow credit for RFO installation if the location of the RFO mitigates the worst-case or credible release events. See the **Additional Resources** section for a sampling of codes, standards, guidelines and global documents that reference RFOs. The credit given for RFOs is most manifest in codes that allow risk-based evaluation of hazards rather than prescriptive control measures. A risk-based code permits calculation of worst-case and credible hazards based on feasible loss-of-containment scenarios. Since a properly positioned RFO can greatly mitigate maximum flow rate from a hazardous gas system due to loss of containment, calculated release rates may be used to determine exposure separation distances, ventilation requirements, emergency treatment system sizing, etc. This is illustrated in NFPA 318 for silane delivery systems, which permits reduced ventilation rates for valve manifold distribution cabinets with RFOs in the upstream supply. Another example is CGA G-13, which allows reduced separation distances based on maximum orifice size for silane source containers. A third example of RFO credit is illustrated by IFC Chapter 37, which permits a toxic or highly toxic gas treatment system to be sized per actual cylinder venting time if the RFO is positioned in the cylinder withdrawal valve or connection rather than a prescribed time based on a worst-case release.

In some of these examples, the benefit to reduced system siting requirements or exhaust ventilation equipment sizing is very significant. For example, NFPA 318 requires the ventilation system for a silane gas cabinet to limit the maximum concentration of silane inside the enclosure to 0.4 percent by volume. For a silane gas cabinet containing a cylinder with 31 lb (14 kg) of product, a 0.020 inch (0.51 mm) RFO installed in the cylinder valve would require a ventilation rate of 2,400 cfm (68 m^3/min), but with a 0.010 inch (0.25 mm) RFO installed the ventilation rate is reduced to 600 cfm (17 m^3/min). The reduced ventilation rate results in much lower energy costs.

The benefits of reduced treatment system sizing may also be very significant. This is illustrated by the assumed complete release time of 30 minutes mandated by certain Codes for a highly toxic liquefied compressed gas with no RFO. However, a 44L pure arsine cylinder complete vent time is approximately 23 hours with a 0.010 inch RFO installed in the cylinder valve outlet. Therefore, the exhaust ventilation rate through the gas cabinet may be significantly reduced to capture the resultant worst-case arsine release due to pigtail rupture. In addition, the ventilation treatment system (i.e., scrubber) flow capacity can be reduced accordingly to achieve the same final arsine discharge concentration to atmosphere.

RFO Sizing

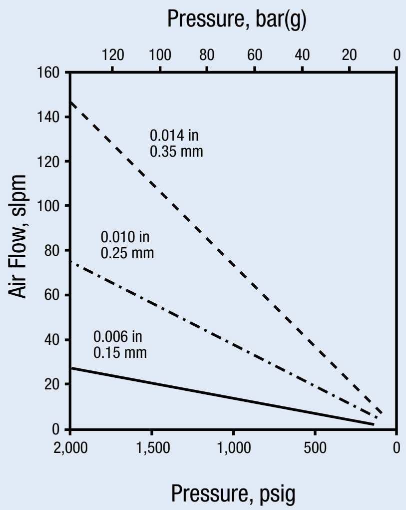
The gas flow through the orifice is dependent on the orifice diameter, inlet pressure, temperature and the specific gravity of the gas. The size of orifices commonly ranges from 0.006 to 0.16 inches (0.15 to 4 mm) in diameter. The orifice needs to allow adequate flow for normal operations, even at lower cylinder pressures, and at the same time must provide adequate flow restriction to limit accidental release. Gas consumers need to ensure that the orifice size can meet their operational needs. If there are no customer specifications, Air Products supplies a 0.010 inch (0.25 mm) RFO in cylinders smaller than 85 liters containing the products shown in Table 1 and in highly toxic mixtures. Cylinders over 85 liters in volume require special consideration, and process flow calculations must be performed to determine sizing and utility, e.g., silane tube modules or 2% phosphine mixtures in 448 liter cylinders.

Figure 2 (shown on next page) shows air flow rates at varying cylinder pressure for three orifice sizes (0.006 inch, 0.010 inch, and 0.014 inch.). The flow rate for other gases or mixtures can be estimated using Formula 1.

Note that certain gases become non-ideal at certain operating conditions, especially at high pressure and/or near their critical temperature, and the scaling of air flow data may not provide an accurate prediction of the RFO flow rate. For these cases, more rigorous calculations or published values should be used. Silane is such an example, and silane-specific flow rates as a function of RFO size and source pressure are reported in NFPA 318 [Table 8.5.3(C)].

Figure 2

Nominal Air Flow Rate (slpm) at Varying Cylinder Pressures [psig and bar(g)] for Orifice Sizes (0.006 in, 0.010 in, 0.014 in)



To calculate the specific gravity of a mixture for use in formula [1], multiply the specific gravity (SG_i) of each component by the volume (or mole) fraction (f_i) of the component in the gas mixture and total these contributions to give the mixture's specific gravity (see Formula 2).

As an example, for a 10% arsine in hydrogen mixture, the specific gravity of the mixture is 0.33 [= 2.7 (0.1) + 0.07 (0.9)].

Formula 1

$$\text{Gas Flow Rate (slpm)} = \text{Air Flow Rate at Same Pressure \& Orifice Size (slpm)} \sqrt{\frac{1}{\text{Specific Gravity}}}$$

Formula 2

$$SG_{mix} = SG_1 f_1 + SG_2 f_2$$

Purge Procedures

An RFO in the cylinder valve outlet will restrict gas flow during purging. A well-planned cycle purge procedure is necessary to fully remove gas between the valve seat and the RFO, both before and after gas use, to ensure gas quality and to prevent any safety or process quality concerns associated with the hazardous gas or atmospheric gases remaining behind the RFO.

Additional Resources:

This list provides a sampling of RFO references for consideration or additional research by the reader.

- SEMI S5-93, *Safety guideline for flow limiting devices*. Semiconductor Equipment and Materials, Inc. Safety Standards. www.semi.org/en/P001204
- British CGA Code of Practice CP-18, *The Safe Storage, Handling and Use of Special Gases in the Microelectronics Industry* (section 10.5.2).
- CGA G-13, *Storage and Handling of Silane and Silane Mixtures*. www.cganet.com
- International Fire Code Chapter 37, *Highly Toxic and Toxic Materials* and Chapter 41, *Pyrophoric Materials*, Section 4106.
- NFPA 55, *Standard for the Storage, Use, and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders, and Tanks*, Chapter 7.9.
- NFPA 318, *Standard for the Protection of Semiconductor Fabrication Facilities*.
- Toxic Gas Ordinance, Ex. Santa Clara County UN-014, *Silane Gas Installation Supplement* and HMCD-019, *Toxic Gas Application Installation*. www.sccgov.org

Emergency Response System

- Call: 1-800-523-9374 (Continental U.S. and Puerto Rico)
- Call: +1-610-481-7711 (other locations)
- 24 hours a day, 7 days a week
- For assistance involving Air Products and Chemicals, Inc. products

Product Safety Information

- For MSDS, Safetygrams, and Product Safety Information www.airproducts.com/productsafety

Technical Information Center

- Call: 1-800-752-1597 (U.S.)
- Call: +1-610-481-8565 (other locations)
- Fax: 1-610-481-8690
- E-mail: gasinfo@airproducts.com
- Monday–Friday, 8:00 a.m.–5:00 p.m.

Information Sources

- Compressed Gas Association (CGA) www.cganet.com
- European Industrial Gases Association (EIGA) www.eiga.org
- American Chemistry Council www.americanchemistry.com

For More Information

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