



CGA G-4.4—2020 OXYGEN PIPELINE AND PIPING SYSTEMS

SIXTH EDITION

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PREFACE

As part of a program of harmonization of industry standards, the Compressed Gas Association (CGA) has issued CGA G-4.4, *Oxygen Pipeline and Piping Systems*, jointly produced by members of the International Harmonization Council and originally published by the European Industrial Gases Association (EIGA) as EIGA Doc 13, *Oxygen Pipeline and Piping Systems*.

This publication is intended as an international harmonized standard for the worldwide use and application of all members of the Asia Industrial Gases Association (AIGA), Compressed Gas Association (CGA), European Industrial Gases Association (EIGA), and Japan Industrial and Medical Gases Association (JIMGA). Each association's technical content is identical, except for regional regulatory requirements and minor changes in formatting and spelling.

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NOTE—Technical changes from the previous edition are underlined.

NOTE—Appendices A and B (Normative) are a requirement.

NOTE—Appendices C, D, E, and F (Informative) are for information only.

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Contents	Page
1 Introduction.....	1
2 Scope and purpose	1
3 Definitions.....	2
4 Design philosophy	4
4.1 General criteria	4
4.2 Materials compatibility for oxygen service	6
4.3 Selection of metals	7
4.4 Velocity and gas pressure criteria	10
4.5 Selection of nonmetal	12
4.6 Piping and pipeline systems.....	14
4.7 Siting, remote operation, use of barriers	15
5 Piping, valves, and equipment	16
5.1 General criteria	16
5.2 Piping and fittings	16
5.3 Valves.....	19
5.4 Equipment	22
5.5 Lubricants	27
6 Cleaning, manufacturing, and inspection	28
6.1 General requirements.....	28
6.2 Specification and manufacture of pipeline material	30
6.3 Precleaned piping.....	31
6.4 Post installation cleaning	33
6.5 Inspection	34
6.6 Records	35
7 Construction	35
7.1 General criteria	35
7.2 Construction plan.....	35
7.3 Pipe fabrication and welding.....	36
7.4 Assembly and installation	36
7.5 Inspection and examination.....	38
7.6 Nondestructive testing.....	39
7.7 Documentation	39
8 Design and construction of control stations.....	40
8.1 Function.....	40
8.2 Design brief	40
8.3 Standards and design codes	42
8.4 Materials	43
8.5 Barriers or screens	43
8.6 Location	44
8.7 Earthing, grounding	45
8.8 Fabrication.....	46
8.9 Installation	46
8.10 Testing.....	46
8.11 Commissioning.....	46
8.12 Operation.....	47

9	Operation, monitoring, and maintenance	48
9.1	General safety instruction	48
9.2	Commissioning pipelines, piping, and stations	50
9.3	Operation and monitoring	51
9.4	Information to third parties, summary of work, records, and update of pipeline drawings	51
9.5	Specialized surveys	52
9.6	Damage to the pipeline system	52
10	General protective measures	52
10.1	Emergency response plan	52
10.2	Power supplies and lightning strikes	54
10.3	Fire	54
10.4	Oxygen deprivation hazards and precautions	55
10.5	Incident and damage report	55
10.6	Safety management system	55
11	References	57
12	Additional references	61

Figures

Figure 1—Oxygen fire triangle	4
Figure 2—Impingement velocity curve	11
Figure 3—Nonimpingement velocity curve	12
Figure 4—Bypass installation	17

Appendices

Appendix A—Table of nominal alloy compositions and ranges (Normative)	66
Appendix B—Table of exemption pressures and minimum thicknesses (Normative)	67
Appendix C—Description of promoted ignition combustion test method (Informative)	68
Appendix D—Potential ignition mechanisms (Informative)	70
Appendix E—Table of minimum safety distances (without barriers) for oxygen control and isolating/metering stations (Informative)	72
Appendix F—Example of preventive maintenance program (Informative)	73

1 Introduction

This publication has been prepared by a group of specialists in oxygen piping and pipeline systems, representing major oxygen producers in various countries of Europe and North America and is based on technical information and experience currently available to the authors.

Oxygen pipeline systems developed over many decades in the various countries of Europe, North America, and in other geographies have shown good and comparable safety records, although company practices show many differences in design and operations. Some national authorities have also introduced legislation that is mandatory for the operators in those countries.

The design and installation requirements and recommendations included in this publication apply only to installations begun after the publication date and not to existing installations. However, the information contained in this publication may benefit existing installations or those in the project phase. Furthermore, to the extent that they exist, national laws supersede the suggested practices listed in this publication. It should not be assumed that every local standard, test, safety procedure, or method is contained in these recommendations or that abnormal or unusual circumstances may not warrant additional requirements or procedures.

2 Scope and purpose

The scope of this publication is for metal oxygen pipelines, distribution piping systems, and gaseous oxygen piping on an air separation plant external to the coldbox. The scope is limited to gaseous oxygen with a temperature range between –22 °F and 400 °F (–30 °C and 200 °C), pressures up to 3000 psi (21 MPa), and a dew point of –22 °F (–30 °C) or less depending on local conditions.^{1,2} Although it is possible to safely use oxygen at higher temperatures and/or pressures, such applications are beyond the scope of this publication. In these cases, additional materials testing and/or a risk assessment, as appropriate to the application, shall be undertaken.

This publication does not apply to the following processes:

- oxygen cylinder filling plants;
- medical oxygen piping installations;
- coldbox internal piping;
- oxygen compressor units;
- liquid oxygen vaporizers;
- bulk oxygen facilities (liquid or high pressure gas) at the customer's site up to the point where gas enters the distribution systems; or
- piping on specialized equipment and machines such as scarfing, jet piercing, etc.

The use of nonmetal piping for oxygen-enriched gases in production plants, transmission systems, or distribution systems is outside the scope of this publication and requires a specific risk assessment and precautions.

The purpose of this publication is to further the understanding of those engaged in the safe design, operation, and maintenance of gaseous oxygen transmission and distribution systems. It is not intended to be a mandatory standard or code.

Some of the practices represent conservative compromises and not all situations are described. The designer is cautioned that this publication is not a complete design handbook and does not do away with the need for

¹ kPa shall indicate gauge pressure unless otherwise noted as (kPa, abs) for absolute pressure or (kPa, differential) for differential pressure. All kPa values are rounded off per CGA P-11, *Guideline for Metric Practice in the Compressed Gas Industry* [1].

² References are shown by bracketed numbers and are listed in order of appearance in the reference section.

competent engineering judgment and interpretation. It is suggested that the user review any special problems or concerns with their oxygen supplier who should be able to provide advice and guidance.

3 Definitions

For the purpose of this publication, the following definitions apply.

3.1 Publication terminology

3.1.1 Shall

Indicates that the procedure is mandatory. It is used wherever the criterion for conformance to specific recommendations allows no deviation.

3.1.2 Should

Indicates that a procedure is recommended.

3.1.3 May

Indicates that the procedure is optional.

3.1.4 Will

Is used only to indicate the future, not a degree of requirement.

3.1.5 Can

Indicates a possibility or ability.

3.2 Technical definitions

3.2.1 Burn-resistant alloys

Engineering alloys that, after being subjected to an ignition event, either do not burn or exhibit burn quenching behavior, resulting in minimal consumption. A metal, used at or below its exemption pressure, for a defined set of process conditions including oxygen purity, temperature, and minimum material thickness is considered to be a burn-resistant alloy under those conditions. Examples of metals that are highly burn resistant and exhibit high exemption pressures are copper, nickel, and copper/nickel alloys such as Monel®. Other engineering alloys such as stainless steel may exhibit varying degrees of burn resistance depending upon oxygen pressure, oxygen purity, temperature, equipment configuration, piping layout, and metal thickness.

3.2.2 Cobalt alloys

Commercially available cobalt alloys generally start with a minimum cobalt content of at least 40 weight %. Wear-resistant alloys such as Stellite 6 or Stellite 6B are sometimes used as coatings on valve trims to minimize erosion damage and improve valve life. Cobalt alloys have a successful history in oxygen when used as coatings, even though the thin cross section may reduce its burn resistance.

3.2.3 Copper-based alloys

Copper-based alloys used in components for oxygen piping and pipeline systems generally contain at least 55 weight % copper. Included within this group are coppers, brasses (copper alloyed primarily with zinc), bronzes (copper alloyed with aluminum, silicon, manganese, tin, lead, etc.), and copper nickels (copper alloyed with nickel). These have had an outstanding application history in oxygen service. Caution should be exercised in the use of aluminum bronzes. Aluminum bronzes containing greater than 2.5% and up to 11% aluminum (by weight) have been extensively used for cast components (for example, valve bodies, pipe fittings, etc.) in oxygen piping and pipeline duty for many years without a significant history of failure. However, use of aluminum bronze is not recommended as flammability tests show that it can support burning if ignited, even at low pressure.

Aluminum content in copper alloys should be limited to 2.5% by weight.

3.2.4 Distribution piping

Piping and components contained on the property (generally owned by the customer) at the oxygen use point.

3.2.5 Dry, oil-free, air or nitrogen

Air or nitrogen with a dew point of -40°F (-40°C) or less and an oil content of 0.5 mg/m^3 or less [2].

3.2.6 Exempt materials

Engineering alloys that are exempt from any oxygen velocity limitations within defined limits of pressure, material thickness, and oxygen purity. Appendix A and Appendix B identify the composition of specific alloys, together with their thickness limitations and exemption pressures in oxygen.

3.2.7 Exemption pressure

Maximum pressure at which a material is not subject to velocity limitations in oxygen-enriched atmospheres where particle impingement may occur.

NOTE—The exemption pressures of the alloys listed in Appendix B are based on industry experience and under the conditions used for the promoted ignition combustion testing with nonflowing oxygen per ASTM G124, *Standard Test Method for Determining the Combustion Behavior of Engineering Materials in Oxygen-Enriched Atmospheres* [3].

3.2.8 Ferrous alloys

Included in this category are carbon steel, low-alloy steel, and all stainless steels irrespective of whether these alloy families are in cast or wrought form.

3.2.9 Gas pressure

Maximum pressure that can be achieved within the piping and pipeline system.

3.2.10 Gaseous oxygen

Gas that contains greater than 23.5% oxygen by volume (with the remainder of its components being inert).

3.2.11 Low purity oxygen

Gaseous oxygen that contains 35% or less oxygen by volume (23.5% to 35%).

3.2.12 Nickel-based alloys

Nickel-based alloys used in oxygen gas transmission pipeline and piping systems containing at least 50 weight % nickel and nickel content up to 99+ weight % have been used. However, some tabulations of nickel alloys may list alloys with nickel content as low as 30 weight %. Generally, the greater the combined nickel and copper content, the more burn resistant the alloy. Combined nickel and cobalt also may be beneficial.

Some of the major nickel alloy families and examples of each are as follows:

- nickel (Nickel 200);
- nickel-copper (Monel-400 and Monel-500);
- nickel-chromium (Inconel 600 and Inconel X-750); and
- nickel-chromium-molybdenum (Hastelloy C-276 and Inconel 625).

3.2.13 Nonferrous alloys

Includes only copper, nickel, and cobalt alloys. It does not include aluminum or reactive materials such as titanium or zirconium.

3.2.14 Plant piping

Piping within the oxygen production facility.

3.2.15 Stainless steel alloys

Ferrous alloys become stainless when they contain a minimum chromium content of at least 10 weight % to 13 weight %. There are a number of stainless steel classifications, which are dependent upon the alloy content, crystalline lattice, strengthening mechanisms, and the ratio of ferrite stabilizers to austenitic stabilizers.

Stainless steel classifications with examples of each type are as follows:

- Austenitic (304, 304L, 316, 316L, 321, 347);
- Ferritic (430);

- Martensitic (410);
- Precipitation hardening (17-4 PH); and
- Duplex (329, SAF 2205).

The preceding alloy designations are for wrought products but there are alloys such as CF-8, CF-3, CF-8M, CF-3M, which are the cast analogs of 304, 304L, 316, and 316L respectively.

Of the various stainless steels, the 300 series stainless steels and their cast analogs are the most commonly used in oxygen gas transmission piping systems.

3.2.16 Standard purity oxygen

The standard purity oxygen is defined as 99.5+% by volume.

3.2.17 Transmission pipeline

Piping between the oxygen production plant boundary and distribution piping boundary including that which passes over public land and third-party property.

3.2.18 Ultra high purity oxygen

Oxygen purity equal or higher than 99.999% by volume

3.2.19 Velocity

Actual volumetric flowrate divided by the minimum internal flow cross-sectional area. It should be noted that the velocity in a pipe and its components may be significantly different.

4 Design philosophy

4.1 General criteria

The safe design and operation of an oxygen transmission pipeline or piping system depends on various factors that can influence each other. This section describes the principal risks and hazards associated with oxygen systems and the manner in which the hazards can be minimized by good engineering design.

The oxygen hazard can be effectively illustrated through the fire triangle, which shows that three main elements are required for a fire to occur: an oxidizer, a fuel, and an ignition source. See Figure 1.



Figure 1—Oxygen fire triangle

In an oxygen system, oxygen itself is the oxidizer and the system fire hazard increases with increasing concentration, pressure, temperature, and flowrate. The fuels in an oxygen system are the materials of construction (metals, nonmetals, and lubricants) or potential contaminants like particulates, oils, or greases. The ignition sources common to oxygen systems include particle impact, compression heating, frictional heating, and others as discussed in the following subsections.

Since each leg of the fire triangle is present in an oxygen system to some degree at all times, an oxygen-compatible design is generally one that minimizes the severity of each leg of the fire triangle to a tolerable level. For example, minimizing the severity of the oxidizer may include reducing the oxygen pressure, temperature, or concentration as practical. Minimizing the severity of the fuels may include ensuring burn-resistant alloys are used in locations where active ignition mechanisms exist. Minimizing the severity of ignition mechanisms may include oxygen service cleaning to reduce particle impact and promoted combustion, elimination of adiabatic compression, and other mechanisms.

Thus, a safe oxygen piping transmission or distribution system, including all its components, is one that is designed taking into account first and foremost:

- Oxidizer—oxygen conditions of service with respect to fluid purity, composition, gas velocity, pressure, temperature, and dew point;
- Fuel—materials of construction, selection of metal and nonmetal components, and burn resistance; and
- Potential ignition mechanisms—contributing factors that contribute to trigger ignition such as gas velocities and impingement sites that contribute to particle impact ignition, frictional heating, or rapid-opening components such as valves that can produce adiabatic compression heating.

Other factors to be considered include:

- local conditions (for example, seismic zone, soil characteristics);
- applicable piping codes and practices for mechanical design (including pressure rating and wall thickness) and installation;
- national laws and regulations that apply to gas transmission pipelines generally and oxygen systems specifically;
- standards of cleanliness for oxygen service; and
- industry codes of practice relating to oxygen systems.

Piping and pipelines from nonmetal such as plastic or composite material has been used for distribution of oxygen-enriched gases at low pressures. However, the use of nonmetal piping for oxygen-enriched gases in production plants, transmission systems, or distribution systems is outside the scope of this publication and does require specific risk assessment and precautions.

Normally, gaseous oxygen transported by piping and pipelines contains negligible quantities of water and no special precautions against corrosion are therefore required. It is, however, important to identify areas where piping and pipeline systems could become contaminated with water, in the event of equipment failure (for example, compressor intercoolers or aftercoolers) and introduce appropriate design and/or monitoring procedures. Piping and pipeline systems specifically intended for the transport of wet oxygen on a continuous basis, whereby the piping could be exposed to free water, may require special precautions such as the use of corrosion-resistant piping material or internal coatings. It is important that any protective internal coatings or corrosion inhibitors used be compatible with oxygen for the process conditions. Potentially flammable coatings or inhibitors are prohibited unless compatibility has been verified.

More detailed background information can be found by consulting the following references:

- ASTM G88, *Standard Guide for Designing Systems for Oxygen Service* [4];
- ASTM G128, *Standard Guide for Control of Hazards and Risks in Oxygen Enriched Systems* [5];
- *Evaluation of the usefulness of security standards, selection and cleaning of materials, resources and appliances in oxygen technology for the application under high partial oxygen pressures* [6];

- ASTM STP 986, *Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres: Third Volume* [7]; and
- ASTM STP 1197, *Flammability and Sensitivity of Materials in Oxygen-Enriched Atmosphere: Sixth Volume* [8].

4.2 Material compatibility for oxygen service

Oxygen material compatibility is dependent on many factors and thus, materials compatibility in oxygen is application specific. In general, acceptance criteria for materials in a given application depends on two key factors: flammability and ignitability.

4.2.1 Material flammability

Some of the factors that determine the flammability of materials include the material composition, thickness, and the operating conditions such as oxygen pressure, temperature, concentration, and others.

Standard test methods are often used to determine the flammability of materials in oxygen. For metals, the promoted ignition test per ASTM G124 is one test that evaluates the flammability behavior as a function of pressure in the condition of the test [3]. A description of the promoted ignition-combustion test method can be found in Appendix C. For nonmetals, the oxygen index (OI) test per ASTM D2863, *Standard Test Method for Measuring the Minimum Oxygen Concentration to Support Candle-Like Combustion of Plastics (Oxygen Index)* is used to determine the minimum percentage of oxygen for self-sustained combustion [9].

ASTM G125, *Standard Test Method for Measuring Liquid and Solid Material Fire Limits in Gaseous Oxidants* is one test that evaluates the flammability behavior of nonmetals as a function of purity [10]. Other guidance is provided in ASTM G94, *Standard Guide for Evaluating Metals for Oxygen Service* for metals and in ASTM G63, *Standard Guide for Evaluating Nonmetallic Materials for Oxygen Service* for nonmetals [11, 12].

4.2.2 Ignition mechanisms and kindling chain

Several ignition mechanisms have been known to cause fires in oxygen piping and pipeline systems. Appendix D lists common ignition mechanisms in oxygen systems, conditions for those mechanisms to be active, and some contributing factors that increase their likelihood.

Ignition mechanisms include particle impact, adiabatic compression (pneumatic impact), promoted ignition by organic materials, frictional heating, electrical arcing, and others as shown in Appendix D. If the specific conditions for an ignition mechanism are present, then the ignition mechanism is assumed to be active. For example, the conditions required for particle impact to be active are:

- particulates;
- high gas velocities; and
- impingement sites.

The design practices described in this publication are intended to minimize the conditions and contributing factors related to ignition.

When a material has been ignited, a fire can propagate through the kindling chain. Once ignited, the combustible material or component generates heat that can, depending on many factors, ignite the surrounding bulk material. The rate and extent of the propagation of the fire along the pressure envelope can depend on the thickness and the flammability of the material, among other factors. The use of burn-resistant materials per this publication, can limit ignition and combustion propagation by interrupting the kindling chain.

4.2.3 Oxygen hazards analysis and risk assessment

Certain operating parameters such as oxygen concentration, pressure, temperature, and velocity increase the risk of fire. When these parameters increase, more stringent oxygen practices are progressively applied:

- cleaning and maintaining cleanliness of piping and equipment;

- use of compatible nonmetals and, if appropriate, lubricants; and
- use of burn-resistant metal.

An oxygen hazard analysis is a method used to evaluate risk of fire in an oxygen system. It assesses the probability of ignition or consequence of ignition (ignition versus sustained burning based on operating conditions) and is discussed further in the following subsections. It can be used to select materials for new designs or to evaluate the compatibility of materials in existing systems.

An oxygen hazard analysis is required if a metal alloy is used above its exemption pressure and gas velocities exceed those allowed by the pressure-velocity curve. The oxygen hazard analysis process is explained in ASTM STP 1197, ASTM G63, and ASTM G94, and generally proceeds as follows [8, 12, 11]:

- Determine application conditions (oxygen purity, pressure, temperature, gas velocity, etc.);
- Evaluate flammability of materials in application pressure and thickness (see 4.2.1);
- Evaluate ignition mechanism severity based upon contributing factors present (see Appendix D). Ignition mechanisms for metals include particle impact, frictional heating/galling, electrical arc, promoted ignition from nonmetals/contaminants, etc. Ignition mechanisms for nonmetals include compression heating, mechanical impact, flow friction, electrostatic discharge, etc.;
- Evaluate reaction effects of fire (should a fire occur) based upon the severity of the reaction effects on personnel and operation;
- Analyze parts list, materials used, drawings, procedures, etc.; and
- Make recommendations, if required, to achieve low probability of ignition and a low consequence of ignition if possible. A priority list for implementing changes in order to reduce the risk of ignition or consequences of a fire is:
 - a) change material
 - b) change design
 - c) change operation; and
 - d) implement barrier protection.

4.3 Selection of metals

Metal flammability is a key consideration for an engineering alloy used in an oxygen piping and pipeline applications. Alloy chemistry, component thickness, temperature, oxygen pressure, and oxygen purity are key variables that affect metal flammability.

For selecting metals used in oxygen piping and pipeline systems, exemption pressures can be used in combination with the pressure velocity curves in this publication to provide helpful guidance. As stated previously, the exemption pressures for many alloys listed herein are based upon flammability data from ASTM G124 and other design factors [3]. By this method, gas velocity restrictions are placed on an application where the alloys of construction are used at pressures greater than their exemption pressures for a given minimum thickness in order to minimize particle impact ignition hazards. If the application pressure is greater than the published exemption pressure for a given minimum thickness, the application gas velocity shall conform to an area below a specific pressure velocity curve depending on the presence of impingement sites. If the application pressure is less than the exemption pressure, the alloy is considered burn resistant and thus no restrictions on velocities are required. It should be understood that pressure velocity curves only address the particle impact ignition mechanism. Other ignition mechanisms may be present and should be evaluated according to Appendix D.

The choice of burn-resistant alloys according to 4.3.1.2 is a simple solution for the designer, who could also perform an oxygen hazard analysis, as explained in 4.2.3, to determine what other options may be available.

Aluminum-based alloys shall not be used in gaseous oxygen piping systems outside the coldbox.

4.3.1 Exemption pressures for standard purity oxygen

4.3.1.1 Engineering alloys

Appendix A lists the nominal compositions of the engineering alloys and alloy systems for which exemption pressures are identified in this publication. Generally, the alloys or alloy systems are those for which published flammability data exist. Techniques by which a flammability assessment can be made for alloys not listed in Appendix A are described in 4.2.1 and Appendix C.

4.3.1.2 Exemption pressures and thickness effects

Appendix B is a listing of exemption pressures for the alloys covered in 4.3.1.1. The exemption pressures are based on a burn criterion of less than 30 mm (1.18 in) for a specimen as described in Appendix C.

Thickness is a very important variable in component flammability. The thickness of a metal or alloy shall not be less than the minimum prescribed in Appendix B. If the thickness is less than the prescribed minimum, the alloy shall be considered flammable and velocity limitations appropriate for the system pressure shall be observed. Exemption pressures should not be extrapolated outside the given thickness range of 0.125 in to 0.250 in (3.18 mm to 6.35 mm).

Alternatively, flammability assessments can be made using appropriate characterization techniques described in 4.2.1 and Appendix D, which can result in a judgment that velocity limitations are not required.

NOTE—Materials may be used above their exemption pressures provided that the pressure velocity values are below the curves in Figures 2 and 3 or a risk assessment has shown that ignition is unlikely to occur or can be mitigated by other safety measures.

4.3.1.3 Protective liners and weld overlays

Protective liners and weld overlays or coatings of burn-resistant alloys may be used in conjunction with carbon steel or stainless steel components, where high oxygen velocities and pressures could result in a particle impact ignition scenario. Copper, nickel, or Monel alloys are typical choices. Minimum thickness shall be specified based on criteria such as material selection, test data, service conditions, experience, etc. A typical thickness of the order of 0.04 in to 0.12 in (1 mm to 3 mm) is generally used for weld overlay, coatings, or liners. Electroplated surfaces are not satisfactory due to the inadequate thickness unless a specific risk assessment has been conducted evaluating factors such as hydrogen embrittlement, wear erosion of the thin protective coating, and others.

Hard-facing alloys are also candidates if abrasion resistance is also required; however, the hard-faced alloy and its substrate alloy burn resistance shall be acceptable for the process conditions either based on system velocity, the exemption pressures shown in Appendix B, or a detailed risk assessment.

4.3.1.4 Gaseous oxygen production systems from vaporized liquid oxygen

For some systems, the designer may choose stainless steel piping and equipment to minimize the presence of particles. An example of such a system is the supply of gas by the vaporization of liquid oxygen. Provided that the system is adequately cleaned, blown out, and inspected and no source of particles can be identified during the commissioning and operational lifetime of the piping, exemption from oxygen velocity limitation requirements can be justified through an oxygen hazard analysis assessing all possible ignition sources.

4.3.2 Reduced purity oxygen-enriched atmospheres

4.3.2.1 Reduced purity effects

There are an increasing number of applications where oxygen enrichment greater than normal atmospheric concentrations but less than the nominal 99.5% by volume may be required. Depending upon specific parameters such as oxygen pressure, temperature, and velocity, reduced oxygen purities can result in a decrease in metals ignition probability and flammability if an ignition event by particle impact occurs. Thus, there may not be any necessity for imposing velocity limitations. Metal flammability data in reduced purity oxygen-

enriched environments are less commonly available although several publications are useful in this regard [7, 8, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23]. Three options may be considered as follows:

- Option 1—Treat the reduced purity oxygen-enriched atmosphere as equivalent to 99.5+% by volume oxygen and use the exemption pressure listed in Appendix B for standard purity oxygen. This is a conservative and very safe approach that becomes increasingly conservative as the oxygen purity decreases; or
- Option 2—Treat the reduced purity oxygen as equivalent to pure oxygen gas at a pressure equivalent to its oxygen partial pressure in the gas mixture. The exempt pressure listed in Appendix B for a specific reduced purity oxygen gas mixture represents an oxygen partial pressure. This is a safe approach but not as conservative as Option 1; or
- Option 3—Flammability testing can be performed with the system materials in the reduced purity oxygen environment using the procedures described in 4.2.1 and Appendix C. If the material is not burn resistant, an oxygen velocity limitation as indicated in 4.4 shall be imposed. If test results indicate the metal is burn resistant for the thickness, oxygen purities, and pressures of interest, there is no need to impose velocity limitations.

4.3.2.2 Oxygen purities less than 35% by volume

At pressures up to 3000 psi (21 MPa) and an oxygen content less than 35% by volume, systems free of hydrocarbons and constructed of ferrous and/or nonferrous materials are exempt from velocity limitations and minimum thicknesses listed in Appendix B do not apply. Under these conditions, both carbon and stainless steels have been proven to be burn-resistant materials by the promoted ignition combustion test method (see Appendix C). However, the oxygen service cleaning and the use of oxygen-compatible nonmetals as described in 4.5 are advised for such piping and pipeline systems.

4.3.3 Ultra high purity oxygen atmospheres

4.3.3.1 General

Increasingly, ultra high purity oxygen is being used in high technology applications. The special requirements of these applications require elimination of particulates, which could contaminate the oxygen for high purity application and also contribute to a particle impact ignition mechanism. In addition to special cleaning procedures, ultra high purity systems require special procedures to ensure particulate-free conditions. These systems are typically fabricated from stainless steel.

4.3.3.2 Velocity exemptions

The absence of particulates and ignitable contaminants in an ultra high purity stainless steel, ultra high purity cleaned oxygen system is a significant factor, which precludes ignition from a particle impact mechanism. Hence, ultra high purity oxygen systems that are cleaned and maintained properly are exempt from oxygen velocity requirements, although other ignition mechanisms (such as adiabatic compression, mechanical friction, and others) may be present that could ignite a nonmetal component.

4.3.3.3 Cleaning ultra high purity oxygen systems

The cleaning of ultra high purity piping systems requires special competencies for cleaning capable of meeting residual contamination levels not exceeding 1000 µg/m³ NVR (nonvolatile residue). Cleaning subcontractors shall be qualified and subject to periodic audits.

4.3.4 Temperature limitations

The metals ignitability and flammability information contained within 4.2 is pertinent to gaseous oxygen pipeline and piping systems up to 400 °F (200 °C).

Systems operated at temperatures in excess of the preceding constraints require additional analysis and/or testing at elevated temperatures to ensure system safety.

In the event of operating temperatures less than -4°F (-20°C), steels that demonstrate adequate ductility and fracture toughness values are required in the same way as for other industrial gases.

High temperature of oxygen may have an impact on metallic material selection with regards to potential oxidation process of construction steels due to the risk of spalling and particle generation and can also affect the mechanical properties of metals.

4.4 Velocity and gas pressure

4.4.1 General

Pipe system sizing is predominantly based on the design velocity. This velocity is based on normal pipeline and plant operation and venting, and not based on velocities that may arise due to mechanical failures or other unusual circumstances such as control valve failure or relief valve lifting. The term velocity means the average axial velocity in the pipe at all defined operating pressures, temperatures, and flow rates. For pipeline and piping equipment, the velocity shall be based on the minimum cross-sectional flow area of the component. There may be multiple operating conditions defined for which all velocities shall be considered.

4.4.2 Impingement velocity curve and metal selection for piping and equipment

The impingement velocity curve, as shown in Figure 2, shall be used for the design and material selection of new pipelines, valves, equipment, and associated piping systems where impingement sites can exist. See 5.2.1 and 5.2.2. The designer can choose the metals according to the impingement velocity curve and their exemption pressures defined in 3.2.7. Less than its exemption pressure (see Appendix B), any metal may be used without velocity limitation. Greater than its exemption pressure, the designer can check that the velocity remains below the impingement velocity curve. For velocities below the impingement velocity curve, carbon steel, stainless steel, and other exempt materials may be used. Above the impingement velocity curve, exempt materials shall be used or alternative measures shall be taken to mitigate risks.

Piping and pipeline systems are usually made of carbon steel and it is therefore necessary to limit the gas velocity to a value below the impingement velocity curve. Other design considerations may also dictate lower velocities such as pressure drop, gaseous buffer effect, noise reduction, vibrations, and the need to limit the kinetic energy.

Velocity limitations in nonimpingement sites are considered in 4.4.3. For pressures less than 30 psi (0.21 MPa), industry experience suggests that it may be possible to use carbon and thin walled stainless steels in oxygen service without velocity limitations, using properly designed components with appropriate risk assessments. This is due to the low burn rates shown by these materials in low pressure flammability tests. It is recommended that components for such applications be evaluated on a case-by-case basis.

A hazards analysis of the system (piping, pipeline, or equipment) may justify solutions other than the use of burn-resistant material, for example:

- using specific design features at impingement locations;
- minimizing the presence of particulate matter by the use of filtration for particles 150 microns or smaller; and
- other exceptions as listed in 4.3.2, 4.3.3, 5.2.2, and 5.2.3.

The curve shown in Figure 2 is valid for design temperatures up to 400 °F (200 °C).

The equation of the impingement velocity curve in Figure 2 is defined as follows:

- If 45 psia (0.3 MPa, abs) $< P < 225$ psia (1.5 MPa, abs) then $V \text{ (m/s)} = 100 \text{ ft/s (30 m/s)}$
- If 225 psia (1.5 MPa, abs) $< P < 1500$ psia (10 MPa, abs) then $P \bullet V = 22\,500 \text{ psia} \bullet \text{ft/s}$ (45 MPa, abs $\bullet$ m/s)
- If 1500 psia (10 MPa, abs) $< P < 3000$ psia (20 MPa, abs) then $V \text{ (m/s)} = 15 \text{ ft/s (4.5 m/s)}$

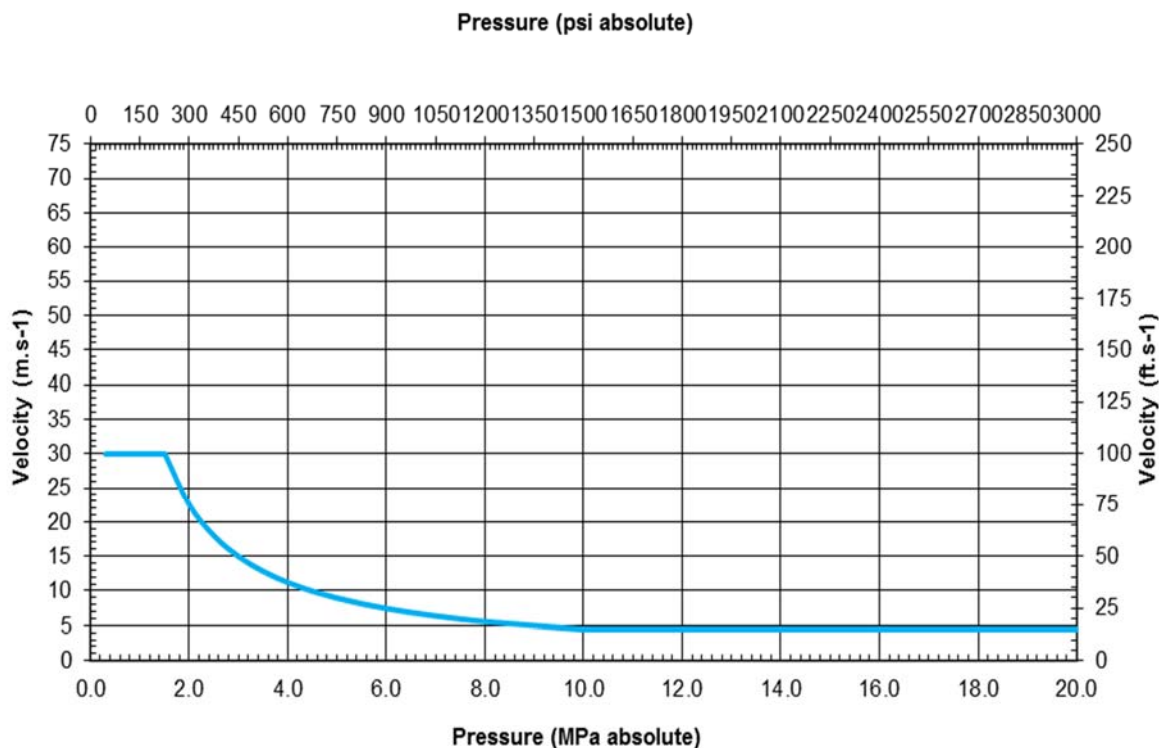


Figure 2—Impingement velocity curve

4.4.3 Velocity limitations in nonimpingement sites

The velocity may be increased up to the curve shown in Figure 3, in the nonimpingement sites of the piping system. See 5.2.1 and 5.2.2.

For velocities greater than the nonimpingement velocity curve, exempt materials shall be used or alternative measures shall be taken to mitigate risks.

The curve shown in Figure 3 is valid for temperatures up to 400 °F (200 °C). Pressures are limited to a maximum of 3000 psi (21 MPa).

The equation of the nonimpingement velocity curve is defined as follows:

- If 45 psia (0.3 MPa, abs) < P < 225 psia (1.5 MPa, abs) then V (m/s) = 200 ft/s (60 m/s);
- If 225 psia (1.5 MPa, abs) < P < 1500 psia (10 MPa, abs) then $P \bullet V = 40\,000$ psia • ft/s (80 MPa, abs • m/s); and
- If 1500 psia (10 MPa, abs) < P < 3000 psia (20 MPa, abs) then V (m/s) = 26.6 ft/s (8 m/s).

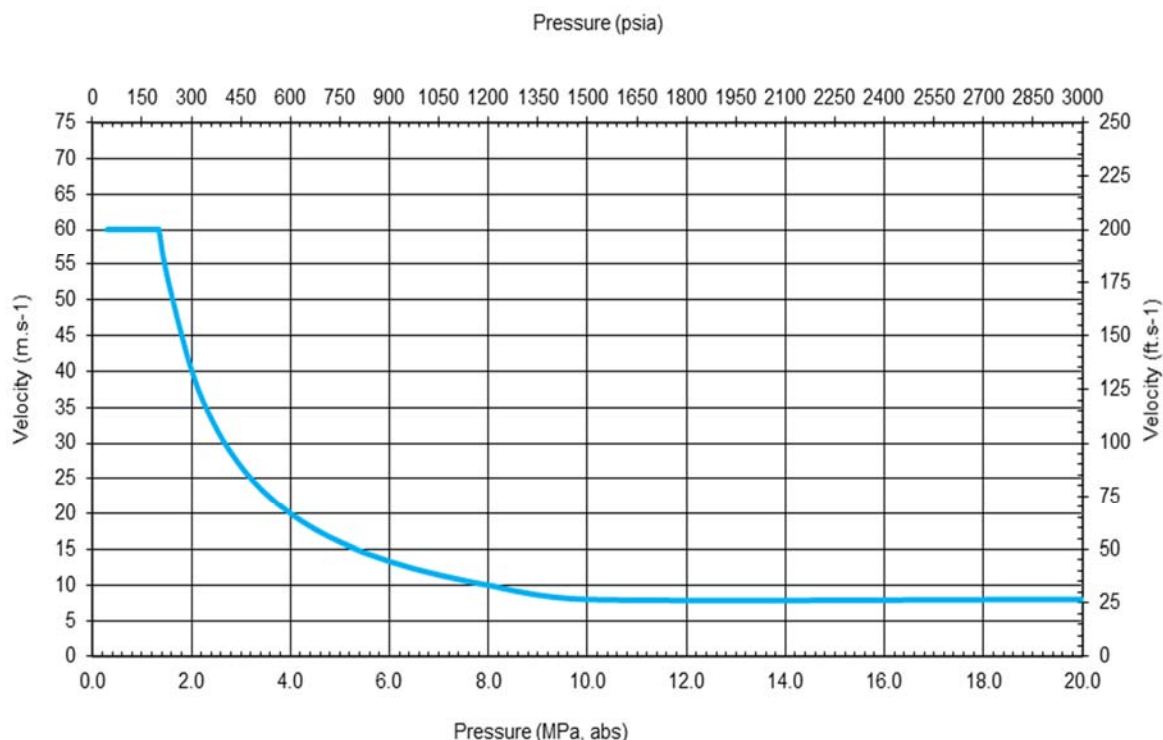


Figure 3—Nonimpingement velocity curve

4.5 Selection of nonmetal

4.5.1 Properties and risks

Most nonmetals are less compatible with oxygen than metals. Nonmetals are used mainly for gaskets, valve seats, lubricants, thread seals, valve packing, and similar applications to reduce friction and to minimize gas leakage.

Most nonmetals are flammable in oxygen even at low pressure and purities greater than 23.5%. The main factors affecting their ignition and combustion propagation are pressure, temperature, and oxygen concentration.

Potential contamination of nonmetals during the manufacturing process can also have an influence on ignition.

The OI is the minimum oxygen content in an oxygen-nitrogen gas mixture that can sustain candle like burning of a test sample. Materials with high OI are preferred. OI data reported in ASTM G63 for various nonmetals are tested at atmospheric pressure [12]. In general, a material's OI decreases as the system pressure increases.

In a kindling chain fire process, the nonmetal part is often the link that promotes the ignition of the bulk metal. Therefore, the heat of combustion of the nonmetal component is an important parameter. The preferred nonmetals have heats of combustion less than 4500 Btu/lb (2500 cal/g), compared with 18 000 Btu/lb (10 000 cal/g) for common hydrocarbon products (see ASTM G63) [12].

To assess the oxygen compatibility of a nonmetal, a significant parameter to be considered is its autoignition temperature (AIT). Ignition of nonmetal material may occur if the AIT is exceeded due to specific operating conditions according to application (for example, gasification, steam injection, heat exchanger, etc.), environment, or for any other reason that can also include, for example, frictional heating in a given piece of equipment.

In practice, it is usual to consider a minimum AIT of 572 °F (300 °C) at a minimum test pressure of 1500 psia (103 bar, abs) according to ASTM G72, Standard Test Method for Autogenous Ignition Temperature

of Liquids and Solids in a High-Pressure Oxygen-Enriched Environment, or at 1740 psia (120 bar, abs) according to EN 1797-1, Cryogenic vessels - Gas/Material compatibility – Oxygen compatibility or ISO 21010, Cryogenic vessels. Gas/material compatibility [22, 23].

In practice, it is usual to allow a margin of at least 212 °F (100 °C) between the operating temperature and the AIT. However, a lower margin of 122 °F (50 °C) may be acceptable subject to complementary tests (see Bundesanstalt für Materialforschung und Prüfung (BAM) procedure for oxygen gasket evaluation) [6]. It is important to check the behavior of the product in oxygen atmosphere at the maximum working pressure and temperature when the test standards allow. The material may be subjected to gaseous fluid impact or to a mechanical impact [19, 20]. For the measurement of AIT, see ASTM G72 and ISO 11114-3, *Gas cylinders - Compatibility of cylinder and valve materials with gas contents—Part 3: Autogeneous ignition test for non-metallic materials in oxygen atmosphere* [22, 24].

As a slow oxidation can occur and change the properties of the product, an aging procedure may be performed [25]. The behavior of nonmetals within generic classifications may vary in oxygen compatibility tests depending upon the source of supply of the materials.

Qualification of manufacturer's products should be considered. For maintenance purposes, it is important to ensure that the correct spare part selected for its oxygen compatibility is used. Many fires have occurred due to confusion in selection and use of spare parts.

The energy necessary to ignite a nonmetal part may be created by:

- adiabatic compression of the oxygen;
- internal flexing of the soft material itself due to vibration, resonance, or flow friction;
- mechanical impact, friction, or rupture after swelling;
- arcing due to static electric discharge or lightning; or
- promoted ignition (such as by burning particles or any other source of energy).

An evaluation of the ignition probability assessment combined with the reaction effect assessment may lead the designer to optimize the design and the choice of materials. Examples of this procedure are given in ASTM G63 [12].

4.5.2 Design practices and material selection

When designing a system containing nonmetals, it is desirable to observe the following practices:

- Minimize the quantity of nonmetals used in oxygen systems;
- Select nonmetal material with low heat of combustion and high AIT (see 4.5.1);
- Take account of energy (heat) dissipation in the design by embedding the nonmetal part in an adequate mass of burn-resistant metal with high thermal conductivity, which can act as a heat sink;
- Avoid locating nonmetals directly in the gas stream;
- Prevent excessive movement of the component;
- Ensure that the material is physically and chemically stable at the service conditions; and
- Ensure that a nonmetal component does not prevent electrical continuity between internal parts except at insulating joints.

In addition to these design practices, care should be taken with the cleaning procedure, particularly if a solvent is used. It is important to check that the solvent is compatible with the nonmetals and thereby avoid any contamination of the nonmetal part, or the item of equipment, by polluted solvent. All cleaning solvent residuals should be removed.

Specific information on the design and installation of nonmetals can be found in the appropriate equipment sections.

For components exposed to adiabatic compression, testing on small equipment items (internal diameter less than 25 mm [1 in]) should be considered, particularly for oxygen regulators [26].

ASTM G63, the results of tests performed by BAM in Berlin, and other relevant publications from EIGA, CGA, and ASTM can help the designer in the selection of nonmetals [12, 27, 7, 8, 11, 14, 28, 29, 30, 26].

Examples of nonmetals exhibiting the best oxygen compatibility are (design temperatures should be considered when selecting nonmetals):

- Fluorinated polymers including plastic products such as polytetrafluoroethylene (PTFE), fluorinated ethylene-propylene (FEP), or polychlorotrifluoroethylene (PCTFE);
- Fluoroelastomer products such as Neoflon®, Kalrez®, Viton®, or Fluorel®;
- Amorphous polymers such as polyimides;
- Ceramics and glass, which are totally oxidized products, are burn resistant but brittle so they are generally used with a binder as composite products. The crystalline structure is very stable and burn resistant as in the case of graphite, which has a high oxygen compatibility even at high temperature; and
- Other products as listed by BAM or ASTM G63 based on given test conditions [27, 12].

WARNING: *Fluorinated polymers can release toxic gases when they burn. Composition of nonmetals can be variable. Users should verify composition and compatibility of nonmetal components prior to use in oxygen service.*

Lubricants are also detailed in 5.5.

4.6 Piping and pipeline systems

4.6.1 Underground piping systems

Piping and pipeline should be of all welded construction in accordance with a specification and inspection code such as American Petroleum Institute (API) 1104, *Welding of Pipelines and Related Facilities* or any other recognized code [31]. Underground piping and pipeline shall be externally coated to an approved specification to protect against corrosion [31]. Reference to current, internationally accepted coatings standards and specifications is recommended [32, 33, 34, 35].

Underground piping and pipeline should be adequately buried to protect it from frost, casual surface construction, shifting due to unstable soil, backfill damage to the external surface of pipe or the coating, and aboveground loads such as vehicles or equipment moving over the path of the pipeline. In the case of crossings, the pipeline should cross the railroad or roadway perpendicularly or as close to perpendicular as possible. Uncased crossings are preferred. When pipe casings or load shields are installed at railroad or road crossings, cathodic protection systems at cased crossings should be reviewed carefully. Casing may reduce or eliminate the effectiveness of cathodic protection. The introduction of a casing creates a more complicated electrical system than would prevail for uncased crossings. This may lead to difficulties in interpreting the cathodic protection measurements at cased crossings. Test stations with test leads attached to the carrier pipe and the casing pipe may be provided at each cased crossing. Load shields should be installed where unusual aboveground loading can occur. Casings or sleeves require special measures to avoid cathodic protection problems and arcing, which can be caused due to an electrical connection forming between the sleeve and carrier pipe owing to settlement, etc.

Underground oxygen piping and pipeline is particularly vulnerable to damage by lightning strikes or ground fault conditions, which may ignite the pipe material. Electrical continuity between underground oxygen piping and aboveground piping or other metal structures should be avoided to prevent cathodic protection problems. Due to the possibility of leaks and risk of enriched atmosphere, it is preferable to have no flanged joints underground either buried or in pits.

4.6.2 Aboveground piping systems

Aboveground oxygen piping and pipeline systems should follow good mechanical design practices as applied to any other aboveground piping system. Aboveground carbon steel piping and pipeline should be painted to an approved specification to protect against atmospheric corrosion.

Aboveground portions of pipeline systems should connect to buried portions through an electrically insulated joint to isolate the cathodic protection system (see 4.6.4, 5.4.6 and 7.4.3).

All aboveground piping and pipelines shall have electrical continuity across all connections, except insulating joints (could be either flanges or monobloc) and shall be earthed at suitable intervals to protect against the effects of lightning and static electricity. The electrical resistance to earth of the installed aboveground piping and pipeline system should not exceed 10 ohms for lightning protection.

Flange bolting can provide the necessary electrical bond provided the bolts are not coated with a di-electric material or paint and are well maintained to avoid rust.

In the case of short aboveground sections where insulating flanges are not used, the pipe should be insulated from the support structure by means of an isolating pad.

Aboveground piping and pipeline should be routed as far away as practical from other lines and process equipment containing fluids that are hazardous in an oxygen environment. If located in a multi-line pipe rack, the mechanical joints in the oxygen line should not be located close to the mechanical joints in other fluid lines where hazardous mixtures could result if simultaneous leaks or failures occurred. Consideration should be given to protecting other fluid lines opposite mechanical joints in oxygen lines from fire. Oxygen lines should not be exposed unnecessarily to external forces that can cause a failure or dangerous situation such as external impingement from hot gas or steam vents, vibration from external sources, leaking oil dripping onto the line, etc.

4.6.3 Pipeline and piping markers

Overhead piping and pipeline should be color coded and/or identified according to national regulations or corporate standards. Underground piping should be identified with distinctive markers placed on the ground near the buried pipeline. Marker posts should also be installed at pipeline changes in direction. Markers should be suitably spaced to indicate the route of the line.

4.6.4 Cathodic protection

Underground pipelines are subject to soil corrosion. The primary protection against corrosion is provided by the coating system. Cathodic protection in accordance with approved standards and specifications should be applied to protect against imperfections in the coating system (see 5.4.6). For additional information, please see NACE SP0169, *Control of External Corrosion on Underground or Submerged Metallic Piping Systems* and EN 12954, *General principles of cathodic protection of buried or immersed onshore metallic structures* [36, 37].

Precautions against induced alternating current sources and lightning strikes should be considered.

There shall be no cad welding (Thermite) of test station wires to in-service oxygen lines. Cold processes can be used or alternative methods stated in 9.1.3.

4.7 Siting, remote operation, use of barriers

Siting of oxygen systems shall be carefully studied especially in the case of stations comprising equipment such as valves and locations where oxygen hazards (such as impingement) may be present. Siting and safety distances should follow established practices and applicable regulations. For details see 8.6.

When there is a concern that the hazards of a system cannot be controlled to an acceptable level of safety with design component selection, compatible materials, operating practices, and siting as defined previously, then remote operation or use of physical barriers shall be considered for protection of the operators and others. For details, see 8.5.

5 Piping, valves, and equipment

5.1 General criteria

This section describes how the design philosophy presented in Section 4 can be applied in practice to piping, valves, specific piping components, and equipment configurations.

5.1.1 Material selection criteria

Selection of material for pipes, valves, and equipment shall be based on 4.2, 4.3, and 4.4.

At impingement sites, the material selection shall be based upon the impingement velocity curve in Figure 2 as explained in 4.4.2.

At nonimpingement sites, the velocity for carbon and stainless steel may be increased but shall be limited by the nonimpingement velocity curve. See Figure 3.

The following subsections address sites where impingement and nonimpingement may occur.

5.2 Piping and fittings

5.2.1 Impingement sites

Impingement occurs when the flow stream changes direction abruptly or when the presence of eddies leads to the impact of particles with the system walls. Pipe impingement sites include, but are not limited to, the following:

- both butt weld and socket weld tees and socket weld elbows;
- branch connections such as fabricated branches, weldolets, sockolets, and threadolets;
- face of multi-hole diffusers and surrounding body;
- short-radius elbows (radius of curvature less than 1.5 diameter);
- socket-weld and threaded reducers;
- reducers (eccentric and concentric) with greater than 3 to 1 inlet to outlet reduction section ratio (for flow from large to small);
- mitred elbows (mitred cut angle greater than 20 degrees); and
- piping downstream of a pressure letdown valve up to a length of 8 pipe diameters (pipe diameters can be based on valve outlet size).

Other impingement sites identified as special inline pipe components are discussed in the following subsections:

- valves, subsection 5.3;
- conical strainers and Y strainers, subsections 5.4.1 and 5.4.2;
- filters, subsection 5.4.3;
- orifices plates, subsection 5.4.4.2;
- noise reduction, devices, subsection 5.4.8.1; and
- other accessories, subsection 5.4.8.2.

5.2.2 Nonimpingement sites

Nonimpingement sites include but are not limited to the following:

- straight piping runs;

- butt-weld tees, with long (or smooth) crotch radius (for flow from main to branch);
- long radius diameter elbows (equal to or greater than 1.5 diameter);
- 90 degree mitred elbows made of 6 pieces (5 welds) as well as 45 degree mitred elbows made of 3 pieces (2 welds), providing that all internal surfaces are ground smooth; and
- eccentric and concentric reducers with a maximum 3 to 1 reduction ratio.

5.2.3 Specific piping locations

5.2.3.1 Bypass piping

Selection of piping material on the inlet and outlet of the bypass valve, see Figure 4, shall be given special consideration since this piping is often exposed to both high velocities and turbulent flow during pressurization. Bypass piping upstream of the bypass valve is defined as a nonimpingement site. The possibility of bidirectional flow shall be considered. Thus, exempt materials are recommended downstream of the bypass valve, and for the entire bypass piping system if bidirectional flow is possible.

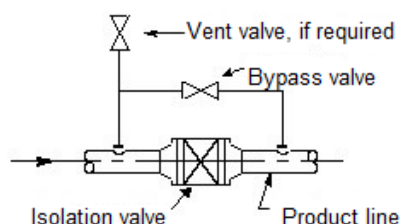


Figure 4—Bypass installation

5.2.3.2 Piping upstream of vents and bleeds

Branch piping upstream of vent and bleed valves and any system isolation bleed valves (i.e., between isolation valves) should be designed as bypass piping.

5.2.3.3 Inlet piping to pressure relief valves

The material selection of inlet piping to a pressure relief valve (PRV) shall be based on the relief valve set pressure and the maximum flow capacity of the relief valve. See 4.4.1.

5.2.3.4 Piping downstream of vent valves and pressure relief valves

Associated vent piping material selection shall be based on the impingement velocity curve. Corrosion-resistant material is commonly used for vent lines since the pipe is open to atmosphere and invites condensation with daily temperature fluctuations. Carbon steel piping may be used for vent piping when the venting is controlled to avoid turbulence immediately downstream of the vent valve. However, exempt materials may provide both corrosion resistance and combustion resistance.

PRVs should be located in the open air so that they discharge in a safe area. If they are unavoidably located inside buildings or enclosures, the vent piping shall discharge outside. Consideration shall be given to the location of the vent outlet, height, direction, adequate spacing, etc., in order to minimize risks due to oxygen-enriched atmosphere in the surroundings.

5.2.3.5 Piping downstream of pressure letdown sites

The piping downstream of a pressure letdown device such as a throttling or process control valve (see 5.3.2.3) or restrictive orifice, experiences high velocity and highly turbulent gas flow. The pipe wall downstream is considered an impingement eddy site for a distance equivalent to a minimum of 8 pipe diameters

where pipe diameters is based on the device outlet size. Particles in the eddy flow regime impinge on pipe walls at a greater velocity than determined by the gas flow calculations. Because of the eddy flow particle velocity, 8 pipe diameters made of exempt materials shall be considered for the piping downstream of the pressure letdown device.

The risk of particle impingement or its consequences may be reduced and nonexempt material considered for any of the following situations:

- If a 150 micron screen or finer filter is installed upstream of the letdown valve, then particle impingement is significantly reduced;
- If the pressure let down occurs across a multi-hole diffuser, the flow downstream of the diffuser may be considered smooth with no high velocity turbulent jet; and
- If the system is shielded to protect personnel and prevent exposure (see 4.6 and 8.5).

5.2.3.6 Gaskets

Gaskets of an oxygen-compatible material shall be sized and installed to match the internal diameter of the pipe thereby minimizing a space where particles can accumulate. Gaskets shall be positioned concentrically in a flange joint to eliminate any protrusion of the gasket in the flow. Gaskets shall be manufactured such that they are clean for oxygen service. Hydrocarbon-based adhesives shall not be used in gaskets that require an adhesive for construction.

- It is not possible to properly clean a gasket once it is wound. Cleaning the gasket could trap cleaning solution in the windings that can be flammable itself and is typically not effective at removing other contaminants in the windings; and
- Manufacturer of the gaskets shall use clean windings. Filler materials (such as graphite) shall not have any organic additives. Winding should also be performed on a winding machine that is free from oils or other lubricants.

Spiral wound gaskets shall have inner rings to prevent inner radial buckling of the windings. The inner rings shall be fully supported between both flange faces to prevent buckling and detachment from the windings.

Gasket sealant should be avoided because extrusion of the sealant into the flowing gas stream is undesirable. If a sealant is necessary, the choice of sealant should be made according to 4.5.

ASTM G63 provides guidance on nonmetals selection [12].

5.2.3.7 Thread sealants

The oxygen user shall confirm that the thread sealant material is compatible for oxygen service at the maximum service pressure and temperature. PTFE products (tape) can be used according to their specifications including cleanliness in order to ensure compatibility with oxygen service (see 4.5). Minimal amounts of thread sealant should be applied to prevent extrusion out of the joint. Provisions shall be made to prevent contamination of open containers of thread sealant.

ASTM G63 provides guidance on nonmetals selection [12].

5.2.3.8 Dust traps and dead ends

The risk of ignition of bulk metal increases with the mass of particles. It is important to avoid accumulation of these particles in dust traps or dead ends. Dead ends where particles can accumulate shall be identified for all possible operational configurations. In these cases, design or operational procedures shall be developed.

In particular, consideration shall be given to lines in standby service such as bypass pipes, vent pipes, or purge lines for which the connection should be on the top of the main line or at least at the same level horizontally. Dead ends and dust traps are to be avoided wherever possible.

Examples of dust traps are manifolds, enlarged diameter tees, gaskets not flush with the internal diameter of the flange, standby lines under the main line, and other locations where the velocity of the gas is reduced, allowing particles to drop out of the gas stream.

5.2.3.9 Fire stops

Fire stops are short spool pieces of copper or nickel-based alloy. Their use is no longer considered common practice in steel pipeline transmission or distribution systems.

5.3 Valves

5.3.1 General

Valves shall be procured from suppliers suitably qualified in oxygen-compatible procedures. See Section 13 of CGA G-4.14, Design, Manufacture, Installation, Operation and Maintenance of Valves Used in Liquid Oxygen and Cold Gaseous Oxygen Systems for quality assurance and quality control requirements [38]. The material and physical design of the valve shall be carefully selected considering both the normal and unusual operating conditions to which the valve can be subjected. Specific design considerations shall be given to manual valves design as they are locally operated by personnel.

Metal selection requirements are related to gas velocity and potential impingement sites, which may exist in a valve depending on its design, function, and type. Nonmetal selection requirements are described in 4.5.

5.3.2 Valve functions

This publication recognizes several classes of oxygen service valves. The classes of valves recognized include the following:

- isolation valves;
- throttling or process control valves;
- emergency shutoff valves;
- bypass valves;
- vent valves;
- pressure relief valves; and
- check valves.

5.3.2.1 Isolation valve risks

There are two risk factors associated with isolation valves when they are opened with differential pressure across the seat:

- high velocity and turbulence through the valve during its opening; and
- rapid downstream pressurization and temperature rise due to adiabatic compression.

The high velocity, turbulence, and rapid pressurization risks can be avoided by the use of a bypass system to equalize pressure across the isolation valve before it is opened. Bypass valves are discussed in 5.3.2.5.

5.3.2.2 Isolation valves

Isolation valves shall be operated in either the fully closed or fully open position and never in a throttling mode. They shall be operated without significant pressure differential by using a bypass system or a specific operating procedure. The downstream pressurization rate shall be controlled to prevent the risk of adiabatic compression.

Isolation valves are normally gate, ball, plug, or butterfly type.

Valves that are intended to be operated with differential pressure during opening and closing are considered throttling valves or process control valves (see 5.3.2.3).

It should be noted that if a closed isolation valve leaks, there can be a high velocity flow across it if a high differential pressure exists.

5.3.2.3 Throttling or process control valves

Throttling or process control valves include those for pressure control, flow control, bypass, or pressure relief.

They are defined as valves that control flow or pressure. Depending on the function necessary, pressure control valves can throttle flow continuously, can allow for slow opening or closing, or can be programmed for quick opening or closing. Process control valves in the vast majority of cases are automated; the exceptions being manually operated throttle valves and spring-operated regulators.

Process control valves are considered to be the most severe class of service in gaseous oxygen systems. This is because their function is to regulate flow or operate with high differential pressure that is associated with high velocity and turbulent impingement flow. The turbulence and impingement are not only present in the trim and body of the valve but are considered to extend to the downstream piping for a length of a minimum of 8 valve diameters. If bidirectional flow is possible, turbulence and impingement can also exist in the upstream piping.

Process control valves are generally globe, modified ball, eccentric plug, or butterfly type. Valves that do not meet the definition of isolation valves shall be considered throttling valves.

5.3.2.4 Emergency shutoff valves

Emergency shutoff valves are usually automated, operate in the fully open position, and are normally closed only in the event of an emergency. Emergency shutoff valves are high flow valves and are normally gate, knife gate, butterfly, or ball type. Although in normal operation the valve experiences nonimpingement flow, in the event of an excess flow condition, the valve can experience excessive velocities and momentary turbulence upon closing. Normally these valves are treated as throttling valves.

5.3.2.5 Bypass valves

Bypass valves are normally piped from immediately upstream to immediately downstream of manual isolation valves. Depending on the process design, a bypass system may be required for certain process control or emergency shutoff valves. They are installed for the purpose of providing pressure equalization across an isolation valve. Once pressure equalization is established, the isolation valve may be safely opened. Bypass valves are also used to slowly pressurize a downstream system to mitigate excessive velocity and rapid pressurization risks. Controlled, slow pressurization requires the use of a throttling flow-control-style valve. Due to their flow-control function, bypass valves are categorized as throttling or process control valves. Although classified as process control valves, bypass valves are normally manually operated valves. Typically, they are globe valves that experience impingement and high velocity turbulent flow throughout the valve body. Exempt materials are recommended for the valve and piping downstream of the bypass valve, and for the entire bypass piping system if bidirectional flow is possible or if indicated by a risk analysis. For gaseous oxygen production systems from vaporized liquid oxygen, see 4.3.1.4.

Bypass valves shall be designed according to the following criteria:

- sized to achieve pressure equalization within an acceptable period; and
- connected into the main pipe at or above the centreline (see Figure 4) to minimize the number of particles that can collect in the bypass line.

Bypass piping should stub-in the main piping such that the bypass line protrudes through the main piping to prevent edge impingement.