OXYGEN PIPELINE AND PIPING SYSTEMS

Doc 13/20

Revision of Doc 13/12

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OXYGEN PIPELINE AND PIPING SYSTEMS

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As part of a programme of harmonisation of industry standards, the European Industrial Gases Association (EIGA) has published EIGA Doc 13, *Oxygen Pipeline and Piping Systems*. This publication was jointly produced by members of the International Harmonisation Council.

This publication is intended as an international harmonised publication for the worldwide use and application by all members of the International Harmonisation Council whose members include the Asia Industrial Gases Association (AIGA), Compressed Gas Association (CGA), European Industrial Gases Association (EIGA), and Japan Industrial and Medical Gases Association (JIMGA). Regional editions have the same technical content as the EIGA edition, however, there are editorial changes primarily in formatting, units used and spelling. Regional regulatory requirements are those that apply to Europe.

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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 applies 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 –30 °C and 200 °C (–22 °F and 400 °F), pressures up to 21 MPa (3000 psi) and a dew point of –30 °C (–22 °F) or less depending on local conditions. 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;
- cold box internal piping;
- oxygen compressor units;
- liquid oxygen vaporisers;
- 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 specialised equipment and machines such as scarfing, jet piercing, etc.

The use of non-metal 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 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 behaviour, 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 of 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 minimise 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 aluminium, 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 aluminium bronzes. Aluminium bronzes containing greater than 2.5% and up to 11% aluminium (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 aluminium bronze is not recommended as flammability tests show that it can support burning if ignited, even at low pressure.

Aluminium 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 °C (–40 °F) or less and an oil content of 0.5 mg/m³ or less [1].[1]

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 non-flowing oxygen per ASTM G124, *Standard Test Method for Determining the Combustion Behavior of Engineering Materials in Oxygen-Enriched Atmospheres* [2].

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

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

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 Non-ferrous alloys

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

3.2.14 Plant piping

Piping within the oxygen production facility.

3.2.15 Pressure

In this publication bar shall indicate gauge pressure unless otherwise noted i.e., (bar, abs) for absolute pressure and (bar, dif) for differential pressure.

3.2.16 Stainless steel alloys

Ferrous alloys become stainless when they contain a minimum chromium content of at least 10 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 stabilisers to austenitic stabilisers.

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 analogues of 304, 304L, 316, and 316L respectively.

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

3.2.17 Standard purity oxygen

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

3.2.18 Transmission pipeline

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

3.2.19 Ultra-high purity oxygen

Oxygen purity equal or higher than 99.999% by volume.

3.2.20 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 minimised 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 oxidiser, a fuel, and an ignition source. See Figure 1.

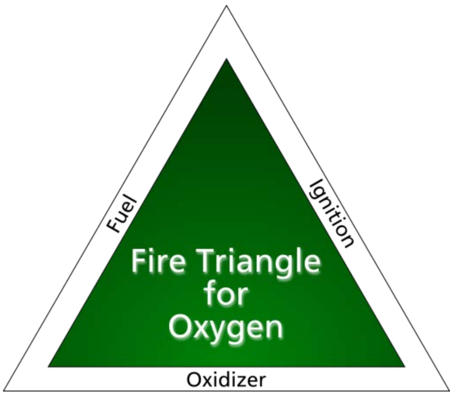

Figure 1 – Oxygen fire triangle

In an oxygen system, oxygen itself is the oxidiser 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, non-metals, 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 minimises the severity of each leg of the fire triangle to a tolerable level. For example, minimising the severity of the oxidiser may include reducing the oxygen pressure, temperature, or concentration as practical. Minimising the severity of the fuels may include ensuring burn-resistant alloys are used in locations where active ignition mechanisms exist. Minimising 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:

- Oxidiser—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 non-metal 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 non-metal such as plastic or composite material has been used for distribution of oxygen-enriched gases at low pressures. However, the use of non-metal 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* [3];

- ASTM G128, *Standard Guide for Control of Hazards and Risks in Oxygen Enriched Systems* [4];

- *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* [5];

- ASTM STP 986, *Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres: Third Volum*e [6]; and

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

4.2 Material compatibility for oxygen service

Oxygen materials 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 behaviour as a function of pressure in the condition of the test [2]. A description of the promoted ignition-combustion test method can be found in Appendix C. For non-metals, 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 [8].

ASTM G125, *Standard Test Method for Measuring Liquid and Solid Material Fire Limits in Gaseous Oxidants* is one test that evaluates the flammability behaviour of non-metals as a function of purity [9]. 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 non-metals [10, 11].

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 minimise 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 non-metals 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 vs. 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 [7, 11, 10]:

- 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 non-metals / contaminants, etc. Ignition mechanisms for non-metals 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;
- Analyse 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 [2]. 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 minimise 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.

Aluminium-based alloys shall not be used in gaseous oxygen piping systems outside the cold box.

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 3.18 mm to 6.35 mm (0.125 in to 0.250 in).

Alternatively, flammability assessments can be made using appropriate characterisation 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 1 mm to 3 mm (0.04 in to 0.12 in) 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 vaporised liquid oxygen

For some systems, the designer may choose stainless steel piping and equipment to minimise the presence of particles. An example of such a system is the supply of gas by the vaporisation 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 [6, 7, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22]. 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 tests 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 21 MPa (3000 psi) and an oxygen content less than 35% by volume, systems free of hydrocarbons and constructed of ferrous and / or non-ferrous 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 non-metals as described in 4.5 is 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 non-metal 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 (non-volatile 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 200 °C (400 °F).

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 –20 °C (–4 °F), 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 non-impingement sites are considered in 4.4.3. For pressures less than 0.21 MPa (30 psi), 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:

- <u>using specific design features</u> at impingement locations;
- minimising 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 <u>200 °C (400 °F)</u>.

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

- If 0.3 MPa, abs (45 psia) < P < 1.5 MPa, abs (225 psia) then V (m/s) = 30 m/s (100 ft/s)

  If 1.5 MPa, abs (225 psia) < P <10 MPa, abs (1500 psia) then P • V = 45 MPa, abs • m/s (22 500 psia • ft/s)
- If 10 MPa, abs (1500 psia) < P < 20 MPa, abs (3000 psia) then V (m/s) = 4.5 m/s (15 ft/s)

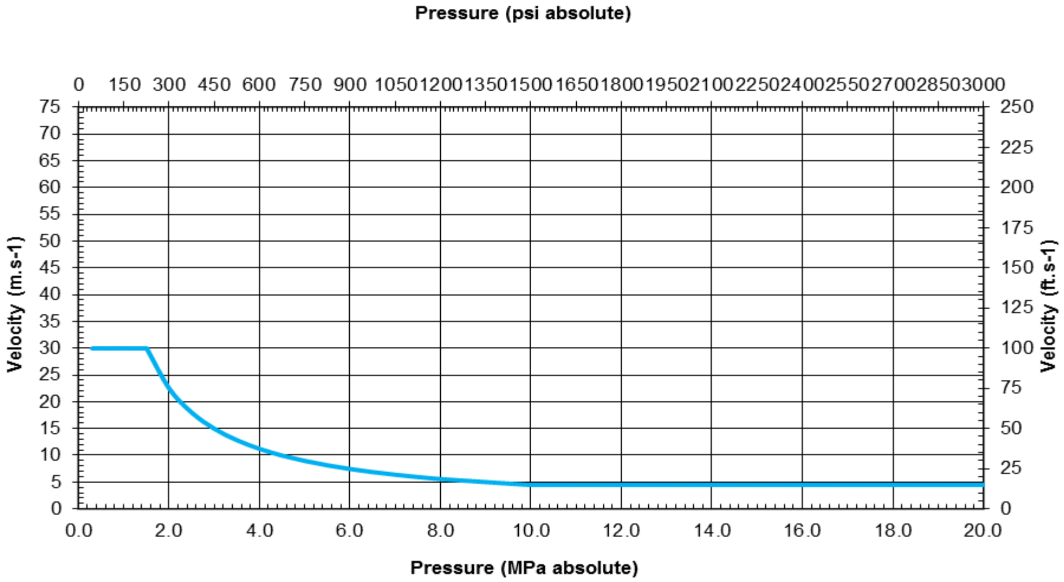

Figure 2 – Impingement velocity curve

4.4.3 Velocity limitations in non-impingement sites

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

For velocities greater than the non-impingement 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 200 °C (<u>400 °F</u>). Pressures are limited to a maximum of 21 MPa (3000 psi).

The equation of the non-impingement velocity curve is defined as follows:

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

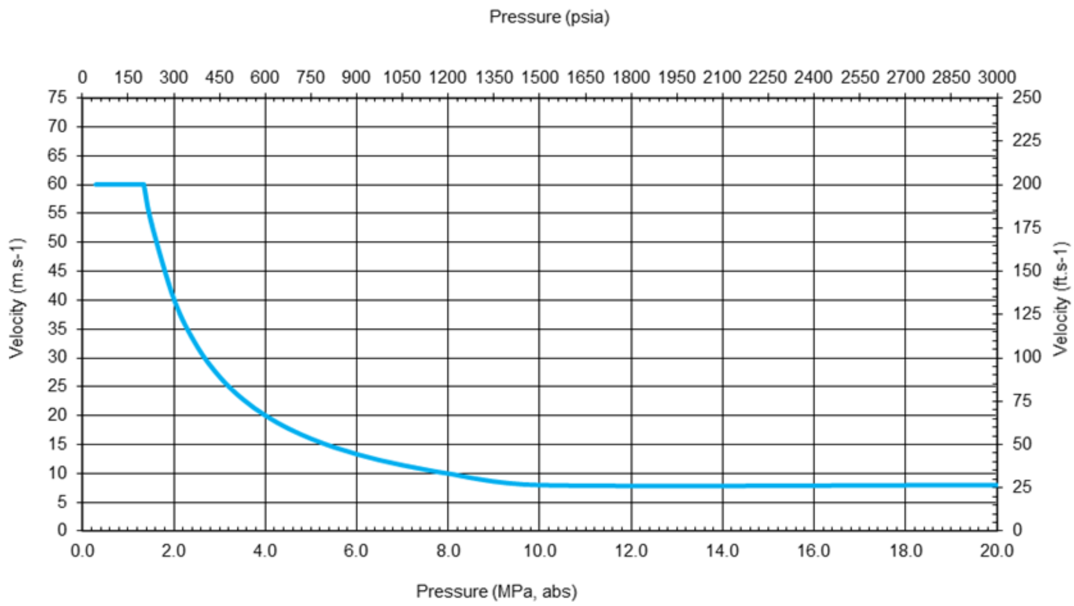

Figure 3 – Non-impingement velocity curve

4.5 Selection of non-metal

4.5.1 Properties and risk

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

Most non-metals 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 non-metals 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 non-metals are tested at atmospheric pressure [11]. In general, a material's OI decreases as the system pressure increases.

In a kindling chain fire process, the non-metal part is often the link that promotes the ignition of the bulk metal. Therefore, the heat of combustion of the non-metal component is an important parameter. The preferred non-metals have heats of combustion less than 2500 cal/g (4500 Btu/lb), compared with 10 000 cal/g (18 000 Btu/lb) for common hydrocarbon products (see ASTM G63) [11].

To assess the oxygen compatibility of a non-metal, a significant parameter to be considered is its autoignition temperature (AIT). Ignition of non-metal 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 300 °C (572 °F) at a minimum test pressure of 103 bar, abs (1500 psia) according to ASTM G72, *Standard Test Method for Autogenous Ignition Temperature of Liquids and Solids in a High-Pressure Oxygen-Enriched Environment* or at 120 bar, abs (1740 psia) according to EN 1797-1, *Cryogenic vessels - Gas/Material compatibility – Oxygen compatibility* or ISO 21010, *Cryogenic vessels. Gas/material compatibility* [21, 22].

In practice, it is usual to allow a margin of at least 100 °C (212 °F) between the operating temperature and the AIT. However, a lower margin of 50 °C (122 °F) 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 behaviour 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* [21, 23].

As a slow oxidation can occur and change the properties of the product, an aging procedure may be performed [24]. The behaviour of non-metals 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 non-metal 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 optimise the design and the choice of materials. Examples of this procedure are given in ASTM G63 [11].

4.5.2 Design practices and material selection

When designing a system containing non-metals, it is desirable to observe the following practices:

- Minimise the quantity of non-metals used in oxygen systems;
- Select non-metal 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 non-metal part in an adequate mass of burn resistant metal with high thermal conductivity, which can act as a heat sink;
- Avoid locating non-metals 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 non-metal 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 non-metals and thereby avoid any contamination of the non-metal part, or the item of equipment, by polluted solvent. All cleaning solvent residuals should be removed.

Specific information on the design and installation of non-metals 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 [25].

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 non-metals [11, 26, 6, 7, 10, 13, 27, 28, 29, 25].

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

- 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 oxidised 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 [26, 11].

WARNING: *Fluorinated polymers can release toxic gases when they burn. Composition of non-metals can be variable. Users should verify composition and compatibility of non-metal 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 recognised code [30]. Underground piping and pipeline shall be externally coated to an approved specification to protect against corrosion [30]. Reference to current, internationally accepted coatings standards and specifications is recommended [31, 32, 33, 34].

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 colour 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* [35, 36].

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

The following subsections address sites where impingement and non-impingement 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 multiple-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 Non-impingement sites

Non-impingement 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 pressurisation. Bypass piping upstream of the bypass valve is defined as a non-impingement site. The possibility of bi-directional flow shall be considered. Thus, exempt materials are recommended downstream of the bypass valve, and for the entire bypass piping system if bi-directional flow is possible.

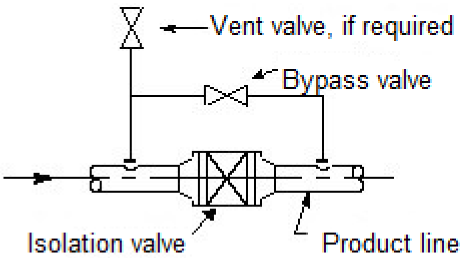

Figure 4 – Bypass connection

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 devices

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 devices

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 minimise 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 should shall be considered for the piping downstream of the pressure letdown device.

The risk of particle impingement or its consequences may be reduced and non-exempt 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 minimising 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 non-metals selection [11].

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 non-metals selection [11].

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 stand-by 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, stand-by 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 EIGA Doc 200, *Design, Manufacture, Installation, Operation and Maintenance of Valves Used in Liquid Oxygen and Cold Gaseous Oxygen Systems* for quality assurance and quality control requirements [37]. 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. Non-metal selection requirements are described in 4.5.

5.3.2 Valve functions

This publication recognises several classes of oxygen service valves. The classes of valves recognised 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 pressurisation and temperature rise due to adiabatic compression.

The high velocity, turbulence, and rapid pressurisation risks can be avoided by the use of a bypass system to equalise 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 pressurisation 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 bi-directional 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 non-impingement 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 equalisation across an isolation valve. Once pressure equalisation is established, the isolation valve may be safely opened. Bypass valves are also used to slowly pressurise a downstream system to mitigate excessive velocity and rapid pressurisation risks. Controlled, slow pressurisation requires the use of a throttling flow-control-style valve. Due to their flow-control function, bypass valves are categorised 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 bi-directional flow is possible or if indicated by a risk analysis. For gaseous oxygen production systems from vaporised liquid oxygen, see 4.3.1.4.

Bypass valves shall be designed according to the following criteria:

- sized to achieve pressure equalisation within an acceptable period; and
- connected into the main pipe at or above the centreline (see Figure 4) to minimise 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.

5.3.2.6 Vent valves

Vent valves normally experience high velocity and impingement and are usually treated as throttling valves. Associated vent piping material selection is covered by sections 5.2.3.2 and 5.2.3.4.

5.3.3 Valve types

The velocity through a valve varies depending on changes in cross-sectional flow area, particularly in the case of globe valves and PRVs. For isolation valves such as ball, plug, butterfly, and gate types that are normally fully open when in operation, the velocity does not change significantly and material selection for body and trim can be based on the velocity at the valve inlet.

5.3.3.1 Ball and plug valves

Ball and plug valves are inherently quick opening. This leads to concerns about adiabatic compression especially for any elastomer / polymer materials in the valve or piping system. Also, the ball typically has a sharp edge in the flow path when it is being closed or opened.

When a ball or plug valve is fully open, the flow is considered smooth and both the body and trim are considered in non-impingement service.

Ball and plug valves may be equipped with gear operators to ensure slow opening.

5.3.3.2 Butterfly valves

When open, butterfly valves operate with the valve disk in the flow stream. Butterfly valves that are specified for low leakage rates use either an elastomer seal or a metal-to-metal seat.

When a butterfly valve is wide open, the flow is considered smooth and the body is considered as a non-impingement site. The disk, however, is directly in the flow stream and is considered as an impingement site.

Butterfly valves are inherently quick opening, which leads to concerns about adiabatic compression and temperature rise, especially for any elastomers in the valve or downstream piping system.

Butterfly valves may be equipped with gear operators to ensure slow opening.

5.3.3.3 Gate valves

When gate valves are fully open, the flow through the valve is considered smooth and the body is considered as a non-impingement site. However, the gate is considered as an impingement site.

There are potential friction surfaces in the moving parts of gate valves such as between the gate and body seat, between the gate and back seat, between the rotating stem and the gate, and between the stem thread and the guide.

If gate valves are in a closed position and pressure is equalised across them using a bypass valve, it is possible in some designs that the pressure in the bonnet area remains low until the valve is opened. This could result in adiabatic compression in the bonnet area on initial opening.

Some gate valves have tack welded, screwed in seats. It can be difficult to clean the thread area after assembly. By design, a gate valve may have an open groove at its base when the valve is open, which is an ideal site for debris collection.

5.3.3.4 Globe valves

Globe valves are commonly used in control applications and are usually automated. Globe valves have a tortuous path with many impingement sites. The trim design varies with specific vendors but it can be of a relatively thin section fitted with elastomer / polymer inserts to minimise leakage and seat damage. Sometimes cage trims are used, which are usually of thin section and provide sites for debris to be trapped and / or "guillotined". Because of these design features, globe valves shall always be considered as throttling valves with both body and trim classed as impingement sites. Exempt materials are commonly used.

5.3.3.5 Pressure relief valves

By nature, PRVs experience high velocity across the trim. There can be impingement on the exhaust part of the housing and outlet piping although these areas are normally at or close to atmospheric pressure. The sizing of the trim and the valve inlet determines the gas velocity at the valve inlet. Valve and trim sizing may sometimes be selected to maintain a low velocity in the inlet area. Both body and trim are considered impingement sites. Exempt materials are often used for seat and trim unless other mitigating measures are in place. PRVs shall comply with national or international standards such as ASME *Boiler and Pressure Vessel Code*, Section VIII [38].

5.3.3.6 Check valves

By virtue of their design, check valves, contain components that are always in the flow stream and can be subjected to high velocities and impingement. Therefore, the disk, plate, piston, or spring of a check valve should be made from exempt materials. Depending on the valve type, the body of a check valve may or may not be regarded as an impingement site. The components of check valves are designed to impact with each other and shall therefore be regarded as potential sources of ignition energy and, possibly, particle generation. Care shall be taken to ensure that the thickness of moving or impacting components in the flow stream is adequate and not less than those indicated in Appendix B unless other mitigating measures are in place.

Plate-type check valves used downstream of a reciprocating compressor require a risk assessment due to the presence of a pulsating flow.

Check valves should be designed to withstand chatter and installed such that the possibility of chatter is minimised.

5.3.4 Valve seals and packing

The party responsible for specifying or procuring valves for oxygen systems should contact the seals and packing supplier for guidance on materials that are compatible and suitable for oxygen service at the design conditions (see 4.5). Information on compatibility of non-metal seal and packing materials may be found in ASTM G63 and BAM [11, 26].

5.3.5 Other possible sources of ignition in valves

- Localised heating due to friction between metal components;
- Arc discharges where two metal components, at different electrical potentials, are separated by a non-metal insulating substance;
- Flow friction, which is flow induced vibration of an elastomer / polymer, causing a localised increase in elastomer / polymer temperature leading to a kindling chain type ignition; and
- Mixing of oxygen and non-compatible oil or grease, for instance in gear boxes or angled valve wheels. If such equipment is used, suitable arrangements such as distance pieces open to the atmosphere, shall be provided to prevent migration of oil or grease down the spindle into the oxygen system.

5.4 Equipment

Special inline pipe components including filters, strainers, orifice plates, venturi flowmeters, thermowells, silencers, and flexible connections are described in the following subsections. The vast majority of inline components experience impingement flow and their materials should be selected based on the following information.

5.4.1 Conical strainers

Conical strainers in gaseous oxygen service are normally designed as a perforated cone with a mesh-screen overlay. The strainer shall be positioned in the piping system such that the mesh is on the outside of the cone with the cone projecting upstream. Commonly used screen sizes are 150 micron and finer.

The mesh of a conical strainer is regarded as an area of high risk because it experiences direct impingement and also captures and accumulates debris and particles. Wire mesh, because it is constructed of thin material offering a high surface-to-volume ratio, is more susceptible to ignition in oxygen service. The mesh overlay material shall be of a burn-resistant material such as nickel, bronze, or Monel. Materials with relatively low burn resistance such as stainless steel mesh shall not be used.

The perforated cone support is also considered an impingement site and the material selection and its thickness should be based on the impingement velocity curve shown in Figure 2 and in Appendix B.

5.4.1.1 Conical strainer buckling pressure

Conical strainer cones should be designed with a high buckling or collapse pressure, preferably 100% of the system design pressure as determined by the setting of the PRV. If the buckling pressure is less than 100%, a pressure differential indicator with an alarm should be installed to warn operating personnel that the element is approaching a failure condition and that corrective action is required. This is to avoid collapse of the cone and the passage of fragments through the piping system thereby creating a potential fire hazard.

5.4.1.2 Conical strainer system design

Systems should be designed to avoid the likelihood of filter or strainer operation in reverse flow. The piping and valve requirements discussed for filters in 5.4.3 also apply to strainers.

5.4.2 Y-strainers

The Y-type strainer body is considered an impingement site, a dead end, and a location where contaminant can be ignited and kindle the surrounding components. As such, usage of Y-type strainers shall be restricted to locations where the potential for contaminant is minimal. Only exempt materials shall be used for the body. Carbon steel is prohibited. The wire mesh and screen shall conform to the guidelines given for conical strainers in 5.4.1.

Blowdown valves on Y-strainer housing shall be avoided in gaseous oxygen service. Though the blowdown valve provides an easy method for cleaning the strainer, it could easily be opened at an inappropriate time and could cause a dangerous localised oxygen-enriched atmosphere along with high gas velocities.

5.4.3 Filters

Gas cleaning with filter elements is required when particle retention specifications exceed the capabilities of a conical strainer.

5.4.3.1 Filter risks

Filter elements are impingement locations that are considered high risk due to their particle retention function. Elements are also high surface area-to-volume components which, depending on the material used, can easily ignite. As such, element material selection requires additional care. Systems should be designed to avoid the likelihood of filter or strainer operation in reverse flow.

5.4.3.2 Filter element material

Common filter element materials include, but are not necessarily limited to, the following:

- fibreglass or woven glass without organic binders;
- woven or sintered nickel; and
- brass, bronze, copper, or Monel 400.

5.4.3.3 Glass fibre filter elements

If filter elements are fitted with non-metal oxygen compatible materials such as glass fibre, they shall be designed and assembled using copper wire to avoid accumulation of electrostatic charges in the medium, following which they shall be thoroughly cleaned to remove lubricants and other agents used during their manufacture.

5.4.3.4 Filter buckling pressure

Collapse of filter elements due to high differential pressure can lead to potential fire hazards. The element shall either be able to withstand maximum line pressure when completely clogged, or at least a pressure differential indicator with an alarm shall be installed (see 5.4.1.1).

5.4.3.5 Filter housing

Housing material selection shall be determined by the application of impingement and non-impingement criteria and reference to the velocity curves shown in Figures 2 and 3.

5.4.3.6 Piping and valve requirements for filters

Filters should be provided with inlet and outlet block valves to permit removal for cleaning. If a line cannot be taken out of service for cleaning the filter, parallel filters should be installed and each should be provided with inlet and outlet block valves. A vent valve should be installed downstream of each filter upstream of the discharge block valve. Filters should not be equipped with valves for in-service backblowing since this entrains a collection of particulate matter at very high velocity. Bypass lines around filters can be considered when filter maintenance can be carried out during periods of low flow rate such as 20% of the design flow rate and velocity, for example at process shutdowns where only low flow rates are used.

5.4.4 Flow measuring devices

5.4.4.1 General requirements

Flow meter systems should be located remotely from other equipment and piping, preferably outdoors. Manual block and bypass valves should be reasonably remote from meters and either located away from any potential fire area or separated by a barrier. Material selection is based on the use of exempt materials such as those shown in Appendix B or meeting the criteria of the impingement velocity curve shown in Figure 2. Filtration shall be considered upstream of carbon steel meter systems.

Static meters such as orifice plates are preferred over moving element meters for oxygen service provided that their measuring performance is able to satisfy the user's requirements. Filtration is generally installed upstream of moving element meters.

5.4.4.2 Orifice plates

Orifice plates are flow measuring devices that are considered to be an impingement site because of the higher velocity and sharp edges at the reduced areas. Exempt materials such as those listed in Appendix B should be used.

5.4.4.3 Moving element flow measuring devices

The design and selection of moving element flow measuring devices shall be suitable for oxygen service and the service conditions of pressure, flow, and temperature. Rotary, turbine, angular momentum mass flow, and positive displacement meters are typical types of moving element meters that are used where broad range ability and accuracy are required. A design of a typical moving element meter station of this type takes into account the concerns of overpressuring, overspeeding, reverse flow, and excess flow. As there may be some additional considerations or simplifications, every case should be individually and carefully analysed for its requirements. Special safety considerations for these types of meters are:

- Piping should be designed and installed to apply minimum stresses on connections to meters that have moving parts;

- Manual maintenance operation should only be carried out on meters after they have been taken out of service, isolated from the system, depressurised, and made safe;

- Lubrication—some dynamic meters require a reserve of lubricant, which shall be selected from among the oxygen-compatible lubricants described in 5.5. If the lubricant reservoir is visible from outside, there shall be a label in a prominent position fixed to the meter specifying the grade of lubricant authorised. Renewal or checking of the lubricant shall be made by personnel authorised by the user;

- Remote indication—meters having integral flow indicators or totalisers should be designed, so they can be read at remote location without approaching the meter; and

- Overspeed protection—some moving element meters such as rotary piston meters are in danger of undergoing excessive deformation when their maximum permitted flow is exceeded. The friction caused by contact of the moving parts or entrained foreign particles may cause jamming, fracture, and / or ignition. These meters shall be protected by a flow limiting device.

5.4.5 Bursting disks

Caution is required with regard to the use of bursting disks on oxygen transmission and distribution piping because of the risk of premature failure, disruption of supply, and subsequent uncontrolled release of large volumes of gas, which can form oxygen rich atmospheres. If their use is for any reason unavoidable, they should be made of exempt material. Stainless steel and nickel alloys less than exemption thickness are permitted based on burst disk design conditions, the requirement to open at a set design pressure, and since they only pass flow upon rupture. Pre-scored non-fragmenting burst disks are preferred. Their outer surface in contact with the atmosphere may be coated with a thin layer of PTFE or FEP in order to prevent deterioration by corrosion.

5.4.6 Insulating joints

An insulating joint is essentially made up of two pipe elements separated by a di-electric material.

The purpose of insulating joints is to provide permanent electrical discontinuity between the parts of the installation with cathodic protection and those without it.

Because of this electrical discontinuity, insulating joints carry potential danger of spontaneous ignition of the insulating material caused by possible heating due to the Joule effect. In the interior of a pipeline, if a continuous deposit of dust connects the two piping and pipeline elements and if the current intensity is sufficient, the dust may be brought to a temperature capable of initiating ignition of the insulating material.

The insulating material in contact with oxygen should combine adequate mechanical and di-electric properties and comply with the provisions in 4.3.

Features for insulating joints using standard flanges include:

- Insulating gaskets, bolt washers, and sleeves shall be compatible with gaseous oxygen at the service conditions;
- Di-electric strength of the gaskets, bolt washers, and sleeves depends on vendors' specifications and purchaser requirements but typically are be in the order of 10 MV/m (254 V/mil);
- Insulating flanges should be installed in the horizontal plane (i.e., a vertical pipe run) to minimise accumulation of debris and moisture inside the flange faces, which can cause bridging across the gasket. The pipe run can be inclined up to a maximum of 45 degrees from the vertical. Gaskets should be full-face type cut to exact pipe internal diameter. The bridging effect and also the possibility of arcing across the gap can also be reduced by using a gasket with an outside diameter greater than the raised face of the flange;
- Insulating flanges should be fitted with a fault current protection cell to provide protection against fires in the event of lightning strikes (see 10.2);
- Design of the cathodic protection system should limit impressed current potentials wherever possible. Insulation joints should be fitted with suitable surge protection devices to prevent sparks or excessive voltage gradients causing localised heating across joint gaps or other locations where metal surfaces at different electrical potentials are separated by insulating materials;

  Features for proprietary insulating joints of the monolithic / mono block type include:

  - Di-electric material and internal gas seals shall be compatible with gaseous oxygen at the service conditions;
  - Di-electric material shall also be non-permeable with respect to gaseous oxygen at the service conditions;

- Di-electric strength of the insulating material should typically be in the order of 10 MV/mm (254 V/mil);

- Monolithic / mono block joints should be provided with connection lugs on the exterior of the unit positioned on either side of the insulation element to allow for the fitting of a surge diverter spark gap and for the ongoing checking of electrical isolation;

- Insulating joints, especially the monolithic block type, are prone to damage and leakage if overstressed either laterally or longitudinally. To reduce the likelihood of joint deformation beyond the acceptable limit, it is critical to select an appropriately conservative mechanical design safety factor for the joint to guard against design uncertainties associated with the piping installation, terrain, local environment, and other factors; and

- Joints are adequately supported and correctly installed.

See also 4.6.2, 4.6.4, and 7.4.2.

5.4.7 Flexible connections

The use of permanent flexible connections, hoses, and expansion joints is not recommended in oxygen pipeline and piping systems due to their thin wall thickness and potential for creating dust entrapment zones in the corrugations.

For pipelines and piping exposed to wide variations in temperature, it may be necessary to insert expansion loops to accommodate the pipeline movement. The radius of curvature of the expansion loops should be chosen to facilitate the use of cleaning pigs if required. The material for the expansion loops should be consistent with 5.2.

5.4.8 Miscellaneous equipment items

5.4.8.1 Noise reduction devices

Shells, baffles, and diffusers of vent silencers shall be entirely of metal and / or concrete construction. The metal should be corrosion resistant and in accordance with the impingement velocity curve shown in Figure 2. The assembly should be designed and manufactured to avoid any relative movement of the components. If silencers make use of sound absorbing materials, these shall be non-combustible and essentially free of oil and grease. Examples of such materials are glass fibre or mineral wool.

<u>Stainless steel wool shall not be used as absorbing material of inline or vent silencers.</u>

5.4.8.2 Other accessories

Any other accessory that may come into contact with oxygen shall be constructed from material selected in accordance with the impingement velocity curve shown in Figure 2. Materials that meet requirements of 4.3 shall be selected for their non-metal components.

Common accessories are:

- pressure sensors and indicators;

- pneumatic control devices;

- thermowells; and

- instrument tubing and instrument manifold valves.

Instrument tubing normally consists of small-bore pipes in a non-flowing application, which permits the use of stainless steel tubing without thickness limitation. Dead legs and particle accumulation should be avoided. Instrument valves are in a throttling mode when opened, and the use of exempt materials such as those listed in Appendix B should be considered.

Dial gauges should be provided at the rear with blowout plugs or bursting disks enabling the oxygen to escape in the event of fracture of the sensing element. Additional safety features such as safety glass and a solid partition between the sending element and the gauge window should be provided. If sensors use hydraulic fluid, the fluid should not be in direct contact with oxygen, and it should be selected on the basis of the information in 4.3 and 5.5. All pressure sensors and indicators should be clearly marked for oxygen service (for example, by a visible inscription OXYGEN, NO OIL OR GREASE).

5.4.9 Protection systems

The design and installation of protection systems including pressure, flow, and temperature switches, and other devices should take into account the following factors:

- quality and reliability of the devices;
- failure modes and effects including, for example, power failure, instrument air failure, and instrument circuit failure;
- use of trips and / or alarms and, in the case of the latter, the ability of the operator to respond; and
- fail-safe requirements and consequence of failure considerations versus supply reliability concerns.

The required safety integrity level (SIL) of any protection systems should be considered as part of the design. For more information, refer to IEC 61508, *Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems—Parts 1 to 7* and IEC 61511, *Function Safety—Safety Instrumented System for the Process Industry Sector—All parts* [39, 40].

5.4.10 Heat exchangers

Caution should be taken when selecting heat exchanger tubing that may be less than 3 mm (0.125 in) as trace moisture can result in premature catastrophic corrosion of carbon steel. Therefore, carbon steel is not recommended for heat exchanger tubing. Exempt alloys are recommended for heat exchanger tubing. Stainless steel tubing can be used at low oxygen velocities (see Figure 2). This publication does not address ambient vaporisers or brazed aluminium heat exchangers.

For oxygen compressors, material selection for heat exchangers is documented in EIGA Doc 10, *Reciprocating Compressors for Oxygen Service* as well as EIGA Doc 27, *Centrifugal Compressors for Oxygen Service* [41, 42].

5.5 Lubricants

All components should be designed to function without lubrication. However, if a lubricant is necessary to permit assembly operations or the functioning of a component or equipment, it shall be selected from lists of lubricants that have been found acceptable for use with oxygen such as lubricants listed in BAM [26]. ASTM G63 is also a pertinent information source [11]. The lubricant should be distributed on the surfaces to be lubricated and its use shall be kept strictly to a minimum. The lubricant shall be incorporated for life when the component is assembled and no trace shall be discernible from the outside. A deviation is permitted in the case of components where experience and comprehensive testing have demonstrated the safe use of such components.

Lubricants and greases suitable for oxygen service are generally halogenated chlorotrifluoroethylene (CTFE) fluids, which are thickened with silicon oxide. The use of these products should be restricted to dry atmosphere applications as they allow moisture to penetrate the oil film and cause severe corrosion.

CTFE fluids should not be used with components fabricated from aluminium alloys under conditions of high torque or shear because of the danger of reactions with freshly exposed surfaces.

Care shall be taken with the selection of oxygen-compatible lubricants because, depending upon the application, the lubrication properties of CTFE fluids are generally not as good as hydrocarbon-based mineral oils or greases.

A lubricant or locking compound is considered as compatible for use for valves if the following conditions are met:

- AIT greater than or equal to 400 °C (752 °F) at the maximum operating pressure in gaseous oxygen or at 103 bar, abs (1500 psia) in case the maximum operating pressure is lower than 120 bar (1740 psi); and

- Lubricant passes a pneumatic impact test in gaseous oxygen at a test pressure of at least.

50 bar (725 psi) greater than the maximum operating pressure, as determined by an acceptable test method (for example ASTM G74, *Standard Test Method for Ignition Sensitivity of Non-metallic Materials and Components by Gaseous Fluid Impact*) [19].

NOTE Even minor contamination of an oxygen-compatible lubricant (for example, hydrocarbons, dust, metal particles, or chips) can significantly reduce the ignition resistance of the lubricant.

Gearboxes typically have hydrocarbon grease as the lubricant. Design features shall ensure that oxygen leakage cannot come into contact with hydrocarbon lubricants and that hydrocarbon lubricants cannot migrate into the oxygen wetted area. When this cannot be ensured, tested oxygen-compatible lubricants shall be used.

Assessment of lubrication migration from the gearbox is especially important for valve design where part of the stem is exposed to the internal oxygen because of rising stem movement, for example, globe and gate valves. The motion of the stem during operation increases the risk of external contamination such as hydrocarbon greases to be transported through the packing of the valve over multiple operations.

Lubricants not in direct contact with oxygen such as bolts on flanges should be oxygen compatible.

6 Cleaning, manufacturing and inspection

6.1 General requirements

6.1.1 Cleaning strategy

Cleaning of a pipeline and piping system can be accomplished by precleaning all piping before installation and maintaining the clean condition during construction, by completely cleaning the pipeline and piping system after construction, or by a combination of the two. It is generally preferred to preclean piping prior to installation. It is both impractical and impossible to fully inspect a system for cleanliness after construction and final cleaning. Therefore, it is necessary that a detailed written procedure including the sequence for construction and cleaning be well established and carefully followed throughout the project. The pipeline and piping system design shall be compatible with cleaning, construction, and pressure testing methods to be used. There should be a written specification for the inspection for cleanliness throughout the material preparation and construction stages. Additional guidance on oxygen cleaning is available in EIGA Doc 33, *Cleaning of Equipment for Oxygen Service* [1].

6.1.2 Standard of cleanliness

A system is considered to be clean for oxygen service when internal organic, inorganic, and particulate matters have been removed to meet acceptance criteria. See 6.5.4 for guidance on acceptance criteria. Removal of contaminants such as greases, oils, thread lubricants, dirt, water, filings, scale, weld spatter, paints, or other foreign material is essential.

6.1.3 Cleaning methods

The cleaning of oxygen pipelines may be accomplished by any one or a combination of more than one of the following methods:

- chemical cleaning (acid or alkali) and passivation;
- pigging;
- mechanical scraping;
- grit, sand, or shot blasting;
- dry carbon dioxide ice blasting;
- water blasting;
- solvent washing;

NOTE Solvents prohibited by the Montreal Protocol shall not be used. Refer to relevant national, European, or U.S. regulations.

- high pressure detergent cleaning;
- high temperature detergent cleaning; or
- high velocity gas purge.

Pigs are commonly used for internal cleaning of pipelines. The types of pigs available fall into the following broad categories:

Type	Application
Gauging	Ensuring freedom from obstruction
Foam (or soft pig)	Dewatering Removal of fine, loose debris, and dust
Rubber disk or cup	Dewatering Removal of loose debris
Wire brush	Removal of pipe scale Removal of adhered particles and rust
Scraper	Removal of pipe scale Removal of adhered particles and rust

In general, pigs are be fabricated from materials that might not be totally compatible with oxygen, particularly those made of foam or rubber. Therefore, it is important to ensure as far as possible that if materials such as foam or rubber are used, they will not adhere to the pipe wall or remain as fragments in the pipeline. The removal of any such particles or fragments can only be achieved by a high velocity gas purge (see 6.3.7 and 6.3.8). However, the correct selection and use of pigs to suit the anticipated condition of the internal surface of the pipe at the various stages of cleaning can minimise the likelihood of damage to the pigs and contamination of the piping system. It is also important that the pigs, the associated launching / receiving traps, and other equipment are compatible with the solvents and cleaning agents to be used and have been cleaned to oxygen service standards.

NOTE If pigs are to be used for cleaning the piping system, their use should be considered at the design stage to ensure, among other things, the correct bend radius is specified.

A fill log of all pig runs should be kept. Pigs should be inspected once they are removed from the receiver.

6.1.4 Pipeline and piping system components

Equipment such as tees, valves, check valves, insulation joints, regulators, meters, filters, and other fittings may normally be purchased as precleaned items for oxygen service and installed after the completion of cleaning operations. If any items of equipment cannot be furnished clean, arrangements shall be made for them to be cleaned at or local to the site to meet the required standards. Visual inspection of equipment items should be carried out just before installation to ensure that the required standard of cleanliness has not been compromised. See EIGA Doc 33 for component cleaning requirements and Section 8 of EIGA Doc 200 for valve cleaning requirements [1, 37].

Branch lines and parallel lines shall be treated as separate systems for the purpose of cleaning, and the final tie-ins shall be made after cleaning is completed.

6.1.5 Welding

The pipe sections shall be welded together using a recognised welding process. Ultimately, it is essential that the internal weld surfaces are smooth and substantially free of slag, beads, or loose debris thereby preserving the internal cleanliness. Refer to 7.3 for further information on welding requirements.

6.1.6 Pressure testing

The pipeline and piping shall be subject to either a pneumatic or a hydrostatic pressure test at the pressure required by the code to which the piping and pipeline has been constructed. The preference is for a pneumatic test (see 6.3.3). Whichever test method is selected, it shall be conducted at a convenient point in the overall piping and pipeline construction program to suit project requirements and to minimise the likelihood of costly rework. For further details on pressure testing, see 7.6.1.

6.1.7 Installation of piping equipment

On completion of final cleaning, all aboveground connections can be installed including precleaned and pretested tees, valves, fittings, branch piping, and other items. See 7.6 for non-destructive testing requirements.

6.2 Specification and manufacture of pipeline material

6.2.1 General requirements

All essential requirements for the specification and manufacture of the pipeline that have a direct bearing on the cleaning process should be formally submitted to the piping component suppliers as part of the full technical specification for the purchase of the pipeline. The origin and quality control of the purchased pipeline shall be fully traceable and the relevant documentation submitted to the purchaser for retention.

6.2.2 Codes and standards

Generally, the manufacturing process, material, grade, and inspection requirements for the piping should be in accordance with standards such as ISO 3183, *Petroleum and Natural Gas Industries – Steel Pipe For Pipeline Transportation Systems*, API Specification 5L, *Line Pipe*, or other codes as defined in the project specification as a result of purchaser requirements, national regulations, or other reasons [43, 44]. The material composition should generally be in accordance with the previous codes and the manufacturer’s normal standard for pipeline. However, for pipe that is to be precleaned before installation, it is desirable that the manufacturing process should not include steps that can generate heavy deposits of mill scale on the internal surfaces of the pipeline (see 6.2.4).

6.2.3 Manufacturing process

Examples of common manufacturing practices are high frequency induction (HFI), electric resistance welding (ERW), laser beam welding (LBW), or submerged arc welding (SAW) process. Seamless rolled pipe can also be used. Pipeline manufactured by other processes should not be used without the prior approval of the purchaser. The purchase order issued to the pipe manufacturer or stock list shall prohibit the application of preservatives such as paint, varnish, or lacquer on the internal surfaces of the pipeline.

6.2.4 Heat treatment

Heat treatment for either the longitudinal weld (normally carried out as part of the continuous welding processes) or the pipe body should be such that the finished pipeline is essentially free of mill scale (see 6.2.2).

6.2.5 Hydrostatic test

Regardless of the nature of the pressure test carried out in the field, the manufacturer of the pipeline shall, as part of the manufacturing and quality control process, carry out a hydrostatic test and / or eddy current test (as permitted by the material specification) on each section of the finished pipe. The test should be in accordance with the requirements of the applicable national regulations or codes such as ISO 3183 or API Specification 5L unless dictated otherwise in the project specification as a result of the purchaser's requirements [43, 44].

6.3 Pre-cleaned piping

6.3.1 General

All piping and pipelines should be constructed with sections of pipe that are largely free of mill scale by virtue of the pipe manufacturing process (see 6.2.2) and that have been precleaned internally either at the manufacturer's works before delivery or local to the site. The method used for precleaning can be either mechanical or chemical, depending on convenience and cost, provided the desired standard of cleanliness can be achieved. External coating for underground pipelines can be carried out before or after internal cleaning is performed as long as precautions are taken to ensure that the external coating process does not compromise the cleanliness standard of the internal surfaces. The open ends of the pipe sections should be sealed after cleaning and coating to prevent contamination of the clean pipe (see 6.3.5).

6.3.2 Pipe fabrication

Pipeline undergoing precleaning for oxygen service should be fabricated in a manner that permits visual inspection along its whole length and, if necessary, recleaning to the required standard. The workshop fabrication of piping for oxygen service should be segregated from other activities.

6.3.3 Pressure testing

Whenever practical, pressure testing of the piping and pipeline system should be carried out pneumatically provided such a test does not contravene the provisions of any of the following:

- relevant design codes;
- national and local regulations;
- internal regulations of the third party (when appropriate); or
- acceptability on the basis of a formal risk assessment.

The requirement for a pneumatic test is dictated by the need to minimise the risk of contamination or corrosion of the oxygen piping as a result of the introduction of water during a hydrostatic test. However, if pneumatic testing is not acceptable for any reason, piping and pipelines shall be subject to a hydrostatic test (see 6.1.6). Draining, drying, and inspection are necessary after the hydrostatic test. See 10.2 of EIGA Doc 33 for details [1].

6.3.4 Internal surface finish

The precleaning process, including blowout, aims to achieve as a minimum requirement an internal surface finish in accordance with Specification B SA2 of ISO 8501-1, *Preparation of steel substrates before application of paints and related products – Visual assessment of surface cleanliness. Part 1: Rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings* or equivalent [45]. The precleaning and blowout can be carried out at the manufacturer's facility (after the hydrostatic test) if so desired. However, if the condition of the internal surfaces of the finished pipe is likely to deteriorate significantly as a result of the period and / or conditions of storage (including transit to site) before installation, the precleaning and blowout should be carried out either on or local to the site. The piping shall be inspected to ensure that the required standard of cleanliness has been achieved (see 6.5).

The formation of rust on the cleaned internal surface can be inhibited by the application of a light phosphate coating. This is common practice after chemical cleaning procedures.

6.3.5 Preparation for shipment

Once the required standard of cleanliness has been achieved, the open ends of the pipe shall be fitted with strong, close fitting plastic caps to ensure a dust-tight, waterproof seal. The caps shall be secured and sealed with strong adhesive tape. Depending on the period and conditions of storage and transit, a desiccant such as silica gel may be placed inside each length of pipeline to minimise corrosion. If a desiccant is used, it should be held in a container system that can be firmly secured to the inside of the plastic caps <u>or connected in groups</u> to guard against the container being inadvertently left in the pipe during installation. The total number of desiccant bags used <u>shall</u> be checked and documented for reference during the installation at site. <u>When removing the bags, care shall be taken to ensure that they are intact and that all are removed</u>. Any small-bore tappings in the pipe shall be sealed by metal or plastic plugs.

6.3.6 Maintaining cleanliness

For pipe that has been cleaned before delivery to site, no further cleaning of the pipe sections needs to be carried out before installation unless visual inspection on site reveals that for whatever reason the cleanliness of the piping has been compromised. In this event, the affected pipe sections shall be recleaned either on or local to the work site in accordance with an approved procedure. During the installation of the piping, the internal surfaces of the pipe shall be maintained in a clean and dry state (i.e., free of oil, grease, soil, debris, and runoff water). This shall be achieved by the preparation of a formal construction plan (see 7.2) that among other requirements shall include all of the following:

- Keep pipe trenches free of water and flammable material, particularly in the area of welding and where there are open-ended sections of pipeline;

- Seal the open ends of pipes with pressure-holding plugs or welded caps at the end of each working day or when welding is not being carried out. As an additional precaution during extended periods of inactivity the piping can be left under pressure with dry, oil-free air or nitrogen at approximately 0.01 MPa (1.5 psi);

- Visually inspect the pipeline before every closing weld by an authorised person. Formal records of the results should be maintained for future reference;

- Maintain the cleanliness of inert gas purging devices (for example, lances, temporary seals);

- Keep all propelling media, gases, and the system for applying them during any type of cleaning operation clean and oil-free so they are not a source of contamination; and

- Wear work clothes that are clean and free from oil contamination and, as far as is practical, keep hands free of oil, grease, and excessive dirt.

During the construction period, the piping can at times be open to atmosphere and can experience some degree of internal surface corrosion due to this exposure. At the completion of construction of pipelines, a determination of the extent of this surface corrosion should be made and consideration should be given to its removal by a formal pigging procedure and high velocity purge. A light film of surface rust is acceptable for carbon steel piping.

Construction personnel should remain in the oxygen-clean work area and not move to other work areas where oil or grease is used.

All tools shall be cleaned and kept aside for use in the oxygen area only. Workbenches covered with clean material should be set up where tools, small parts, etc. can be placed.

If for any reason lubricants are deemed to be necessary for oxygen-wetted parts, they shall be used only with the prior approval of the specifier (see 7.4.2 and 7.4.4). See 5.5 for the selection of oxygen compatible lubricants.

Pressure-holding pipe plugs shall be kept clean and stored in clean plastic bags when not in use.

6.3.7 Final cleaning

Final cleaning shall be performed at a convenient point in the overall construction program to suit project requirements. The cleaning procedure depends on a number of factors including, among others, risk of contamination during construction, nature of potential contaminants, and method used for pressure test whether conducted before or after cleaning. In any event, the use of pigs should be considered to provide an indication as to the nature and degree of any residual contaminants remaining in the pipeline system. If chemicals, solvents, or detergents have been used for cleaning, it is important that any liquid residues be completely drained or otherwise removed from the system prior to commissioning. See 6.1.3 for a summary of available cleaning methods.

6.3.8 Leak testing and blowout

The completed pipeline system without equipment can be leak tested with dry, oil-free, air or nitrogen at the system design pressure and then a high velocity blowout is required. Valves, orifice plates, strainers, filters, and other items of precleaned equipment should not be installed during the blow-out process to protect them from damage or contamination by particulate matter. The final high velocity gas purge should achieve a high velocity (typically 25 m/s [82 ft/s]) sufficient to substantially remove residual particulate matter. The effectiveness of the high velocity gas purge can be subjectively judged by visual examination of the free and unobstructed purge gas plume at the full-bore vent outlet pipe. Alternatively, target plates located at the purge gas exit can be used to assess the true effectiveness of the gas purge operation.

The effective removal of particulate matter from the system by the blowout operation should be demonstrated by the use of target plates mounted at the discharge end of the pipeline. Targets may be polished metal or cardboard on plywood. Targets that have been used are aluminium of hardness 25 HB to 35 HB (see ISO 6505-1, *Metallic materials—Brinell hardness test—Part 1: Test method*) [46]. Suitable grades are 1050 A-0 and H1080 A0. The sheets shall be securely mounted at the discharge end of the pipe, allowing a gap between the plate and the pipe outlet equivalent to half the pipe diameter. As an alternative, steel plates may be used with a uniform smear of oxygen-compatible grease to trap particulate material.

The blowout shall be judged as complete when there is no perceptible evidence of particles on the target detected by the naked eye or touch (i.e., scars or pits greater than 0.2 mm [0.008 in]). For grease-smeared plates, there shall be no evidence of collected particles as detectable by the naked eye.

If nitrogen is used as the purge gas, care shall be taken with the orientation and location of the gas vent to minimise the exposure of personnel to oxygen-deficient atmospheres.

6.4 Post installation cleaning

6.4.1 General

All pipelines should be installed with sections of pipe that are generally in accordance with 6.2. Otherwise there are no other special requirements. It is important, however, to ascertain the likely condition of the piping (for example, degree of mill scale) as delivered from the stock list or manufacturer's works to ensure that the proposed cleaning method is capable of achieving the desired standard of cleanliness. See 6.1.3 for methods of cleaning.

6.4.2 Pressure testing

See 6.3.3.

6.4.3 Internal surface finish

The cleaning process including blowout (if required) should aim to achieve an internal surface finish in accordance with Specification B SA2 of ISO 8501-1 [45]. The piping and pipeline shall be inspected to ensure that the required standard of cleanliness has been achieved (see 6.5).

6.4.4 Maintaining cleanliness

During the installation of the piping and pipeline system, every effort should be made to minimise the ingress of contaminants (for example, oil, grease, soil, debris, and runoff water). See 6.3.6 for guidance.

6.4.5 Leak testing and blowout

If a blowout is required, see 6.3.8 for details.

6.5 Inspection

6.5.1 Procedure

After satisfactory completion of the construction, testing, and cleaning processes, the piping and pipeline shall be inspected at both the inlet and discharge ends and at all accessible points to assess the condition of the internal surface. If considered necessary, according to the quality control procedure, samples can be taken at all accessible openings by wiping the internal surface of the pipeline with white, lint free cloths or filter papers of a type that have not been treated with optical brighteners. If so desired, the wipes used for sampling can be identified, sealed in a polyethylene bag, and retained as part of the pipeline quality control dossier.

The examination should be conducted using one or more of the following procedures:

- Visual inspection of the internal surfaces using white light to ensure that the cleaning has been effective and that a grey metal finish, free of grease, loose rust, slag, scale, and other debris has been achieved. A light film of surface rust is acceptable for carbon steel;

- Inspection of end sections of internal bore by ultraviolet (UVA) light to verify the absence of oil or grease; and

- Inspection of wipes (if taken) by bright white light and UVA light to verify the absence of oil or grease.

6.5.2 Ultraviolet light examination

For UVA light examination, see EIGA Doc 33 [1].

6.5.3 Inline inspection

Inspection of a pipeline may be done using an inline inspection tool (also known as an intelligent or smart pig) that uses a non-destructive testing technique to inspect the pipeline from the inside.

6.5.4 Acceptance criteria

Acceptance criteria are addressed in EIGA Doc 33 [1].

6.5.5 Remedial action

If at any stage during the precleaning or in situ cleaning process an acceptable standard of cleanliness has not been achieved and there is evidence of contamination due to heavy corrosion, adhered particulate matter, oil, grease, or similar hydrocarbon-based material present in the debris collected during pigging, the organisation responsible for the cleaning shall submit to the purchaser proposals and method statements for achieving a satisfactory standard of cleanliness.

6.5.6 Sealing, purging, and monitoring

Following the piping and pipeline system inspection and acceptance of the standard of cleanliness, the pipework shall be sealed at all open ends. When the system is complete, it shall be purged with dry, oil-free, air or nitrogen (dew point no greater than –40 °C [–40 °F]) until the dew points of the inlet and exit gas are essentially the same. Once the oxygen content and dew point have reached the required levels, the pipeline system shall be sealed and pressurised with the dry, oil-free air or nitrogen to approximately 0.01 MPa (1.5 psi). The pressure shall be monitored on a regular basis and maintained in this condition until the system is required for service with the product gas.

6.6 Records

Records of cleaning activities and details of inspections on oxygen service pipelines should be established and maintained.

7 Criteria

7.1 General criteria

The total installation of the piping and pipeline system including testing and cleaning should be undertaken by an organisation with a proven record of experience in pipeline construction. The fabrication, testing, and cleaning procedures shall have been reviewed and approved by the purchaser before the piping and pipeline is installed. The detailed construction program including the sequence of testing and cleaning procedures shall be defined to suit specific project requirements. The design of the piping system shall have made provision for the cleaning and pressure testing methods to be used.

The construction of oxygen piping systems should follow good engineering practice in accordance with recognised national or international piping and construction codes. An important factor to be considered is the cleanliness of the piping system for oxygen service. See Section 6 for further information on cleaning and inspection procedures.

Systems of work shall be in place to ensure the safety of the construction personnel in the fabrication and erection areas.

Every effort shall be made to ensure the quality and the operational safety of the piping being installed.

The oxygen piping system shall be fabricated and installed in accordance with the piping and construction codes as defined in the project specification.

All necessary precautions and measures should be taken to protect materials and piping from damage caused during offloading, storing, installing, or other activities. Piping should be carefully stored and handled to prevent contamination of the interior of the pipe and to prevent damage to the exterior protective coating (if applied).

The pipeline shall be fabricated and / or installed in accordance with approved drawings. Installation of the pipeline shall include all manual valves, special piping items, control valves, relief valves, inline items, and pipe supports as required by the approved drawings.

Whenever practical, prefabrication of pipework to oxygen cleanliness standards should be arranged to enable visual inspection along its whole length.

The fabrication of oxygen service pipework in a workshop environment shall be segregated from other activities to ensure oxygen cleanliness.

Procedures for any remedial work that may be required should be agreed upon with the purchaser prior to the work being performed.

7.2 Construction

A formal construction plan should be developed that provides for a comprehensive, logical progression of work including proper supervision, regular inspection, and verification. The following procedures and guidelines can be incorporated in the formal construction plan for any given oxygen piping and pipeline project:

- Whenever practical, assembly work should be scheduled at a late stage in the overall project and started only when all oxygen service piping and components are available on site; and

- A small group of construction personnel and an inspector should be assigned to the oxygen system and every effort made to keep the same personnel on the job until completion.

The guidelines for maintaining cleanliness are summarised in 6.3.6.

7.3 Pipe fabrication and welding

7.3.1 General

Piping shall be assembled by welding except at connection to valves, meters, or other equipment where threaded or flanged joints are permitted.

To preserve the internal cleanliness of the piping, the internal weld surfaces shall be smooth and substantially free of slag, beads, or loose debris (see 6.1.5). The required weld surface finish can be achieved broadly by various methods such as:

- Gas tungsten arc welding (GTAW), also known as tungsten inert gas (TIG) welding process, for the root pass in conjunction with, if so desired, an internal argon or other suitable backing gas. Subsequent weld passes can be made using either the GTAW or other weld processes as preferred. This process can produce the desired smooth finish on the internal weld surface. Other welds such as final tie-ins can also use the GTAW root pass to achieve the desired internal weld surface finish; or

- Manual metal arc (MMA) welding technique, also known as shielded metal arc welding (SMAW), followed by cleaning of the internal weld surfaces with wire brush or blade tool pigs to remove slag, beads, and loose debris and thereby achieve the desired finish.

Inspection should be made of all pipe spools and components prior to assembly to ensure that flange or weld faces are clean and that there is no dirt or contamination inside the pipe. Any debris or foreign material inside the pipe shall be removed before pipe welds or flange connections are made.

7.3.2 Qualification

All pipe welding shall be performed in accordance with welding procedures and by welders qualified to the procedures in accordance with the piping code as defined in the project specification.

7.3.3 Backing rings

No backing rings shall be used for the welding of carbon, stainless steel, or Monel piping intended for oxygen service for the following reasons:

- Gaps between the backing ring and the pipe wall can trap dust and debris, which cannot easily be removed during the cleaning processes. Accumulated particulate debris could act as a potential source of combustible material;
- Absence of backing rings facilitates the use of pigs for cleaning operations; and
- Backing rings can act as impact sites.

7.3.4 Preparation for welding

All weld joints shall be prepared in accordance with the approved welding procedure and the relevant piping code. The longitudinal seams of welded pipe in adjoining pipe sections shall be staggered.

On precleaned systems, internal line up clamps for welding should not be used to avoid the risk of contamination. If a system is to be cleaned in place after completion of construction, this requirement may be relaxed provided systems are in place to ensure removal of such devices before the cleaning operation.

7.4 Assembly and integration

7.4.1 Alignment

Before bolting up, the alignment deviation of the flange face and flange bolt holes shall not exceed the values defined in the project specification. All bolts shall pass easily through both flanges.

The tolerance on the termination of all piping other than flanged connections shall be as shown in the design drawings and specifications.

7.4.2 Flanged joints

Pipe stress at flanged joints shall be minimised. Piping shall not be hung from flanges of compressors or other equipment without adequate supports.

Gaskets shall be installed in accordance with the design drawings. When gaskets containing non-metal parts are used, non-metals shall be chosen according to 4.5. The use of gasket types or materials other than those defined in the project specification shall be prohibited unless approved by the purchaser. If gaskets are not individually packaged or if the package seal is broken and contamination is suspected, the gaskets should be either cleaned in accordance with EIGA Doc 33.

Gaskets shall be correctly sized to ensure that no part of the gasket projects beyond the inner wall of the pipe into the flowing gas stream. See 5.2.3.6.

The reuse of any gasket is prohibited. It is essential that new gaskets be inserted every time a flange is released. When a joint leaks on pressure test, the joint shall be remade using new gaskets and bolts.

Gaskets, nuts, and bolts shall be visually inspected to ensure that they are clean and in good condition. A solvent rinse container may be available for washing nuts and bolts just prior to installation. If so desired, a suitable lubricant as defined in the project specification may be applied to bolt threads and bearing faces of nuts and washers before bolts are inserted into flanges and tightened.

Lubricants shall be clearly identified, used sparingly, and their application made under close supervision. Oxygen-compatible lubricants are preferred; however, they can promote corrosion on parts due to their tendency to adsorb moisture. Non-oxygen-compatible lubricants have been successfully used for this service; however, great care shall be exercised through formal procedures and rigorous supervision to ensure oxygen-wetted surfaces are not contaminated and that the lubricant is not mistakenly assumed to be oxygen compatible.

Alternatively, the use of lubricants can be avoided by the use of appropriate, corrosion-resistant materials for bolts, nuts, and washers.

Bolting shall be pulled up gradually using a crossover sequence. The bolt type and size shall be matched to the flange and gasket material. If bolt loads are specified, the contractor should use torqueing or tensioning procedures to achieve the correct bolt loading. If bolt torque values are specified, the contractor can use torque wrenches via the nuts to develop the necessary bolt load. The use of torque or tensioning equipment may dictate the use of a suitable lubricant on the bolt threads. If no bolt loads or torque values are specified, bolts shall be tightened in accordance with good engineering practice or vendor information to ensure that the joint is capable of holding the test pressure without leakage.

7.4.3 Insulating joints

Insulating joints for cathodic protection systems particularly those of the monolithic / mono block type are prone to damage and leakage if overstressed either laterally or longitudinally. To reduce the likelihood of joint deformation beyond the acceptable limit, it is important that joints are adequately supported / anchored and correctly installed in accordance with design drawings and good construction practices (see also 4.6.2, 4.6.4 and 5.4.6).

7.4.4 Threaded joints

Apart from compression fittings, the use of threaded joints should be restricted to small-bore piping. Threaded joints shall be made with an oxygen-compatible tape or sealant such as PTFE thread tape. The use of threaded joints in piping systems shall be limited as far as is practically possible. Clean cut taper threads in accordance with the design requirements shall be used and shall be fully deburred. Unions shall be installed as per the design drawings.

7.4.5 Valves

All valves shall be supplied with identification tags or plates and installed in the location defined by the design drawings. Identification tags or plates shall remain attached to each valve after installation. It is not permitted to interchange valves.

To minimise exposure to damage, valve top works, actuators, and other associated equipment can be stored in a clean condition and installed as required after major construction work has been completed.

All valves shall be installed in accordance with the piping design drawings and handled in a way that maintains their cleanliness and prevents ingress of moisture, oil, dust, and other contaminants. Particular care should be taken with valves, whether manual, automated, or pressure relief, to ensure that both the flow direction and orientation are correct.

The use of valve lubricants should be avoided whenever possible but, if required, they shall be oxygen compatible and used sparingly.

The following precautions shall be observed with respect to the installation of PRVs and other PRDs:

- Apart from those required for construction and testing purposes, no PRVs or other PRDs shall be installed until all pressure testing, cleaning, and blowout work have been completed;

- All relief valve nozzles not to be used during construction shall be fitted with caps or blind flanges as appropriate to maintain cleanliness during storage;

- All relief valves and piping installed solely for construction and testing purposes shall be removed before the pipeline is put into service; and

- The purchaser shall be informed of any visible damage to a valve before it is installed.

Before welding any valve into a piping system, the valve shall either be fully opened or the top works removed to prevent thermal distortion of the valve components. Soft seats and other components vulnerable to damage by heat should be removed. After welding, soft seats, and other vulnerable components can be replaced following which the valve should be checked for ease of operation and remedial action taken if excessive force is required to operate the valve.

7.4.6 Supports, guides, and anchors

Supports, guides, and anchors shall be positioned and secured before the installation of the piping. Additional temporary supports can be used during installation, but they shall not be welded or bolted to any permanent structural members. Temporary supports, guides, and anchors shall be removed before the piping and pipeline is commissioned.

All welded connections such as earth clamps or supports attached directly to process piping or equipment intended for service at elevated pressures shall be made before pressure testing. Welding on pressure containing equipment after the successful completion of a pressure test is not permitted.

7.5 Inspection and examination

During construction, regular on-site inspections should be made to ensure that correct procedures for installation and maintenance of pipeline and piping system cleanliness are being observed. After completion of construction, the pipeline and piping system should be inspected and tested in accordance with the relevant piping code and procedures as defined in the project specification. Such inspections should, as a minimum, verify the following:

- pipe concentricity;
- specified wall thickness;
- internal cleanliness (for example, pigging);
- protective coating integrity;
- absence of mechanical damage (for example, gouges, dents, etc.);
- joint preparation;
- welding fit-up;
- welding;
- absence of arc burns; and
- review of X-ray examination.

7.6 Non-destructive testing

7.6.1 Pressure testing

If permissible, the pressure test should be conducted pneumatically using dry, oil-free, air or nitrogen to minimise the possibility of contamination (see 6.3.3). The test shall be carried out in accordance with the code to which the piping system has been designed and constructed. Safety precautions to minimise the potential consequences of a pressure release shall be taken while the test is in progress. If nitrogen is used as the test medium, the risk of exposure of personnel to oxygen-deficient atmospheres shall be assessed and appropriate precautions taken to prevent the risk of asphyxiation.

If it is not permissible to carry out a pneumatic pressure test, a hydrostatic test should be carried out in accordance with the relevant piping code. The test shall be conducted using clean, oil-free water (preferably from a public supply). If so desired, a de-oxygenating agent and passivation agent may be added to the water provided that the agents do not create any disposal problems. The filling and testing operations shall be planned as a continuous operation to ensure that water does not remain in the system for any longer than necessary, particularly if freezing ambient temperatures are foreseen during the test period.

After the completion of a hydrostatic test, the water should be removed immediately either by draining or pigging or a combination of the two. The piping system should then be dried either by purging with dry, oil-free, air or nitrogen to achieve a maximum dew point of –40 °C (–40 °F) or by a recognised vacuum drying process using oxygen-compatible vacuum pumping equipment.

In the event that welding is required for repairs, pipe tie-ins, or final closing welds, the relevant piping code may waive the need for a pressure test provided that a prescribed alternative method of non-destructive testing is carried out.

7.6.2 X-ray examination

Butt weld joints in the pipeline shall be radiographically examined in accordance with the piping code defined in the project specification. Final closing welds can be subject to 100% X-ray examination without pressure testing as acceptable to the authority having jurisdiction [AHJ] (see 7.6.1). Socket weld and fillet weld joints can be suitably tested using other non-destructive examination in accordance with the applicable code. For socket and fillet welds, dye penetrant testing is acceptable.

In situations where the radiological hazards presented by X-rays (or Gamma rays) cannot be accommodated by reasonable means, 100% ultrasonic examination (UE) by a qualified operator with a specific report for each weld shall be employed.

Longitudinal pipe seams that exist as a result of the pipe manufacturing process are exempt from on-site X-ray or UE.

7.7 Documentation

The following documents relating to the construction and installation of the pipeline and piping shall be retrieved and retained for reference by the purchaser:

- pressure test report;
- weld procedures and qualification records for each welder;
- weld joint X-ray negatives and reports;
- records of weld tests / rejects / repairs;
- weld map;
- report of internal pipe cleaning and inspection;
- as-built drawings;
- as-built data logs;
- records of construction personnel qualifications;
- material control certificates; and
- other reports and certificates required by local and / or national authorities, relevant piping code, and project specification.

In addition, for underground pipelines:

- test report (for example, Holiday test) for detecting pinholes or defects in the external coating; and
- cathodic protection and electrical isolation report.

8 Design and construction of control stations

8.1 Function

The function of a process control station is to control and meter gas in conjunction with a supply pipeline. Each process control station is designed and constructed for individual customer requirements and incorporates appropriate process control equipment.

8.2 Design brief

A design brief summarising the basic requirements (process definition and process and instrument diagram [P&ID]) should be used as the basis for design.

The design brief should be developed by reference to the following:

- process pattern data supplied by customer;
- environmental, customer, and other statutory requirements; and
- site requirements including interaction with surrounding plant.

A hazard and operability (HAZOP) study and / or risk assessment may need to be considered with the design brief.

<u>A HAZOP study and a risk assessment shall consider:</u>

- <u>transient and abnormal modes of operation including deviation in process conditions;</u>
- <u>plant restarts, commissioning systems, restoring depressurised systems after maintenance;</u>
- <u>air separation unit trip with back-up system piping blinded, functions of automatic valves (if present); and</u>
- <u>pipeline station operation and maintenance (if present).</u>

8.2.1 <u>Valves</u>

<u>See Section 13 of EIGA Doc 200 for quality assurance and quality control requirements for the qualification of valves [37].</u>

8.2.1.1 Emergency shutoff valves

Emergency shutoff valves may be provided to afford protection against pipeline failures. The closure of the valves can be initiated manually or automatically from a central control room or by automatic signals derived from high flowrate, low pressure, or rate of decay of line pressure (see also 5.3.2.4).

8.2.1.2 Isolation valves

See 5.3.

Isolation valves are normally of gate, ball, plug, or butterfly type design and should be positioned in the fully open or fully closed position. Valves may be manually or automatically operated. Isolation valves made of non-exempt materials shall never be closed during a flowing condition nor opened under a differential pressure greater than 34 kPa (5 psi) unless a risk assessment has been completed. See 5.3.2.5 for more information regarding near equalisation of pressure.

Because isolation valves are typically operated without differential pressure, they shall be designed in accordance with the requirements in 5.3.1 and 5.3.2. They should not be operated in the throttling or regulating mode, and if so, are not considered isolation valves and shall be designed as throttling valves (see 8.2.1.3).

8.2.1.3 Throttling and control valves

As defined in 5.3.2.3, throttling valves operate with high differential pressures and high internal velocities. Throttling valves may be either automatic or manual valves. Throttling valves shall be designed with exempt alloys or equipped with barriers to protect personnel when operating the valves.

8.2.1.4 Pressure relief and vent valves

See 5.3.2.6 and 5.3.3.5.

Where required, a PRD is installed downstream of the pressure controllers to protect the system against the abnormally high pressure that is experienced under failure conditions.

The PRDs are designed to accommodate the full flow to the system, which could result from control valve failure in the open position at maximum upstream pressure including an allowance for pressure drop. Vent stacks from relief devices shall be arranged to discharge in a safe outdoor location to prevent oxygen enrichment.

8.2.2 Filters and strainers

See 5.4.1, 5.4.2, and 5.4.3.

Filters may be installed at the inlet to the process control station to protect control devices from particulate matter (originating from the upstream carbon steel pipeline or equipment / machinery) that may be entrained in the gas stream.

For ultra-high purity applications (for example, electronics) more stringent filtration levels (typically less than 5 µm) may be specified.

8.2.3 Flowmeters

See 5.4.4.

The invoice meter accurately measures the total quantity of gas passing through the process control station. The meter consists of a primary device and instrumentation to convert the output signal to a volumetric or mass flow value.

Orifice plate meters are frequently used. Bypass provision may also be required to facilitate removal for calibration and maintenance.

The selection of flow meter type is normally based on the accuracy requirements for the required range of gas flow to meet customer requirements. Instrumentation for converting the output from the volumetric primary device into a mass flow may use an integrated electronic system, which may be comprised of the following:

- pressure transmitter;
- temperature transmitter;
- differential pressure transmitter;

- hot wire transmitter;
- ultrasonic transmitter; and
- mass flow computer.

8.2.4 Flow and pressure control

Flow control devices can be incorporated to overcome erratic flow patterns to produce constant supply irrespective of customer demand or to limit the flow available to the customer. Pressure control systems regulate the variable pipeline pressure to deliver gas at constant pressure to the customer.

Dual pressure control valve streams may be required to give reliable supply and ease of maintenance.

8.2.5 Gas storage

Storage vessels or additional volume of piping may be required to provide buffer capacity to satisfy peaks in customer demand and to provide downstream capacity to facilitate efficient control valve operation.

8.2.6 Spill or vent control

Spill control allows the selected pipeline supply to continue when gas demand falls. This allows automatic venting of the surplus flow to atmosphere without the operation of the PRV.

8.2.7 Instruments

Instruments are usually controlled by electronics and / or by pneumatic systems. The instrument operation shall be one or a combination of the following:

- electronic using a secure power supply;
- pneumatic using a secure instrument air supply; or
- pneumatic using the service gas.

NOTE All instrument components used in oxygen service shall be manufactured from compatible materials and shall be suitably cleaned and degreased before installation.

Systems using gaseous oxygen as the service gas shall be installed in an outdoor or well-ventilated location to avoid the risk of oxygen-enriched atmospheres.

8.3 Standards and design codes

Design, fabrication, inspection, examination and testing shall be in accordance with national or international standards such as ASME B31.3, *Process Piping* [47].

For designs in copper and copper-nickel only, the allowable design stress shall be obtained by reference to a specific design code such as EN 13480-1, *Metallic Industrial Piping—Part 1: General* or ASME B31.3 [48, 47]. Electrical and instrument installations shall be designed and installed in accordance with the relevant international or national standard [39].

8.4 Materials

Due to the many unavoidable restrictions and variations in gas velocity within the pipework and components (for example, meters, valves, and filters), the designer shall carefully evaluate pressure and flow rates under operating conditions. Exempt materials shall be used where necessary to meet the requirements of Section 4.

Only lubricants formally approved for oxygen service shall be used (see 5.5). It is important to maintain disciplined inspection and quality control procedures from procurement of raw materials and components to final testing, commissioning, and subsequent maintenance.

8.5 Barriers and screens

8.5.1 Barrier requirements criteria

Where compliance with the velocity curves (Figures 2 and 3) as discussed in 4.4.2 and 4.4.3 cannot be ensured in all operational modes, protective personnel barriers or screens shall be considered. Whether a component should be located behind a protective barrier depends upon the material selection, pressure, gas velocity, piping size (see 4.7), personnel exposure, siting (see 4.6 and 8.6), and a risk assessment. The function of such barriers or screens is to mitigate, if it is not possible to contain, the effects of any incident and to provide additional protection for operators, maintenance personnel, and the surrounding environment and equipment.

8.5.2 Design criteria

When barriers are used the following guidelines and requirements apply:

- Barriers shall protect personnel and, if so desired, adjacent equipment from hazards that occur during an oxygen combustion fire. They shall withstand loads from high temperature combustion, released fluid pressure, and molten metal spatter. These loads vary according to the pressure of the oxygen and the proximity of the barrier to the breech of the pipe or component;

- Oxygen station barrier materials should be capable of withstanding the thermal and erosive loading generated during an oxygen promoted metal fire. Oxygen promoted metal fires can vary considerably in terms of energy, thermal, and erosive loading as well as potential consequences at a specific site. Hence, the requirements for barrier materials may need to be defined via a risk analysis. The barrier material that is close to a potential fire breech point should be capable of impeding an oxygen lance burning at approximately 2760 °C (5000 °F) placed at 15 cm (6 in) from the barrier material for a minimum of 3 sec. The recommended lance should be 1.85 cm (0.75 in) nominal pipe diameter and fed with gaseous oxygen at a pressure between 0.8 MPa and 1.5 MPa (100 psi and 200 psi). The barrier should also be able to withstand the breech jet load on the barrier surface caused by the pressurised oxygen release. The jet load force for a barrier design is known to be proportional to PD2, where P is the nominal gas pressure and D is the nominal pipe diameter. In practice, a reducing factor could be used depending on the piping configuration and system volume. The detailed calculation of jet loads is outside the scope of this publication. The user should refer to specialists with expertise in gas dynamics and structural design of barriers for these calculations;

- Barrier materials should be non-flammable such as concrete, reinforced masonry, or insulation reinforced with metal structural sheets. The fire barrier membrane materials may also be asbestos-free to follow national regulations. For barriers not close to any potential fire breech point, steel plate can be used;

- Barriers shall be designed to withstand applicable loads from wind, snow, and seismic activity;

- Barriers may be in any configuration but should have features that prevents any molten metal splash from being deflected past the barrier;

- Vertical barriers open to the sky or building roof are acceptable;

- Barriers should preferably be at least 30 cm (12 in) away from any component having an oxygen fire potential;

- Attention should be given to barriers located in the area adjacent to bends, bypass, and emergency shutoff valves and related piping;

- Barrier height should be at least 2.5 m (8 ft) and block any line of sight view of the equipment from walkways, permanent platforms, or public buildings within 15 m (50 ft). The barrier should have no apertures except for piping or equipment penetrations where the maximum clearance should be no greater than 2 cm (0.8 in). Penetrations through the barrier should be sealed; and

- Barriers shall be constructed such that maintenance personnel and operators can work safely outside the barriers. In cases where there are two control stations to ensure continuity of oxygen supply, a barrier should be placed between the two stations.

Valves with non-exempt material should not have the valve stems exit the barrier horizontally as there is a risk of injury to the operator. Mitigations measures include:

- valve with a shield welded on the stem inside the wall;

- valve with a gearbox mounted at 90 degrees that directs any fire from the valve upwards rather than horizontally;

- valve stem exits horizontally but has its handwheel connected via a chain to a secondary handwheel located approximately 1 m (3 ft) to the side. All valve packing shall be behind the barrier; and

- valve with stem and handwheel inside the protection barrier. In order to operate the valve from outside the barrier, the valve gear needs to be connected via a cable solution to the handwheel positioned at a safe location outside the barrier.

Where possible, the gaseous oxygen product line should enter the fire protection barrier from the top and exit the barrier to the top in order to avoid any pipe penetration of the gaseous oxygen product line through the barrier wall. This prevents any fire from following the pipe and out through the barrier.

8.5.3 Operational requirements

Personnel are not allowed to enter an area enclosed by a barrier while the piping system is under oxygen pressure without an approved procedure.

Equipment that shall not be located within the protective barriers includes:

- operator controls including instrument air valves and pressure reducers;

- instrument readouts and equipment on which maintenance shall be made during operation;

- emergency shutdown switches;

- check valves (unless individually protected with its own barrier);

- emergency shutoff valves (unless individually protected with its own barrier); and

- sampling valves.

Manual valves located within barriers that need to be operated while oxygen is flowing shall be equipped with an extension wheel located outside the barrier so any ejection of the valve spindle cannot strike the operator.

8.6 Location

The location of oxygen stations should be chosen to avoid the immediate proximity of vulnerable areas and equipment such as flammable product storage tanks, aboveground flammable pipelines, public roads, public buildings, car parks, and transfer stations. Vessels or aboveground piping in service with flammable fluids should be located as far away as practical from oxygen stations. Mechanical joints such as flanges in aboveground flammable fluid piping, particularly piping in service with hydrogen, should not be located close to an oxygen station to minimise the risk of fire in the event of simultaneous leaks or failures.

Oxygen stations should be located where there is no danger of oil contamination or projected material from nearby equipment and machinery. If there is a nearby public or internal plant road, a vehicle barrier rail should be installed to protect the station from impact damage. The station should be fenced to restrict access by unauthorised persons. Exits should open outwards into areas that are free of obstructions.

Smoking shall be forbidden within a minimum of 5 m (17 ft) from the oxygen station. This distance can be increased depending on the risk involved at a specific location. Activities involving the use or production of flames, sparks, or other ignition sources shall also be forbidden except as authorised by a safety work permit.

An acceptable standard of lighting shall be provided to illuminate the station to ensure personnel safety.

For stations located inside enclosures, the risk of oxygen-enriched atmospheres, atmosphere monitoring, and ventilation requirements shall be considered.

The exposure of people, equipment, and activities adjacent to an oxygen station can be minimised by appropriate separation or safety distances. The selection of separation distances depends on a number of factors including the following:

- stored energy level in the system;
- function and complexity of the station, i.e., control, metering, and / or isolation;
- environmental considerations;
- public and personnel exposure;
- exposure of equipment and adjacent activities; and
- consequence of gas release.

It is convenient to use the potential energy of the gas inventory in an oxygen control station as a basis for determining separation distances. The potential or stored energy in an oxygen station can be expressed as $P \cdot D^2$ where P is the normal maximum operating pressure (bar abs) and D the pipe diameter (cm). For control stations, three categories of energy release level together with appropriate safety distances have been used:

- Category 1: $P \cdot D^2 > 3000$, $P > 4$ bar abs, $D > 2.5$ cm;
- Category 2: $1500 < P \cdot D^2 <= 3000$, $P > 4$ bar abs, $D > 2.5$ cm; and
- Category 3: $P \cdot D^2 <= 1500$, $P > 4$ bar abs, $D > 2.5$ cm.

For PD^2 greater than 3000, a specific risk assessment should be performed to determine if safety distances greater than listed in Appendix E are necessary.

For stations intended for isolation or metering purposes only and where there are no automatic flow control or pressure reducing valves, the risk of failure is significantly reduced and the energy release level is therefore of less significance.

Typical arrangements for the siting of the oxygen stations in relation to other areas and equipment can be found in the table of Appendix E for each of the defined energy release levels. The distances refer to stations without barriers (except for vehicle barriers) as summarised in 8.5.2. The safety distances indicated in Appendix E may be reduced by the use of specific design or installation measures such as the use of exempt material throughout the station and / or by the installation of barriers or screens provided that these can be justified by a detailed site risk assessment procedure. The stations considered in Appendix E are control stations (Categories 1, 2, and 3) and those for isolating and / or metering purposes only (Category 4).

8.7 Earthing, grounding

The resistance to earth (or ground) of the station pipework should not exceed 10 ohms at any point throughout the installation. Tests shall be conducted from a known earth point. If necessary, cross flange bonding may be required to achieve the stated minimum value. If cross bonding has been adopted, measures shall be taken to prevent corrosion of component parts.

Pipework systems should not be used for earthing associated equipment. The method to be adopted is supplementary earthing from a system earth point.

Pipework systems together with all other common services shall be bonded at a common point.

All test results including reference earth point shall be recorded and periodic testing undertaken.

8.8 Fabrication

Process control stations shall be fabricated in accordance with the approved design.

All butt welds shall be subject to examination and non-destructive testing in accordance with the relevant design code. Verification that the required standard has been achieved shall be confirmed by a quality assurance authority or authorised inspector.

8.9 Installation

All pipes and components shall be cleaned, degreased, and prepared before installation and scrupulous cleanliness maintained thereafter (see Section 6). However, should contamination occur during installation, additional cleaning shall be carried out with analytical checks to ascertain that all traces of the cleaning agent have been removed.

Installation shall be carried out by contractors approved in their particular discipline, i.e., mechanical, civil, electrical, instruments. Installation work shall be completed in accordance with the design drawings and specifications. The completed installation should be inspected and approved by the relevant technical authority.

8.10 Testing

8.10.1 Post-fabrication

Following completion of fabrication, the pipework shall be pressure tested in accordance with a national or international standard. If hydrostatic testing is used, the pipework shall be thoroughly drained, dried, and cleaned, <u>and inspected</u> after testing.

8.10.2 Post installation

Completed installations shall undergo a pneumatic test with dry, oil-free, air or nitrogen in accordance with a national or an international standard (see 7.6.1).

8.11 Commissioning

The preparation of a suitable commissioning procedure should be undertaken with details of the following accommodated:

- interaction with customer processes; and
- safety considerations.

A responsible person shall be appointed to control all aspects of the commissioning procedure.

8.11.1 Safety

When practicable, non-essential personnel should be excluded from a minimum 20 m (66 ft) distance from piping, valves, and equipment during the first pressurisation and then the first flowing of oxygen through a new piping system. Thus, only personnel required to operate valving during commissioning of the system should be allowed inside this exclusion area and these operators should have the training outlined in 9.1.1. The responsible person shall coordinate and control the commissioning and shall ensure that the customer and all personnel are properly briefed. Normally, a commissioning program and procedure is prepared by the responsible person and discussed with all concerned before commissioning starts. All gas supplier and customer standing orders and safety instructions shall be observed.

When nitrogen is used as the test gas, precautions against asphyxiation shall be specified. Vent pipes should be fitted, where necessary, to ensure that gas is discharged to a safe area.

8.11.2 Procedure

The commissioning procedure should start after satisfactory completion of pressure testing and the issue of the relevant test certificates. The procedure should include the following pre-commissioning checks:

- <u>Constructed according to the approved design (P&ID);</u>
- Relevant material, cleaning, authenticated calibration, and test certificates are available;
- Warning notices and instruction plates are posted;
- Filter elements are fitted, if and where specified; and
- Satisfactory operation and adjustment of:
  - meters
  - flow controllers
  - spill valves
  - pressure controllers
  - safety valves (if fitted)
  - safety shutoff valves (if fitted)
  - shutoff valves; and
  - safety devices, alarms, and trips.

8.11.3 Filters

Initially on a new process control station, due to high velocity test and purge flowrates during commissioning, any filters may receive a considerable amount of foreign matter from the pipeline and may choke rapidly.

During commissioning, the filter differential pressure gauges should be monitored (especially in the first phases of commissioning) in order to detect when filter element changes are required. Such a monitoring exercise should also be carried out following maintenance / shutdown / modification.

8.12 Operation

Process control stations are normally automatic in operation once the controls have been set. The only manual operations required are:

- opening and closing of isolating valves to meet process and maintenance requirements;
- monitoring of gauges and other indicator displays to ensure the process control station or components are operating within limits;
- maintenance of a clean process control station area and particularly the exclusion of flammable products; and
- completion of items defined under the planned preventative maintenance system.

Personnel entrusted with the operation of the process control station shall be trained in the operating techniques required, the potential hazards associated with oxygen, and the emergency procedures.

9 Operation, monitoring, and maintenance

9.1 General safety instruction

- Before performing work on oxygen systems, a safety work permit should be issued. Guidance on work permit systems is found in EIGA Doc 40, *Work Permit Systems* [49];
- Smoking is forbidden in stations and within a safety distance of 5 m (17 ft) (see also 8.6);
- Naked flames are prohibited in the safety zone (see also 8.6);
- Ensure that all traces of oil and grease are removed;
- Cap open pipes ends when not working on the pipe;
- Earthing of any equipment such as welding equipment onto oxygen piping and pipeline systems while in oxygen service is not permitted;
- Cathodic safety equipment shall not be checked during storms when there is a high risk of lightning;
- Procedures should ensure that personnel do not remain in the area of oxygen stations during storms when there is a high risk of lightning; and
- As for other piping and pipelines, provisory grounding is recommended during maintenance work (risk of alternating induced current created by a ground defect on a nearby electric power line).

9.1.1 Personnel for operation and maintenance

In addition to being trained in work safety knowledge, personnel who operate and maintain oxygen systems shall also have specific training and understanding of oxygen safety requirements. They shall be familiar with the location of the pipelines, the stations, and the control equipment. All the relevant operating and safety procedures shall be available to operations personnel.

Subcontractor personnel shall be informed about and have access to all the relevant safety information.

Operations and maintenance personnel shall work with clean hands, work clothing, and gloves that are free of lint, fibres, and uncontaminated by oil or grease.

9.1.2 Operating isolation valves

Whereas control valves may be designed for operation with large pressure differences, this may not be the case with conventional shutoff valves that may not be designed for use in throttling mode. An isolation valve not fabricated from exempt materials may only be operated after reducing the pressure differential to 0.34 kPa (5 psi) or less by the use of a bypass valve or other specific procedures. See 8.2.1.2. Provisions shall be made for monitoring the pressure difference across isolation valves regardless as to whether they are locally or remotely controlled. An isolation valve can be used in throttling service provided it is manufactured from exempt materials. By definition, the valve then is defined as a process control valve.

9.1.3 Welding and cutting work

Any welding on in-service oxygen pipelines and piping could cause localised heating and / or adversely affect the integrity of the piping system and therefore shall be avoided.

The only exceptions are:

- drilling small openings in depressurised pipelines and piping during connection work; and
- welding on cathodic protection studs using a stud welding unit as explained in the next paragraph.

A process qualification shall be made beforehand in order to ensure that little or no heat is generated on the inside of the piping during the time the bolt is being welded on. This activity requires equipment and procedures specific to the work involved. It may only be carried out under the supervision of personnel trained in this process and relevant procedures. The process qualification shall verify that the pipe metallurgy and properties are not adversely affected by the process. Despite good experience with such technique, it is preferred that the process be carried out when the oxygen line is out of service.

9.1.4 Oxygen enrichment and deficiency

Work shall only be carried out in well-ventilated areas where ambient air is available.

The following limits should be adhered to:

- upper limit: 23.5% by vol (oxygen enrichment); and
- lower limit: 19.5% by vol (oxygen deprivation).

The ambient air shall be checked over a wide area around the place of work.

Particular care is required when working inside buildings, within walled areas, and in ditches. The risk is considerably reduced when working in the open.

Oxygen can collect or concentrate in low lying areas if its temperature is equal to or less than that of the surrounding air. The human senses cannot detect changes to the concentration of oxygen in the ambient air. Checking the oxygen concentration using naked flames is strictly forbidden. The oxygen concentration at the workplace and in the environment should be checked using equipment such as a portable oxygen analysis unit. These devices shall be checked and calibrated at regular intervals.

9.1.5 Shutdown / start-up of pipelines and piping systems

Written procedures are required for shutdown / start-up and maintenance of pipelines and piping systems. The personnel involved in the work including contractors shall be informed of the specific risks related to oxygen and the tasks to be performed.

Authorisation for these activities by a responsible person shall be given as follows:

- prior to starting maintenance work, after shutoff procedures are completed; and
- prior to re-pressurising the pipeline or piping system, when maintenance work is completed, and cleanliness for oxygen service has been verified.

No repair work may be carried out on equipment and plant until the work area has been cordoned off. When carrying out maintenance on components during pipeline operations that does not require disconnection of the system, or activities involving no hot work, isolation by closing a single valve is acceptable provided the system can be depressurised satisfactorily. A check valve cannot be used as a shutoff mechanism for maintenance work.

A positive shutoff is required if major work such as cutting and welding is being carried out. This shutoff can be carried out by:

- complete disconnection of the section concerned from the pipeline system;
- installing blind flanges;
- closure and mechanical locking of two valves arranged in tandem with an open venting valve between them (if the valve has an electric drive, the power should also be disconnected): double block and bleed valve; and
- closing a valve and placing a sealing balloon (bubble) inside the pipe with an intermediate bleed valve (may be used if there are no other possibilities).

Tags should be placed to indicate that the equipment has been locked in the shutoff position.

Continuous monitoring of the oxygen concentration shall be made.

After dismantling an item of equipment, the pipe opening should be sealed since leaks, chimney effects, air pressure changes, and heated gas can cause release of oxygen.

9.1.6 Venting and pressure relief

9.1.6.1 Venting

- Large quantities of oxygen shall be vented to atmosphere, preferably outside buildings and enclosures, in a location where neither personnel nor vulnerable items of equipment are exposed to oxygen-enriched atmospheres;
- Compressors and vehicles with combustion engines should not be operated in oxygen-enriched atmospheres; and
- Venting should not take place directly beneath high voltage overhead lines.

9.1.6.2 Pressure relieving

When the pressure is being relieved, an auxiliary valve in throttling mode may be installed downstream of the actual blowout valve. The auxiliary valve protects the actual blowout valve during the venting procedure and therefore guarantees its functionality (tightness). The auxiliary valve should be installed downstream of the blowout valve and kept closed until the blowout valve is fully open. Venting can then take place using the auxiliary valve.

9.1.7 Purging

Dry, oil and grease-free, air or nitrogen shall be used to purge oxygen from the pipeline and piping. A purging program including all branches shall be followed in order to avoid leaving any oxygen pocket in the pipeline system.

When using nitrogen, it shall be ensured that unauthorised access to the outlet is prevented and that no one can be endangered by either oxygen-enriched or oxygen-deficient atmospheres.

Rooms, walled-in areas, or ditches can be aerated by extraction fans or supplied with fresh air.

9.1.8 Tools

Tools and accessories that are used (including, for example fasteners and connecting pieces) shall be clean and free of oil and grease.

9.2 Commissioning pipelines, piping and stations

Supplier's and manufacturer's instructions for commissioning the equipment and plant shall be followed. After the successful completion of strength and tightness testing as per the applicable regulations and cleaning, drying, and inspection (if the pipeline has been subjected to a hydrostatic test), the pipeline can be put in service. If possible, new pipelines shall be blown through with a large quantity of dry, oil-free, air or nitrogen using as large an outlet as possible to remove dust from the pipeline (see also 6.3.8 and 6.4.5).

When commissioning starts, the system shall first be purged with oxygen so the air or nitrogen that is already in the pipe is removed. The purging process is carried out using throttling and bypass valves, if present (depending on the nominal diameter of the pipeline) via the last valve under pressure. The oxygen should be introduced in a specific direction in order to ensure oxygen purity.

The purity of the oxygen should be measured at all outlets using analysis equipment. If the purity is adequate at the outlet, the relevant valve can be closed.

When the system has been purged and all the purging points have been closed, the piping can be pressurised using a bypass valve, a throttling valve, or a control valve in order to slowly pressurise the pipe up to the operating pressure.

The flange connections should be checked for leaks at regular intervals during commissioning.

9.3 Operation and monitoring

Supplier's and manufacturer's instructions for the equipment and systems shall be followed. Pipeline and stations shall be kept in good working order from an operational and safety point of view.

The operator shall follow a preventive maintenance program including all safety and technical monitoring measures. A detailed description of the work to be carried out shall be included in work instructions.

An example of a preventive maintenance program is in Appendix F, which illustrates the main tasks to be performed. The frequency at which inspections are performed is dictated by national regulations and / or established company practices.

9.4 Information to third parties, summary of work, records, and update of pipeline drawing

9.4.1 General

The maintenance of pipelines does not concern just technical and operational considerations.

Statistics from pipeline companies show that more than two out of three incidents occurring on underground pipelines are due to external events.

To protect pipelines and ensure the reliability of supply, it is necessary that third parties be informed of the location of the pipelines, any work adjacent to the pipelines, and information regarding the installation of new pipelines.

9.4.2 Flow of information

National regulations, when they exist, shall be followed.

These regulations usually require that:

- operators of underground structures (pipes, cables, etc.) submit a declaration to the local authorities concerned;
- contractors performing earthworks in the area of underground structures inform the operators of those underground structures about the nature of such work in the form of a declaration; and
- operators respond to the contractors in a timely manner.

In the absence of national regulations, a similar plan for information flow should be adopted.

9.4.3 Summary of work

A summary of work carried out on pipelines or near pipelines and also of work not performed should be made by the pipeline operator.

When work is performed adjacent to pipelines, the summary should be formalised by the issuance of a written document countersigned by the site manager.

9.4.4 Records

Records of the following should be made by the pipeline operator:

- requests from contractors;
- replies to those requests with the transmitted documents; and
- work supervision documentation.

9.4.5 Updating of pipeline drawings

Updating of pipeline documents, in particular pipe installation drawings, should be carried out on existing pipelines to reflect deviations and modifications that occurred when work was performed.

9.5 Specialised surveys

In addition to the routine monitoring of the cathodic protection system potentials, a close interval potential survey (CIPS) should be performed at 5 year intervals, and implementation of an integrity management program on the pipeline should be performed in accordance with applicable regulations.

Problems with cathodic protection systems for the pipeline identified by annual surveys, close interval surveys, or other means, may be diagnosed using a variety of techniques, such as:

- CIPS;
- Alternating current voltage gradient (ACVG) survey or direct current voltage gradient (DCVG) survey;
- Current attenuation survey / pipeline current mapping survey (PCM); or
- Pearson survey.

A full list of aboveground survey techniques can be found in NACE SP 0502, *Standard Practice – Pipeline External Corrosion Direct Assessment Methodology* [50].

These indirect inspection techniques may be applied as an integral part of a pipeline integrity management program.

9.6 Damage to the pipeline system

9.6.1 Leakage

If a leakage of product from the pipeline is suspected and cannot be located through visual or audible evidence, the pipeline should be isolated in sections and pressure tested to identify the source of the leak or prove that the pipeline is sound.

<u>A mechanical clamping system shall not be used due to the non-oxygen-compatible organic sealing material</u>.

9.6.2 Revalidation

Consideration should be given to revalidation (a detailed inspection including a pressure test) to establish the pipeline's suitability for continued service following a leakage, fire, or other incident not attributable to third-party interference, or a significant modification to the pipeline system.

10 General protective measures

10.1 Emergency response plan

An emergency response plan procedure document is required to ensure that all operating staff and others who may be involved, including the public authorities, are adequately informed of the action to be taken in the event of an emergency. An emergency response plan shall be developed to meet the particular needs of each individual pipeline system. National laws or regulations may dictate the form and content of such a plan; however, the following subjects should be considered when compiling such plans.

10.1.1 Liaison with public authorities and other consultees

The effective handling of a pipeline incident may require the cooperation of public authorities (for example, police, fire, public utilities, etc.). A list of emergency contacts should be established and copies of the relevant sections of the emergency procedure should be circulated to those authorities that may be involved.

10.1.2 Description of pipeline system

This should include all relevant technical data such as routing, length, diameter, pressure of the pipeline, location, and drawings of control stations including location of isolation valves.

10.1.3 Control centres

The role and location of the control centre for dealing with an emergency should be established, and communication media (for example, telephone, radio, e-mail and / or facsimile) should be identified. Clear instructions for dealing with emergencies shall be established and formalised.

10.1.4 Notification of an incident

The incident might be detected by operators at a pipeline control centre or be notified by a third party through the observation of some abnormal condition on site. The control centre should be responsible for identifying the precise location of the incident, recording all details, and passing the information to the emergency response team without delay.

10.1.5 Altering procedure

The control centre shall alert personnel on call. The emergency procedure should clearly identify the initial action to be taken by all personnel on receiving an emergency call. Any restrictions on entering land should be included. Provision shall be made for the mobilisation of a responsible person at the site together with staff capable of assessing and dealing with the scale of the operation.

The alerting procedure should also include requirements to inform all concerned when normal conditions are restored.

10.1.6 Shutting down a pipeline

A clear procedure and understanding with the public authorities regarding the isolation and shut down of the pipeline in an emergency situation should be established. It is important that the pipeline control centre take charge of these events in the interests of the safety of all involved.

10.1.7 Emergency equipment

Equipment to deal with the emergency shall be kept in a state of readiness at an appropriate location.

Typical examples are transportation for equipment and manpower, effective communication system between control centre and the incident location, analysis equipment, fire extinguishers, protective clothing and safety devices, lighting sets and power supply, repair materials, and tools.

10.1.8 Remedial action

A detailed assessment of the action to be taken in dealing with the emergency can only be established following an initial assessment at the site.

However general guidelines on the approach to be taken should be indicated in the procedure (for example, steps to be taken in dealing with a fire).

10.1.9 Pipelines with cathodic protection

If a pipeline has been severed, the cathodic protection system should be isolated and temporary bonds established (if required).

10.1.10 Incident report from

Details of the incident should be compiled and recorded on the form required by the regulatory requirements of the country concerned and / or the company reporting procedure.

10.1.11 Emergency exercises

To ensure that the emergency procedure adequately covers the requirements of the pipeline system for which it is drawn up, it is recommended that emergency exercises be carried out periodically.

10.2 Power supplies and lightning strikes

The power installation and lightning protection in the stations shall be installed in accordance with applicable standards and specifications such as NACE SP0177, *Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems* [51].

The pipeline may be affected by alternating current if it runs parallel to overhead high voltage cables or direct current if adjacent to tram / railways. The induced effect of the alternating or direct currents on the relevant pipeline sections can be minimised by taking suitable measures such as splitting the pipeline into several sections using insulating flanges and active / passive earthing. For more information, refer to EN 50162, *Protection against corrosion by stray current* and ISO 18086, *Corrosion of metals and alloys – Determination of AC corrosion – Protection criteria* [52, 53].

The cathodic protection should not be affected by these measures even for short periods.

Particular care shall be taken to protect installed electrical equipment from overloading. It is particularly important to consider the need for protection against short circuits and earth faults on overhead high voltage cables using direct current decoupling devices such as polarisation cells.

10.3 Fire

The specific fire risks that can occur in oxygen systems are:

- Spontaneous combustion occurring inside the oxygen system, which can rapidly develop into a fire. Generally, this fire will extinguish after a few seconds, but the mass of oxygen released can create an oxygen-enriched atmosphere; and

- Combustion in oxygen-enriched air, which can be dealt with using conventional firefighting methods after the supply of oxygen has been cut off.

The only effective way of dealing with oxygen fed fires is to isolate the supply of oxygen (see 10.6.3). Under oxygen-enriched conditions, appropriate firefighting media include water, dry chemical (powder), or carbon dioxide. The selection needs to take into account the nature of the fire (for example, electrical, etc.). For example, fires on persons or their clothing shall be extinguished by water as covering in a fire blanket allows oxygen-enriched clothing to burn.

Firefighting equipment should be properly installed and maintained. Operating personnel should know where it is located, how to operate it, and which equipment to use for which type of fire [54].

It is dangerous to enter an area with a high oxygen concentration in order to extinguish the fire or to help a person who is on fire since the rescuer's own clothing may also ignite.

If safety showers are available, the water supply shall be protected against the risk of freezing, where required.

Persons who have been in oxygen-enriched air shall not come into contact with ignition sources (cigarettes, welding torches, sparks, etc.) and immediately leave the area. These people shall undo or loosen their clothing and ventilate it for at least 15 min in order to remove the excess oxygen.

When a fire occurs, the following actions should be taken, although the order in which they are taken may need to be adapted to the situation:

- rapid risk assessment;

- warn personnel on site;

- leave the danger zone;

- bring the equipment into a safe condition (emergency shutoff, turn off using valves, etc.);

- notify firefighters and police if necessary;

- notify supervisors and the emergency crew;

- give first aid to injured persons; and

- block access to the area, including the surrounding roads that are affected.

10.4 Oxygen deprivation hazards and precautions

Persons exposed to oxygen-deficient atmospheres can immediately lose consciousness.

Do not attempt to assist a person who is in an oxygen-deficient atmosphere without breathing or rescue equipment. Without such equipment the rescuer is exposed to the same hazard as the person in difficulty.

The rescuer shall wear a safety harness and line and be monitored by another person who is outside the danger zone.

The person who is suffering from oxygen deprivation shall immediately be given first aid such as artificial respiration or administration of oxygen until medical assistance arrives.

10.5 Incident and damage report

If a pipeline incident occurs, a thorough investigation should take place. The report should contain an exact description on the conditions of the pipeline system during the last minutes before the incident, the material involved, and the consequences of the incident such as a secondary ignition, injury to people, and damage to equipment or property.

The cause of the incident / damage should be determined and remedied. A typical method for investigating oxygen pipeline incident is described in ASTM G145, *Standard Guide for Studying Fire Incidents in Oxygen Systems* [55].

10.6 Safety management system

Consideration should be given to establishing a specialised form of safety management system commonly referred to as a pipeline integrity management system (PIMS). Such a system enables formal control of key aspects of safety management to be established and demonstrated.

The system should provide detailed information specific to the particular pipeline, to cover the following subjects.

10.6.1 Notification to authorities and consultation on routing

These are normally stipulated in the prevailing legislation and rules applying to the country in which the pipeline is to be installed.

10.6.2 Design and construction

Overall design and construction practice are dictated by the relevant design standards, codes of practice, and specifications acknowledged in the country concerned. In addition to these, industry and / or company standards and specifications that relate to the particular product to be transmitted are applied.

10.6.3 Shutdown systems

Shutdown may be manual or automatic. Shutdown devices (for example, emergency shutoff valves) may be actuated by a leak detection system or by sensing high flow, low pressure, or rate of decay of system pressure.

10.6.4 Operations

A control strategy is devised to control the pipeline supply safely within the design envelope. Variables incorporated into the control strategy can include:

- pressure—to ensure that the required delivery pressure from the pipeline is maintained. Protection against excess pressure is generally not an issue since pipelines are normally designed to withstand pressures in excess of the maximum that can be developed by the production unit. A suitable PRD may be required upstream of the pipeline to provide protection against overpressure beyond the design criteria;

- temperature—to ensure that cryogenic liquids from the storage units do not enter the pipeline system;
- flow—to match customer demand by product flow into the pipeline; and
- product purity—to ensure any product that does not meet specification does not enter the pipeline system.

Any product disposal needed to maintain the required pipeline conditions is normally achieved through controlled venting on the production site.

10.6.5 Control of third-party interference

Measures typically employed are:

- marker posts on the pipeline route;
- distribution of "as laid" drawings and information on the pipeline route to landowners, local authority planners, and other interested parties;
- similar information distributed to "one call" systems; a single point of contact where information on all pipelines and services can be obtained (where applicable); and
- regular patrols of the pipeline by foot or aerial survey to search for unauthorised interference (see also 10.6.6).

10.6.6 Maintenance and inspection

A disciplined planned preventative maintenance and defect rectification system (including routine patrols of the pipeline) is normally employed.

Typical examples of the tasks included in such program are:

- routine testing of cathodic protection system;
- visual leak check on aboveground flanges;
- visual check for signs of unauthorised interference with the pipeline system;
- visual check for signs of land subsidence;
- visual check for any accidental damage to the system;
- visual check for any development activities in the vicinity of the pipeline; and
- visual check that all pipeline marking devices are in place.

10.6.7 Major incident prevention policies and safety management systems

A document detailing the organisation and personnel, hazard identification and evaluation, operational control, management of change, planning for emergencies, monitoring performance, and audit / review may be prepared (dependent upon the perceived extent and nature of the major incident hazards presented by the pipeline and local regulations and practice).

10.6.8 Emergency planning

An emergency response plan is prepared so any incident can receive effective response. This plan is specific to the parent site(s) and defines the roles of local personnel in an emergency situation. It also identifies any emergency contacts both internal and external to the operating company. The plan is structured to be locally self-sufficient.

Personnel who could be called on to deal with an incident shall receive training appropriate to their role in such an event. Any special protective clothing and equipment that may be required is kept readily accessible and is maintained in a fit condition for use.

10.6.9 Information to the public and interested parties

Pipeline plans and documentation shall be filed with the appropriate authorities and other parties who may have an interest in the pipeline (for example, railway, mining authorities, road authorities, fire and police departments). Where appropriate, information is also provided to the public by means of marker posts along the route of the pipeline (see also 4.6.3).

10.6.10 Land use planning

The pipeline operator can exercise some control over the land area defined by his wayleave / easement agreement. Land outside the limits of this right of way is not, however, controlled by the pipeline operator. Such land may be controlled by the governing authority.

10.6.11 Incident reporting

Incident reporting is normally included in the legislative requirements of individual member states or local authorities.

Industry associations / reviews of incident causes and data are shared with member companies who also have their own internal safety reporting and management systems.

11 References

Unless otherwise specified, the latest edition shall apply.

[1] EIGA Doc 33, *Cleaning of Equipment for Oxygen Service*, European Industrial Gases Association. www.eiga.eu.

NOTE This publication is part of an international harmonisation program for industry standards. The technical content of each regional document is identical, except for regional regulatory requirements. See the referenced document preface for a list of harmonised regional references.

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[4] ASTM G128, *Standard Guide for Control of Hazards and Risks in Oxygen Enriched Systems*, ASTM International. www.astm.org.

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[15] McIlroy, K., R. Zawierucha, and J.F. Million, "A Review of the Promoted Ignition/Combustion Behavior of Engineering Alloys," The Minerals, Metals & Materials Society (TMS) 1994 Materials Week, Rosemont, Illinois, October 2-6, 1994. www.tms.org.

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Appendix A – Table of nominal alloy composition and ranges (Normative)

Material type or alloy	EN-MAT No.	UNS No.	Nominal composition range
Brass alloys [1)]		**2.0380**	**Various 55Cu to 85Cu, 15Zn to 44Zn, 1 to 3 (Sn, Pb, Fe)**
Cobalt alloys			
Stellite 6	Stellit 6	R30006	55.5Co, 29Cr, 4.5W, 3Ni, 1C, 7 (Fe, Si, Mn, Mo)
Stellite 6B	Stellit 6B	R30016	53Co, 30Cr, 4.5W, 3Ni, 1C, 8.5 (Fe, Si, Mn, Mo)
Ultimet		R31233	54Co, 26Cr, 9Ni, 5Mo, 3Fe, 2W, 0.8Mn, 0.3 Si, 0.08N, 0.06C
Copper	**2.0090**	**C10100**	**99.9+Cu**
Copper-nickel alloys	**2.0882**	**C70600**	**67Cu to 87Cu, 10Ni to 31Ni, 1 to 2 (Fe, Mn, Zn)**
Ferrous castings (non-stainless)			
Gray cast iron	0.6030	F12801	3C, 2Si, 0.8Mn, Balance Fe
Nodular cast iron	0.7040	F32800	3.6C, 2.7Si, 0.4Mn, Balance Fe
Ni Resist Type D2	0.7673	F43010	20Ni, 3C, 2SI, 2Cr, 1Mn, Balance Fe
Ferrous castings (stainless)			
CF-3 [2)]	1.4308	J92500	19.5Cr, 10Ni, 2Si, 1.5Mn, Balance Fe
CF-8 [2)]	1.4308	J92600	19.5Cr, 10Ni, 2Si, 1.5Mn, Balance Fe
CF-3M	1.4408	J92800	19Cr, 11Ni, 3Mo, 1.5Si, 1.5Mn, Balance Fe
CF-8M [3)]	1.4408	J92900	19Cr, 11Ni, 3Mo, 1.5Si, 1.5Mn, Balance Fe
CG-8M [4)]	1.4439	J93000	20Cr, 12Ni, 3Mo, 1.5Si, Balance Fe
CN-7M [5)]		N08007	21Cr, 29Ni, 4Cu, 3Mo, 1.5Si, 1.5Mn, Balance Fe
Nickel alloys			
Monel 400	2.4360/2.4366	N04400	67NI, 32Cu, 1Fe
Monel K-500	2.4375	N05500	66.5Ni, 30Cu, 3(Al, Ti)
Nickel 200	2.4060/2.4066	N02200	99.0 Ni min.
Hastelloy C-22	2.4602	N06022	56Ni, 22Cr, 13Mo, 3Fe, 3W, 2.5Co, 0.5Mn, 0.08Si, 0.01C, 0.35V, 0.5Co
Hastelloy C-276	2.4819	N10276	56Ni, 16Cr, 16Mo, 4Fe, 3W, 2.5Co
Inconel 600	2.4816	N06600	76Ni, 15Cr, 9Fe
Inconel 625	2.4856	N06625	60Ni, 22Cr, 9Mo, 5Fe, 4Nb
Inconel X-750	2.4669	N07750	74Ni, 15.5Cr, 7Fe, 2.5Ti, 1Al
Stainless steels, wrought			
304	1.4301/1.4306	S30400	19Cr, 9Ni, 2Mn, 1Si, Balance Fe
304L	1.4301/1.4306	S30403	19Cr, 9Ni, 2Mn, 1Si, Balance Fe
316	1.4401/1.4404	S31600	17Cr, 12Ni, 2Mn, 3Mo, 1Si, Balance Fe
316L	1.4401/1.4404	S31603	17Cr, 12Ni, 2Mn, 3Mo, 1Si, Balance Fe
321	1.4541	S32100	18Cr, 11.5Ni, Ti 5XC min., Balance Fe
347	1.4550	S34700	18Cr, 11.5Ni, Nb 8XC min., Balance Fe
410	1.4006/1.4024	S41000	13Cr, 1Mn, 1Si, Balance Fe
430	1.4016/1.4742	S43000	17Cr, 1Mn, 1Si, Balance Fe
17-4PH [6)]	1.4542/1.4548	S17400	17Cr, 4Ni, 4Cu, 1Si, Balance Fe
X3 Ni Cr Mo 13-4	1.4313	S41500	13Cr, 4.5Ni, 1Mo, 1Si, Balance Fe
Carpenter 20 Cb-3	2.4660	N08020	35Ni, 20Cr, 3.5Cu, 2.5Mo, Balance Fe
Tin bronzes	**2.1080**	**Various**	**85Cu to 89Cu, 5 Sn to 11Sn, 5 to 10 (Zn, Pb, Ni)**

NOTES

1 EN MAT Number is listed in EN 10027-2, *Designation systems for steels. Numerical system* [56].

2 UNS Number is listen in DS56L-EB, *Metal and Alloys in the Unified Numbering System (UNS)* [57].

1) Aluminium brasses not included

2) Cast analogs of 304L/304 stainless steel

3) Cast analogs of 316L/316 stainless steel

4) Cast analog of 317 stainless steel

5) Alloy 20

6) Age hardened condition

Appendix B – Table of exemption pressure and minimum thicknesses (Normative)

Engineering alloys	Minimum thickness	Exemption pressure
Brass alloys [1)]	**None specified**	**20.68 MPa (3000 psi)**
Cobalt alloys [2)]		
Stellite 6	None specified	3.44 MPa (500 psi)
Stellite 6B	None specified	3.44 MPa (500 psi)
Ultimet	3.18 mm (0.125 in)	7.0 MPa (1015 psi)
Copper [3)]	**None specified**	**20.68 MPa (3000 psi)**
Copper-nickel alloys [1), 3)]	**None specified**	**20.68 MPa (3000 psi)**
Ferrous castings, non-stainless		
Gray cast iron	3.18 mm (0.125 in)	0.17 MPa (25 psi)
Nodular cast iron	3.18 mm (0.125 in)	0.34 MPa (50 psi)
Ni resist type D2	3.18 mm (0.125 in)	2.07 MPa (300 psi)
Ferrous castings, stainless		
CF-3/CF-8, CF-3M/CF-8M, CG-8M	3.18 mm (0.125 in)	1.38 MPa (200 psi)
CF-3/CF-8, CF-3M/CF-8M, CG-8M	6.35 mm (0.250 in)	2.6 MPa (375 psi)
CN-7M	3.18 mm (0.125 in)	2.58 MPa (375 psi)
CN-7M	6.35 mm (0.250 in)	3.44 MPa (500 psi)
Nickel alloys [3)]		
Hastelloy C-22	3.18 mm (0.125 in)	9.70 MPa (1406 psi)
Hastelloy C-276	3.18 mm (0.125 in)	8.61 MPa (1250 psi)
Inconel 600	3.18 mm (0.125 in)	8.61 MPa (1250 psi)
Inconel 625	3.18 mm (0.125 in)	6.90 MPa (1000 psi)
Inconel X-750	3.18 mm (0.125 in)	6.90 MPa (1000 psi)
Monel 400	0.762 mm (0.030 in)	20.68 MPa (3000 psi)
Monel K-500	0.762 mm (0.030 in)	20.68 MPa (3000 psi)
Nickel 200	None specified	20.68 MPa (3000 psi)
Stainless steels, wrought		
304/304L, 316/316L, 321, 347	3.18 mm (0.125 in)	1.38 MPa (200 psi)
304/304L, 316/316L, 321, 347	6.35 mm (0.250 in)	2.58 MPa (375) psi)
Carpenter 20 Cb-3	3.18 mm (0.125 in)	2.58 MPa (375 psi)
410	3.18 mm (0.125 in)	1.72 MPa (250 psi)
430	3.18 mm (0.125 in)	1.72 MPa (250 psi)
X3 Ni Cr Mo 13-4	3.18 mm (0.125 in)	1.72 MPa (250 psi)
17-4PH [4)]	3.18 mm (0.125 in)	2.07 MPa (300 psi)
Tin bronzes	**None specified**	**20.68 MPa (3000 psi)**

NOTES

1 This table does not include all possible exempt materials. Other materials may be added based on the results of testing as described in 4.2.1.

2 These exemption pressures are applicable for temperatures up to 200 °C (400 °F).

3 Exemption pressure is defined in Section 3.

1) Cast and wrought mill forms

2) These cobalt alloys are commonly used for weld overlay applications for wear resistance. Use at exemption pressures greater than those specified in this table should be justified by a risk assessment or further testing (as described in 4.2.1).

3) Nickel alloys have been used safely in some applications at thicknesses less than those shown in this table. Use of thinner cross sections should be justified by a risk assessment or further testing (as described in 4.2.1).

4) Age hardened condition

Appendix C – Description of promoted ignition combustion test method (Informative)

C1 Criteria

In this test method the test specimen is ignited in an oxygen atmosphere by a promoter, for more information see Section 12. The test specimen may be completely consumed in which case it is adjudged to be flammable. If combustion arrest occurs after a minimal burn, the result indicates that the specimen is not flammable. Various burn lengths between combustion arrest and complete consumption are indicative of transitory behaviour. Arbitrary burn length criteria may be established as being indicative of a burn. Selection of burn criteria requires an understanding of the promoted ignition combustion transition curve and the safety design factors required. ASTM STP 1111, *Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres: Fifth Volume* describes the promoted ignition-combustion transition curve in considerable detail [13]. A determination that the test alloy is not flammable is the basis for a determination that it is exempt from the velocity limitation. A flammable determination would require imposition of a velocity limitation.

NOTE The standardised test described in ASTM G124 may have less options on configuration than what is described in this appendix [9].

C2 Specimen configurations

The most common specimen in use in promoted ignition combustion tests is the rod configuration with a nominal diameter of 3.2 mm (0.125 in) and length ranging between 10 cm and 15.3 cm (4 in and 6 in). However, in making flammability assessments, diameters greater or less than 3.2 mm (0.125 in) may be used. Technical papers on promoted ignition combustion testing that describe various test specimens are found in ASTM STP Series [27, 18, 6, 12, 13, 7, 16, 28, 29].

C3 Promoter

Promoter selection may involve consideration of the type of contaminant most likely to be encountered in service. Iron wire, iron-hydrocarbon, aluminium, magnesium and pyrofuze® (aluminium-palladium composite wire) promoters have been used by various investigators. Previously cited references should be reviewed in this regard.

C4 Oxygen purity

Oxygen atmospheres used in flammability tests can be chosen to suit potential applications. The bulk of published data involves standard purity 99.5+% oxygen. However, metals flammability data obtained with substantially lower oxygen purities exists. Premixed cylinder blends or point-of-use blends both have been used in flammability experiments. Previously cited references should be consulted on this test parameter.

C5 Test vessels for promoted ignition combustion testing

C5.1 General

There are two types of vessels used in metals promoted ignition combustion testing that may be referred to in the literature. One of these is the static or fixed volume tester. The other is the flow tester, which is also referred to as an OI apparatus. Descriptions of these testers are found in ASTM STP Series [6, 7, 12, 13, 15, 16, 17, 1, 27, 28, 29].

C5.2 Static tester

Static testers have generated data over the 3.55 MPa to 34.5 MPa (500 psi to 5000 psi) range. One area of concern is that at lower pressure, the test atmosphere may be diluted by combustion products from the test procedure and false indications of non-flammability may be generated.

C5.3 Flow tester

The low pressure limitation of the static tester can be overcome by using a flow tester. Continuous flow of oxygen past the test specimen occurs, and results can be obtained at relatively low pressure. Contaminant build-up can be minimised using this approach.

C5.4 Interpretation of results and design safety factors

If promoted ignition-combustion tests are conducted over a wide range of pressures, the data may take the form as shown in ASTM STP 1111 [13]. Three distinct zones may be observed: burn resistance (minimal specimen consumption), transition zone, and self-sustained burning (substantial to complete specimen consumption).

Design criteria by which a material is exempt from velocity limitation are based upon a burn length of

3 cm (1.2 in) or less, within which combustion is arrested. Exemption pressures in this publication based upon burn resistant behaviour are inherently conservative. The exemption pressure for stainless steel has been further reduced based on industry experience.

It is necessary to test at least three to five test specimens at each test pressure, use of smaller specimen numbers may be misleading particularly if combustion arrest occurs. ASTM STP 1040, *Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres* is also of significance relative to ranking methods [12].

Appendix D – Potential ignition mechanisms
(Informative)

The following ignition mechanisms are known to be active in gaseous oxygen piping system when the contributing factors are present.

Ignition mechanisms	Conditions	Contributing factors
Particle impact	• Particle(s) present • Velocities greater than Figure 2 • Impact point • Flammable targets related to operating conditions	• Density, quantity, and composition of particles present • Impact point in the flow path of the particle; ignition enhanced as angle approaches perpendicular • High pressure drop
Adiabatic compression	• Rapid pressurisation • Exposed non-metal or contamination close to the end • High pressure ratio	• Quick-opening valve • Volume of gas pressurised • Function of final pressure, initial temperature, and pressure ratio (incl upstream pressure). Low AIT of non-metals can lead to ignition at pressure greater than 10 bar (145 psi)
Promoted ignition/ kindling chain	• Ignition mechanism present and active • Flammable materials to kindle or propagate	• Usually non-metals • Ignition and combustion of a flammable material (for example, contamination) igniting a less flammable material
Mechanical friction	• Two or more rubbing surfaces • Relative motion • Mechanical load • Galling	• High speed and/or high load on rubbing surfaces (usually leading to severe surface disruption) • More severe with aluminium alloys • High rotational velocity or high oscillation/vibration frequency under normal load
Mechanical impact	• Single or repeated impact loading • Non-metal or metal at point of impact	• Porous material (exposed to liquid oxygen in most cases) • Quick closing valve • Chattering check or relief valve
Thermal ignition	• External heat capable of heating a material to its AIT in a given environment • A material with an AIT less than the temperature created by the heat source in a given configuration and environment • Flash point of the lubricant or other flammable contamination	• Open flame • Smoking • Sparks • Welding • Thermal runaway • Heat source • Heat that is capable of autoigniting a flammable material or a flammable gas mixture
Electrical arcing	• Electrical power source • Arc with sufficient energy to melt or vaporise materials • Flammable material exposed to ignition from arcing	• Ungrounded or short-circuited powered components in the presence of oxygen (including electric motor, electrical control equipment, instrumentation, electrical cables, etc.) • Lightning strike

Less common ignition mechanisms include resonance, static discharge, and flow friction. Although some may not be well understood, these mechanisms can be active in specific circumstances.

Resonance occurs when there is a resonance cavity in the piping, when acoustic oscillations within a resonant cavity cause a rise in temperature, and when there is a flammable component (such as a valve component), particulate, or debris in the resonant cavity. Short dead-end tees may can resonate when there is a high velocity flow in the other legs.

Static discharge occurs when there is an electrostatic charge accumulation, the discharge energy is sufficient for ignition, and there is flammable material exposed to discharge.

Flow friction can exist when there is a leak or pressure differential, exposed non-metal is in the flow path, and pressure is greater than 30 bar (435 psi).

For more information about these less common ignition sources, see ASTM G63, ASTM G88, and ASTM A36, *Standard Specification for Carbon Structural Steel* [11, 3, 25].

Appendix E – Table of minimum safety distances (without barriers) for oxygen control and isolating / metering stations (Informative)

Nature of exposure	Category 1 stations [1)]	Category 2 stations	Category 3 stations	Category 4 stations
Aboveground pipeline (flammable fluid) without close proximity of mechanical joints (see 8.6).	15 m	6 m	2 m	2 m
Buried tank (flammable fluid)	5 m	2 m	2 m	2 m
Pressure vessel (non-flammable fluid) with $P \bullet V$ > 200 bar m^3 water capacity ($P \bullet V$ >100 000 psi ft^3)	5 m	3 m	3 m	2 m
Flammable product storage	8 m	5 m	2 m	2 m
Liquid hydrogen storage	15 m	15 m	15 m	15 m
Transformer station	15 m	6 m	3 m	2 m
Administrative building with openings or air conditioning intake owned by customer	10 m	8 m	8 m	2 m
Public building	15 m	10 m	10 m	2 m
Public road/railway/car park	15 m	10 m	6 m	2 m
Internal road/railway	3 m	3 m	3 m	2 m
High tension electric cable (aboveground)	10 m	6 m	5 m	2 m
Boundary of user's property	15 m	10 m	2 m	2 m
Internal car park	15 m	6 m	2 m	2 m
Flame and/or spark producing activities. For smoking restrictions (see 8.6).	15 m	8 m	3 m	2 m

NOTES

1 Category 1 Stations: $P \bullet D^2 > 3000$, $P > 4$ bars, $D > 2.5$ cm.
Category 2 Stations: $1500 < P \bullet D^2 <= 3000$, $P > 4$ bara, D > 2.5 cm; and
Category 3 Stations: $P \bullet D^2 <= 1500$, $P > 4$ bars, $D > 2.5$ cm.
Category 4 Stations: Isolating and/or metering purposes only.

2 Oxygen stations should not be beneath high-tension cables without protection.

1) For PD^2 greater than 3000, a specific risk assessment should be performed to determine if safety distances greater than listed in this table are necessary.

Appendix F – Example of preventative maintenance programme (Informative)

NOTE Intervals shown are only examples and do not reflect required or universal practice.

a. Pipeline Systems

Flyover [1)]	**Checking interval**						
	1 Month	1/4 Year	1/2 Year	1 Year	2 Year	3 Year	When required
Underground pipelines		X					
Aboveground pipelines		X					
On-foot inspection							
Underground pipelines	X [2)]			X			
Aboveground pipelines	X [2)]			X			
Leak test							X
Inner pipeline inspection							X
Effect of mining (subsidence)							X

1) Flyover are used for long pipelines.
2) If there are no flyovers.

b. Slide valve shafts and stations

On-foot inspection	**Checking interval**						
	1 Month	1/4 Year	1/2 Year	1 Year	2 Year	3 Year	When required
General condition				X			
Pipeline condition		X					
Supports				X			
Leak check (audible)		X					
Leak check (brushing test)				X			
Internal filter inspection					X		

c. Anti-corrosion systems

Checking	**Checking interval**						
	1 Month	1/4 Year	1/2 Year	1 Year	2 Year	3 Year	When required
Operating status				X			
Measurement/readout (stray current)	X						
Measurement/readout (parasitic current)		X					
Adjust protection system				X			
Remote transmission/alarm							X
Electrical isolation (isolating flange)				X			
Electrical isolation (tubular jacket)						X	
Pipe/ground potential, on/off						X	
Pipe/ground potential, on				X			
CIPS							X (5 years)

d. Safety equipment in the production areas

Equipment checking for preventing							
Unacceptable pressures	**Checking interval**						
	1 Month	1/4 Year	1/2 Year	1 Year	2 Year	3 Year	When required
Limit value marking				X			
Accuracy and limit monitoring				X			
Alarms and switching sequences				X			
Equipment checking for preventing unacceptable temperatures							
Limit value marking				X			
Accuracy and limit monitoring				X			
Alarms and switching sequences				X			
Equipment checking							
Restrict quantity of escaping gas		X					

e. Checking for station safety equipment

	Checking interval						
	1 Month	1/4 Year	1/2 Year	1 Year	2 Year	3 Year	When required
Safety shutoff valves, shutoff valves				X			
Safety valves						X	
Restrict quantity of escaping gas		X					
Gas removal sensors (ambient air)		X					
Roof and radial ventilators				X			
Checking of other equipment							
External medium-controlled slide valves				X			
Manually operated valves				X			
Display instruments					X		
Checking of electrical lightning protection earthing systems							
Local systems and operating equipment					X		
Emergency power supply				X			
Lightning protection and earthing						X	

f. Safety equipment at the operating control point

Equipment checking for	**Checking interval**						
	1 Month	1/4 Year	1/2 Year	1 Year	2 Year	3 Year	When required
Detecting losses				X			