OXYGEN PIPELINE SYSTEMS

AIGA 021/05

GLOBALLY HARMONISED DOCUMENT

Asia Industrial Gases Association

298 Tiong Bahru Road #20-01 Central Plaza Singapore 168730
Tel : +65 62760160 Fax : +65 62749379
Internet : http://www.asiaiga.org

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- PIPING SYSTEM
- TRANSPORTATION

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1 Introduction

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

The industrial gases companies have engaged, through CGA and EIGA, in a process of developing harmonized safety practices and this publication is one of them.

It must be recognized, however, that oxygen pipeline systems, developed over 40 years in the various countries of Western Europe and North America have shown good and comparable safety records, although national practices show many differences in design and operations. Some national authorities have also introduced legislation, which is mandatory for the operators in those countries.

Thus, the information contained in this document applies only to future installations and not to existing installations or those in the project phase, as of the date of this publication. 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. The authors make no representations or warranties on the information in or the completeness of this document and disclaim all warranties, express or implied including, but not limited to, the warranty of merchantability and the warranty of fitness for a particular use or purpose.

ISO units and corresponding Imperial units in brackets are used in this document. Corresponding values may be approximate.

2 Scope and purpose

The scope of this document is for metallic oxygen transmission and distribution piping systems, as shown in Diagram 1 of Appendix A. It is limited to gaseous oxygen with a temperature range between –30°C (-22°F) and 200°C (400°F), pressures up to 21 MPa (3000 psig) and a dew point of –30 °C (-22°F) or lower depending on local conditions.

This document does not apply to the following processes:

- Oxygen cylinder filling plants
- Medical oxygen piping installations
- Oxygen producing plants
- Oxygen compressor units
- Bulk oxygen facilities (liquid or high pressure gas) at the customer's site up to the point where gas enters the distribution systems
- Piping on specialized equipment and machines, such as scarfing, jet piercing, etc.

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. It contains a summary of the current industrial practices. It is based upon the combined knowledge, experience, and practices of the major oxygen producers in Western Europe and North America as represented by their members on the EIGA/ CGA ad hoc group on oxygen pipeline transportation systems.

Some of the practices represent conservative compromises and not all situations are described. The designer is cautioned that this document 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 reviews any special problems or concerns with his oxygen supplier who should be able to provide advice and guidance.

Although the technical information provided in this document is not intended to be mandatory, the word « shall » is frequently used. The use of "shall" implies a strong concern that the particular practice referenced be followed for safety reasons. The use of « should » implies that the referenced practice is commonly followed, but recognizes that other safe practices are sometimes utilized.

3 Definitions

- **Distribution piping**

Piping contained on the property (generally owned by the customer) at the oxygen use point such as mains, feeders, station connections, and valves.

- **Plant piping**

Piping within the oxygen production facility.

- **Transmission piping**

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

- **Gaseous oxygen**

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

- **Copper based alloys**

Copper based alloys used in components for the transmission of oxygen via pipeline generally contain at least 55 weight % copper. Included within this group are the coppers, brasses (copper alloyed primarily with zinc), bronzes (copper alloyed with aluminium, silicon, manganese, tin, lead, etc) and copper nickels (copper alloyed with nickel). Generally, copper based alloys have had an outstanding application history in the transmission of oxygen via pipelines. However, caution should be exercised in the use of aluminium bronzes. Aluminium bronzes (containing typically up to 10 weight % aluminium) have been extensively used for cast components (e.g. valve bodies, pipe fittings, etc) in oxygen pipeline duty for many years, without a significant history of failure. Ignition tests on this material show that it is difficult to ignite by particle impact, but once ignited it is flammable in this duty range. In this document, bronze alloys are limited to a maximum aluminium content of 2.5 weight %.

- **Nickel base alloys**

Nickel based alloys used in oxygen gas transmission pipeline systems contain at least 50 weight % nickel and nickel contents up to 99+ weight % have been used. However, some tabulations of nickel alloys may list alloys with nickel contents as low as 30 weight %. Generally, the higher the combined nickel and copper content, the more combustion 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).

- **Stainless steel alloys**

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

Stainless steel classifications, with examples of each type, are as follows:
- Austenitic (304, 304L, 316, 316L, 321, 347)
- Ferritic (430)
- Martensitic (410)
- Precipitation hardening (17-4 PH)
- Duplex (329, SAF 2205).

The preceding alloy designations were for wrought products but there are alloys such as CF-8, CF-3, CF-8M, CF-3M which are the cast analogs of 304, 304L, 316 and 316 L respectively.
Of the various stainless steels, the 300 series stainless steels and their cast analogs are the most commonly used in oxygen gas transmission piping systems. The combustion resistance of stainless steels is intermediate to carbon low alloy steels and nickel or copper alloys.

- **Cobalt alloys**

The commercial listings of cobalt alloys generally start with a minimum cobalt content of at least 40 weight %. Combustion resistance of some cobalt alloys may be comparable to nickel alloys; however, availability limits their use. 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.

- **Non ferrous alloys**

When the term nonferrous alloys is used in this document, it includes only copper, nickel and cobalt alloys. It does not include aluminium or reactive materials such as titanium or zirconium.

- **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.

- **Combustion resistant alloys**

Combustion resistant alloys are engineering alloys which, after being subjected to an ignition event, either will not burn, or exhibit combustion quenching behaviour, resulting in minimal consumption. Examples of engineering alloys, which are highly combustion resistant, are copper, pure nickel and Monel. Depending upon oxygen pressure, oxygen purity, temperature and configuration, other engineering alloys, such as stainless steel, may exhibit varying degrees of combustion resistance.

- **Exempt Materials**

For the purpose of this document, exempt materials are engineering alloys, which are exempt from any oxygen velocity limitations within defined limits of pressure, material thickness and oxygen purity. Only those materials, which demonstrate combustion resistance, when subjected to particle impact and/or promoted ignition tests conducted in oxygen enriched atmospheres can be qualified as exempt. Appendix C and Appendix D identify the composition of specific alloys, together with their thickness limitations and exemption pressures in oxygen.

- **Very High Pressure (VHP) Oxygen**

Pressurized oxygen over 10.3 Mpa (1500 psig)

- **Standard Purity Oxygen**

The standard purity oxygen is defined as equal to or greater than 99.5 % by volume.

- **Low Purity Oxygen**

Gaseous oxygen which contains less than 35% oxygen by volume. (23.5 % to 35 %)

- **Ultra High purity (UHP) Oxygen**

Oxygen purity equal or higher than 99.999% by volume

- **Velocity**

The volumetric flow rate at the actual pressure and temperature divided by the pipe inside cross-sectional area

- **Gas Pressure**

The Gas Pressure is the operating pressure of the piping system.

4 Design Philosophy

4.1 General criteria

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

A safe oxygen piping transmission or distribution system, including all its components, is one that is designed taking into account:

- Local conditions e.g. seismic zone, soil characteristics.
- Applicable piping codes for mechanical design (including pressure rating and wall thickness) and installation.
- Conditions of service with respect to fluid composition, gas velocity, pressure, temperature and dew point.
- Selection of metallic materials.
- Selection of non-metallic materials.
- Velocity considerations in impingement and non-impingement flow locations.
- National laws and regulations which apply to gas transmission pipelines generally and oxygen systems specifically
- Standards of cleanliness for oxygen service
- Industry codes of practice relating to oxygen systems

Piping fabricated from non-metallic material, such as plastic or composite material, has been used for distribution of oxygen enriched gases at low pressures. However, the use of non-metallic piping material for oxygen enriched gases in production plants, transmission systems or distribution systems is outside the scope of this document and is not encouraged.

Normally, gaseous oxygen transported by pipeline contains negligible quantities of water and no special precautions against corrosion are therefore required. It is, however, important to identify areas where pipeline systems could become contaminated with water, in the event of equipment failure (e.g. compressor intercoolers or aftercoolers) and introduce appropriate design and/or monitoring procedures. 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 coatings.

More detailed background information can be found by consulting the references in Appendix G, in particular those given in 1.5, 1.13 and 7.29 to 7.31

4.1.1 Causes of fire: Ignition mechanisms and kindling chain

Ignition mechanisms which can result in pipe failures include:

- particle impact ignition caused by impingement of metallic or non-metallic materials with the metal components of the pipeline.
- adiabatic compression (or pneumatic impact), acoustic resonance and flow friction, which create temperature increase.
- promoted ignition initiated by the combustion of organic materials, or contaminants entrained in the oxygen flow.
- friction caused by rubbing as in a valve between adjacent moving and stationary parts.

- electric arcing between metallic components due to static electricity or lightning which generates enough energy to ignite metallic or non metallic materials.

When the ignition mechanism has started, the combustion can propagate through the kindling chain. Once ignited, the combustible material or component generates heat, which can, depending on many factors, ignite the bulk material of the pressure envelope. The rate and extent of the propagation of the fire along the pressure envelope will depend on the thickness and the flammability of the material. The use of exempt materials will limit the propagation of the combustion by interrupting the kindling chain. The flammability of metals is discussed in 4.2.
The rate and extent of the propagation of the fire is also influenced by oxygen parameters such as pressure, purity, temperature and the total oxygen inventory available to support combustion. For pressures below 0.21 MPa (30 psig), experimental data show that the combustion rates of potential materials used in oxygen pipeline components such as carbon steel are very low and decrease with decreasing pressure. This effect has contributed to the excellent service experience demonstrated by properly designed carbon steel components in selected very low pressure oxygen applications.

Many causes of fire can be avoided and their consequences reduced by good design practices. Other causes of fire may be due to unsuitable maintenance and operating practices, such as:

- overheating due either to a process failure or to an oxygen leakage from the system resulting in an external fire adjacent to the pipeline
- accidental mixture with fuel, due either to a process failure or to pollutant introduction during maintenance or modification work.

4.1.2 Hazards analysis and risk assessment

Certain operating parameters of oxygen systems are recognized as hazards such as: oxygen concentration, pressure, temperature and velocity. When these parameters increase, more stringent oxygen service practices are progressively applied:

- cleaning of piping and equipment
- use of compatible non metallic materials and, if appropriate, lubricants (oxygen compatible lubricants).
- use of combustion resistant metallic material.

When the oxygen concentration exceeds 23.5% by volume, consideration shall be given to the degree of cleaning and to the selection of compatible materials for the process involved. Up to 35% volume oxygen concentration, carbon steel may be used, with no velocity limitation. At more than 35% volume oxygen concentration, performing a risk assessment may be a desirable safe practice (see Appendix G, reference 1.13). To reduce the risk of fire, important factors to consider are:

- Design (see this chapter and chapter 5)
- Selection of metallic and non metallic materials (see 4.2, 4.3 and 4.4)
- Equipment selection (see chapter 5)
- Cleaning (see chapter 6)
- Construction (see chapter 7)
- Design and construction of stations (see chapter 8)
- Fire prevention practices and operator training (see chapters 9 and 10)
- Remote operation or use of barriers to minimise the consequences of a fire (see 4.6 and 8.5).

In some cases, it could be useful to perform a hazard analysis of a critical item of equipment or system, following for example the method explained in Appendix G, reference 7.31.

4.1.3 General design precautions

Industry practices include the following:

- selecting compatible non metallic materials and minimizing their quantities
- maintaining oxygen cleanliness
- avoiding particles by, for example, filtration
- taking particular care to avoid dust traps and impingement zones
- selecting compatible metallic materials
- adopting good equipment design and layout rules

- minimizing the consequences of a fire by appropriate fire protection measures.

The choice of metallic material is important as the consequences of a fire depend mainly on the degree and rate of its combustion propagation. The appropriate use of a combustion resistant material in critical locations may confine the fire inside the piping.

As explained in 4.1.1, an ignition mechanism, which dictates the need for oxygen velocity limitation, is particle impact. In general, cleaning procedures used in oxygen systems eliminate or minimize the potential for a particle impact ignition mechanism. Inadvertent or accidental system contamination, for example when a new system is connected to an existing pipeline, may result in the ignition of flammable materials if they are subjected to particle impact at high velocity. However, even in a properly cleaned oxygen piping system, the potential for particle impingement can still exist.

For some systems, the designer may choose stainless steel piping and equipment to minimize the presence of particles. An example of such a system could be the supply of gas by the vaporization of liquid oxygen. Provided that the system is adequately cleaned and that no source of particles can be identified, exemption from oxygen velocity requirements could be justified.

4.2 Metallic Materials, Combustion Resistant Alloys, Exemption pressure

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

Depending upon the flammability of a metal at the use conditions, oxygen velocity may require limitation. Combustion resistant alloys do not require velocity limitations if they are combustion resistant at the system design pressures. The velocity exemption pressure is the maximum pressure up to which an engineering alloy is exempt from velocity limitations, as described in 4.4. It may be based on an assessment of alloy flammability using the promoted ignition combustion test method described in Appendix B.

Alternative test methods for evaluating metallic materials can be found in documents such as ASTM G94, “Standard Guide for Evaluating Materials in Oxygen Service” (Appendix G, reference 1.7).

The choice of combustion resistant alloys according to paragraph 4.2.2.2 is a simple solution for the designer, who could also perform a hazards analysis, as explained in 4.1.2, to determine what other options might be available.

4.2.1 Flammability testing

There are two main approaches by which systems or materials can be characterized to determine if oxygen velocity limitations must be imposed:

- Particle impact tests of materials and/or functional components
- Promoted ignition-combustion tests of candidate engineering alloys.

Published particle impact test data are relatively scarce as are facilities capable of performing such tests over a wide range of oxygen pressures and purities. Considerable “” experience may be required in the conduct and interpretation of particle impact test procedures. Particle impact tests require the selection of particulate species likely to be in a system, selection of candidate/target materials and selection of velocities.

Promoted ignition-combustion test approaches and data have frequently been cited in the literature and are a relatively inexpensive alternative to particle impact testing. A description of the Promoted Ignition-Combustion Test Method can be found in Appendix B.

Other test methods have been developed, such as flammability tests of hollow vessels (see Appendix G, reference 7.27).

4.2.2 Velocity Exemption Pressures for Standard Purity Oxygen

4.2.2.1 Engineering Alloys

Appendix C lists the nominal compositions of the engineering alloys and alloy systems for which velocity exemption pressures are be identified in this document. 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 C, are described in 4.2.1 and Appendix B.

4.2.2.2 Exemptions pressures and Thickness Effects

Appendix D is a listing of exemption pressures for the alloys covered in 4.2.2.1. The exemption pressures are based on an upper shelf burn criterion of less than 30 mm (1.18 inches) for a specimen as described in Appendix B.
Thickness is a very important variable in component flammability. The thickness of a metal or alloy must not be less than the minimum prescribed in Appendix D. If the thickness is less than the prescribed minimum, the alloy must be considered flammable and velocity limitations appropriate for the system pressure must be observed. Exemption pressures should not be extrapolated outside the given thickness range of 3.18 to 6.35 mm (0.125 to 0.250 inch).

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

4.2.2.3 Protective liners and coatings

Protective liners and coatings of combustion resistant alloys can 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. A minimum thickness of the order of 1.5 mm to 3 mm (0.06 to 0.12 inch) is generally needed. Stellite hardfacing alloys are also candidates, if abrasion resistance is also required. Electroplated or electro less surfaces are not satisfactory, due to the inadequate thickness of the coating most commonly employed for these processes.

4.2.3 Reduced purity Oxygen Enriched Atmospheres

4.2.3.1 Reduced Purity Effects

There are an increasing number of applications, where oxygen enrichment, in excess of normal atmospheric concentrations but less than the nominal 99.5 % by volume, may be required. Depending upon specific parameters such as oxygen pressure and temperature, reduced oxygen purities may result in a decrease in metals flammability and a decrease in the possibility of combustion if an ignition event occurs. Thus, there might not be any necessity for imposing velocity limitations. However, metals flammability data in reduced purity oxygen enriched environments is less available although several publications are useful in this regard (in Appendix G, see references 7.2, 7.3, 7.4, 7.5, 7.6, 7.8, 7.9, 7.10, 7.11, 7.20, 7.22). There are three options, which 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 D for high purity oxygen. This is a conservative and very safe approach which becomes increasingly conservative as the oxygen purity decreases.

- 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 D for a specific reduced purity oxygen gas mixture will therefore represent an oxygen partial pressure. This is a safe approach but not as conservative as Option 1.

- 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 B. If the material is not combustion resistant, an oxygen velocity limitation as indicated in 4.4 must be imposed. If tests results indicate the metal is combustion resistant for the thickness, oxygen purities and pressures of interest, there is no need to impose velocity limitations.

4.2.3.2 Oxygen Purities ≤ 35 % by volume

At pressures up to 21 MPa (3000 psig) and an oxygen content lower than 35% by volume, systems free of hydrocarbons and constructed of ferrous and/or nonferrous materials are exempt from velocity limitations. Under these conditions, both carbon and stainless steels have been proven to be combustion resistant materials by the Promoted Ignition Combustion Test Method (see Appendix B). However, the oxygen service cleaning and the use of oxygen compatible non metallic materials as described in 4.3 is advised for such piping systems.

4.2.4 Ultra High Purity (UHP) Oxygen Atmospheres

4.2.4.1 General

Increasingly, UHP oxygen is being utilized in high technology applications such as semiconductors and electronics. The special requirements of these applications require almost total elimination of particulates which could contribute to a particle impact ignition mechanism. In addition to special cleaning procedures, UHP systems require special monitoring procedures to ensure particulate free conditions. These systems are typically fabricated from stainless steel.

4.2.4.2 System Pressures

Bulk gas system pressures usually are below 4 MPa (600 psig). Higher pressures may be encountered in delivery systems utilizing high pressure cylinders.

4.2.4.3 Velocity Exemptions

The absence of particulates and ignitable contaminants in a UHP oxygen system is a significant factor which precludes ignition from a particle impact mechanism. Hence, UHP oxygen systems that are cleaned and maintained properly are exempt from oxygen velocity requirements.

4.2.4.4 Cleaning UHP Oxygen Systems

The cleaning of UHP piping systems require special cleaning subcontractors capable of meeting contaminant levels not exceeding 1000 micrograms per square meter. Such vendors must be rigorously qualified and subject to periodic audits, inspections and process reviews.

4.2.5 Very High Pressure (VHP) Oxygen Applications

4.2.5.1 General

Increasing use of high pressure oxygen is likely over the long term. Enhanced Oil Recovery (EOR), supercritical wet oxidation (SWO), aerospace and chemical process industry (CPI) areas are potential applications for Very High Pressure Oxygen.

4.2.5.2 Combustion Resistant Materials

Materials, which have been determined to be non-flammable at pressures up to 21 Mpa (3000 psig) are listed in Appendix D and are suitable for Very High Pressure oxygen applications without velocity limitations.

Materials not listed in Appendix D require either system or material promoted ignition-combustion characterization tests. See 4.2.1.

4.2.5.3 Flammable Materials and Velocity Constraints

Materials which are found to be flammable within the Very High Pressure range should be subjected to oxygen gas velocity limitations as indicated in 4.4. Thickness limitations, where applicable, must be observed.

4.2.5.4 Other Special Requirements

Due to the substantial stored energy inherent in Very High Pressure gas systems, additional system piping analyses involving fracture mechanics techniques may be required depending upon the materials selected. This is a problem usually involving high strength low alloy steels as opposed to austenitic or non-ferrous materials with high toughness.

4.2.6 Temperature Limitations

The metals flammability information contained within 4.2 is pertinent to transmission systems up to:

- 150°C (303°F) for carbon steel piping systems
- 200°C (398°F) for stainless steel and non-ferrous piping systems.

Systems operated at temperatures in excess of the preceding constraints will require additional analysis. Components or material may require metals flammability or particle impact testing at elevated temperatures to ensure system safety.

In the event of operating temperatures below -20°C, steels, which demonstrate adequate fracture toughness values, will be required in the same way as for other industrial gases.

4.3 Non metallic materials

4.3.1 Properties and Risks

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

Many non-metallic materials are flammable in oxygen even at low absolute pressure and purities greater than 23.5%. The main factors affecting their ignition and fire propagation are the pressure, temperature and oxygen concentration.

The Oxygen Index (OI) is the minimum oxygen content in an oxygen-nitrogen gas mixture which will sustain candle like burning of a test sample. Materials with high Oxygen Index are preferred.

In a kindling chain fire process, the non-metallic part is often the link which promotes the ignition of the bulk metallic material. The heat of combustion of the non-metallic component is therefore an important parameter. The preferred non metallic materials have heats of combustion less than 2500 cal/g (4500 BTU/lb), compared with 10 000 cal/g (18000 BTU/lb) for common hydrocarbon products (see Appendix G, reference 1.1, in particular paragraph 7.6.6 of this referenced document).

To assess the oxygen compatibility of a non metallic material, a significant parameter to be considered is its Auto Ignition Temperature (AIT). In practice it is usual to allow a margin of at least 100°C between the operating temperature and the AIT. A lower margin of 50°C may, however, be accepted subject to complementary tests (see Appendix G, reference 7.30 where BAM explains its procedure for oxygen gasket evaluation). However, it is important to check the behaviour of the product in oxygen atmosphere at the maximum working pressure and temperature. The material may be subjected to gaseous fluid impact (see Appendix G, reference 1.3) or to a mechanical impact (see Appendix G, reference 1.4). The result of mechanical impact in a liquid oxygen environment may be a useful indication of the behaviour of the product as liquid oxygen can be considered as a high density oxygen source. For the measurement of AIT, see references 1.2 and 5.3 in Appendix G.

As a slow oxidation may occur and change the properties of the product, an aging procedure (see Appendix G, reference 1.8) may be performed. The behaviour of non-metallic materials within generic classifications may vary in oxygen compatibility tests depending upon the source of supply of the materials.

Qualification of vendors supplied 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-metallic part may be created by:

- Adiabatic compression of the oxygen. This phenomenon is a frequent cause of fires in high pressure oxygen systems (>3 MPa/ 450 psig)
- 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
- Promoted ignition by burning particles.

An evaluation of the ignition probability assessment combined with the reaction effect assessment may lead the designer to optimize the design and the choice of materials. Examples of this procedure are given in document ASTM G 63 (see Appendix G, reference 1.1).

4.3.2 Design practices and material selection

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

- Minimize the quantity of non metallic materials used in oxygen systems
- Take account of heat dissipation in the design by embedding the non-metallic part in an adequate mass of combustion resistant metallic material which will act as a heat sink.
- Avoid locating non metallic materials directly in the gas stream
- Prevent excessive movement of the component
- Ensure that the material is physically and chemically stable at the service conditions
- Ensure that a non-metallic component does not prevent electrical continuity between internal parts.

In addition to these design practices, special 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-metallic materials and thereby avoid any contamination of the non-metallic 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-metallic materials can be found in the appropriate equipment sections.
For oxygen systems with pressures above 3MPa (450 psig), adiabatic compression testing on small equipment items (<25 mm/1 inch) should be considered, particularly for oxygen regulators, see Appendix G, reference 5.9.
The document ASTM G 63 (reference 1.1 in Appendix G), the results of tests performed by BAM in Berlin (references 6.10and 7.30 in Appendix G) and other relevant publications from EIGA, CGA and ASTM (see references 7.32 to 7.52 in Appendix G) could help the designer in the selection of non-metallic materials.

Examples of non metallic materials exhibiting the best oxygen compatibility are:

- Fluorinated polymers including plastic products such as polytetrafluoroethylene (PTFE), fluorinated ethylene-propylene (FEP) or polychlorotrifluoroethylene (PCTFE)
- Elastomer products such as Neoflon, Kalrez, Viton or Fluorel
- Amorphous polymers such as polyamides (Vespel SP21)
- Ceramics and glass, which are totally oxidized products, are combustion resistant but brittle so they are generally used with a binder as composite products. The crystalline structure is very stable and combustion resistant as in the case of graphite, which has a high oxygen compatibility even at high temperature
- Other products as listed by BAM (see reference 6.10 in Appendix G).

WARNING: Fluorinated polymers may release toxic gases when they burn

Lubricants are also detailed in 5.5.

4.4 Velocity and gas pressure criteria

4.4.1 General

Pipe system sizing is predominantly based on the design velocity. This velocity is based on normal plant operation and venting, and not based on velocities which 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 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 must be considered.

4.4.2 Impingement Velocity Curve and Metallic material selection for piping and equipment

The Impingement Velocity Curve, shown as Figure 1, shall be used for the design and material selection of new pipelines, valves, equipment and associated piping systems, where impingement sites may exist. See 5.2.1 and 5.2.2. The designer will choose the metallic materials according to the Impingement Velocity Curve and their exemption pressures defined in 4.2. Below its exemption pressure (see Appendix D), any metallic material may be used without velocity limitation. Above its exemption pressure, the designer will 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, only Exempt Materials may be used (see 4.2).

Pipelines 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 below 0.21 MPa (30 psig), it may be possible to use carbon and thin walled stainless steels in oxygen service without velocity limitations, using properly designed components. 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 or equipment)may justify solutions other than the use of combustion resistant material, for example:

- The use of a protection plate made of exempt material at impingement locations
- Minimising the presence of particulate matter by the use of filtration lower than 70 microns.
- Other exceptions as listed in 4.2.3, 4.2.4, 5.2.2, and 5.2.3.

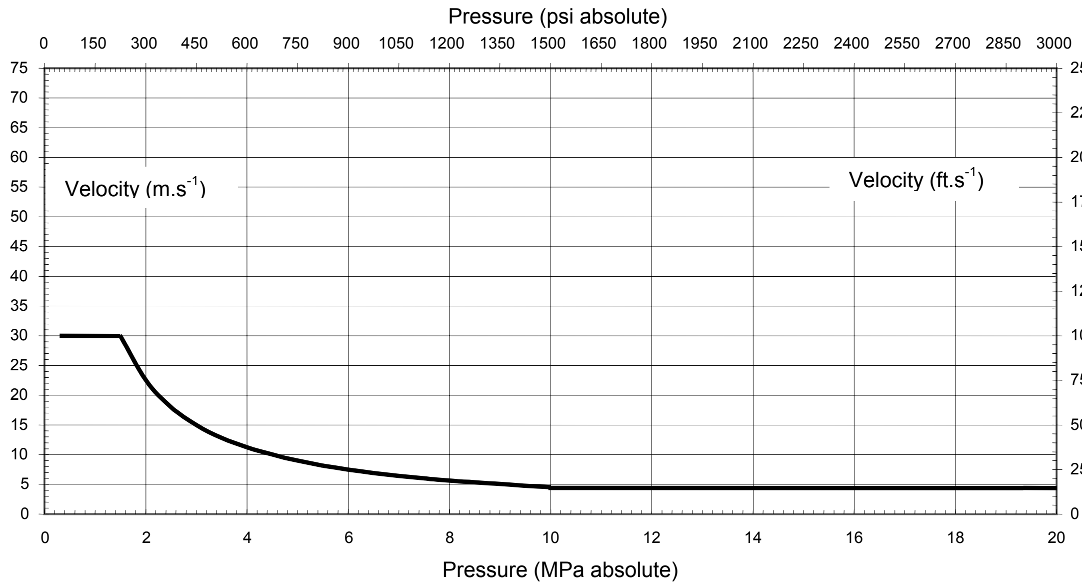

Figure 1: Impingement Velocity Curve

The curve shown in Figure 1 is valid for design temperatures up to 150°C (302°F) for carbon steel pipes and 200°C (392°F) for stainless steel pipes. The carbon steel temperature limitation may be increased to 200°C (392°F) provided a hazard analysis is performed which takes into account factors such as site conditions, operating experience, experimental data, etc. Pressures are limited to a maximum of 21 MPa (3000 psig).

The equation of the Impingement Velocity curve in Figure 1 is defined as follows :
0.3 MPa abs (45 psia)< P < 1.5 MPa (225 psia): V = 30 m/s (100 ft/sec)
If 1.5 MPa (225 psia) < P <10 MPa (1500 psia) : P.V = 45 MPa. m/s (22500 psia. ft/s)
If 10 MPa (1500 psia) < P < 20 MPa (3000 psia) : V(m/s) = 4.5 m/s (15 ft/s).

4.4.3 Velocity limitations in non impingement sites

The Impingement Velocity Curve shall be used for the design of new pipelines.

The velocity may be increased, as shown in Figure 2, in the non-impingement sites of the piping system, when carbon steel pipe is used at temperatures up to 150°C (302°F) and stainless steel pipe is used at temperatures up to 200°C (392°F). See 5.1.1 and 5.2.2
For velocities above the Non Impingement Velocity Curve, exempt materials shall be used in the non-impingement sites.

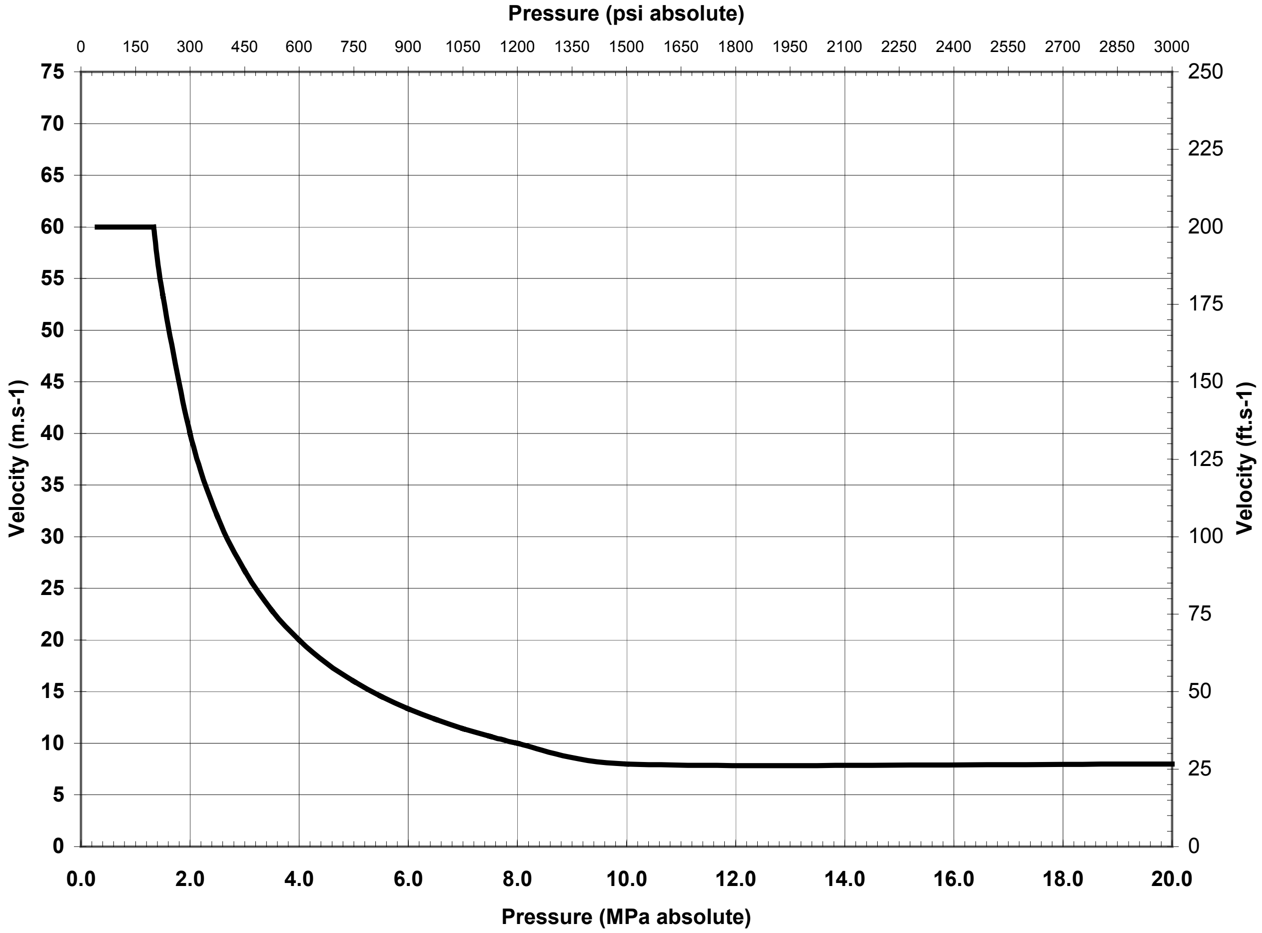

Figure 2: Non-Impingement Velocity Curve

The curve shown in Figure 2 is valid for temperatures up to 150°C (302°F) for carbon steel pipes and 200°C (392°F) for stainless steel pipes. The carbon steel temperature limitation may be increased to 200°C (392°F) provided a hazard analysis is performed which takes into account factors such as site conditions, operating experience, experimental data, etc. Pressures are limited to a maximum of 21 MPa (3000 psig).

The equation of the Non Impingement Velocity Curve is defined as follows:

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

4.5 Piping Systems

4.5.1 Underground piping systems

Piping should be of all welded construction in accordance with a specification and inspection code such as API 1104 (Appendix G, reference 6.5) or any other recognized code. Underground piping must be externally coated to an approved specification, to protect against soil corrosion. Reference to current, internationally accepted, coatings standards and specifications is recommended (see Appendix G, references 6.17 to 6.20)

Underground piping should be adequately buried to protect it from frost, casual surface construction, shifting due to unstable soil, back fill 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. Pipe casings or load shields, if required by special agencies, should be installed at railroad or road crossings or where unusual aboveground loading can occur. Casings or sleeves require careful consideration and 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 due to settlement, etc. In general the use of metallic casings or sleeves is to be avoided wherever possible.

Underground oxygen piping 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 above ground piping, or other metal structures, should be avoided if possible. 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.

4.5.2 Above-ground piping systems

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

Aboveground portions of pipeline systems should connect to underground portions through an electrically insulated joint to isolate the underground cathodic protection system (see 4.5.4, 5.4.5 and 7.4.3).
All aboveground pipelines shall have electrical continuity across all connections, except insulation flanges, 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 pipeline should not exceed 10 ohms for lightning protection.

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

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

Aboveground piping should be routed as far away as practical from other lines and process equipment containing fluids which 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 which 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.

4.5.3 Pipeline markers

Overhead piping should be colour coded and/or identified according to national or corporate standards. Underground piping should be identified with markers placed on the ground near the buried pipeline. Markers should be suitably spaced to indicate the route of the line.

4.5.4 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 5.4.5).

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

There shall be no cad-welding (Thermit) of test station wires to in-service oxygen lines. Cold processes can be used, or alternative methods stated in paragraph 9.2.3.

4.6 Siting, Remote Operation, use of barriers

Siting of oxygen systems must be carefully studied, especially in the case of stations comprising valves and locations where impingement may occur. 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 above, 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 chapter describes how the design philosophy presented in Chapter 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 1 as explained in paragraph 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 2).

Sites where impingement and non-impingement may occur are listed below.

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:

- Tees (for flow from branch into main)
- Socket-weld tees and elbows
- Branch connections such as, fabricated branches, weldolets, sockolets, and threadolets
- Multiple -hole diffusers and surrounding body.
- Short-radius elbows (radius of curvature < 1.5 d).
- Socket-weld and threaded reducers.
- Reducers (eccentric and concentric) with greater than 3:1 inlet to outlet reduction section ratio (for flow from large to small).
- Mitred elbows (metered cut angle more than 20°).
- 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 in-line pipe components, are discussed in the paragraphs shown:

- Valves, section 5.3
- Strainers, section 5.4.1
- Filters, section 5.4.2
- (Flow Measuring Devices 5.4.3
- Silencers, section 5.4.7.1
- Thermo wells, section 5.4.7.2

5.2.2 Non-impingement sites

Non-impingement sites include, but are not limited to, the following:

- Straight piping runs
- Buttweld tees, with long (or smooth) crotch radius (for flow from main to branch)
- Long radius diameter elbows (equal 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.
- Eccentric and concentric reducers with a maximum 3 to 1 reduction ratio.

5.2.3 Specific piping locations

5.2.3.1 By-pass piping

Selection of piping material on the inlet and outlet of the bypass valve, see Figure 3, shall be given special consideration since this piping is often exposed to both high velocities and turbulent flow during pressurization. By-pass piping upstream of the bypass valve is defined as a non-impingement site. Piping downstream of the by-pass valve is defined as an impingement eddy site which is considered to exist for a length of a minimum of 8 pipe diameters downstream of the bypass valve. The possibility of bi-directional flow shall be considered. Exempt materials may not be required for the by-pass piping, if the velocity is below the Impingement Velocity Curve in Figure 1. See paragraph 5.3.2.5.

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 by-pass piping.

5.2.3.3 Inlet piping to pressure relief valves

The inlet piping to the pressure relief valve is considered a non-impingement site. Its size and material selection shall be based on the gas velocity as determined for the main line.

5.2.3.4 Piping downstream of vent valves and safety relief valves

Associated vent piping material selection shall be based on the Impingement Velocity Curve in Figure 1. 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.

Pressure relief valves 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 must be given to the location of the vent outlet, height, direction, adequate spacing, etc, in order to minimize risks due to oxygen enriched atmosphere in the surroundings.

5.2.3.5 Piping downstream of pressure letdown sites

The piping downstream of a pressure let-down valve (throttling or process control valve, see 5.3.2.3) experiences high velocity and highly turbulent gas flow. The pipe wall downstream of a throttling or process control valve is considered an impingement eddy site for a distance equivalent to a minimum of 8 pipe diameters, where pipe diameters is based on the valve 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, exempt materials should be considered for the piping in the eddy site zone.

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

- If the diameter of the seat is less than ¼ of the diameter of the valve flange, it is considered that there is low turbulence at the outlet of the valve body.
- If a 70 micron or better filter is installed upstream of the let-down valve, then particle impingement is significantly reduced.
- If the pressure drop across the valve is less than 15% of the upstream pressure the downstream piping is considered a non-impingement site.
- If the pressure letdown occurs across a multi-hole diffuser, the flow downstream of the diffuser may be considered smooth with no high velocity turbulent jet.
- If 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 must be sized carefully and installed in order to match the internal diameter of the pipe thereby eliminating a space where particles can accumulate. 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 paragraph 4.3.
Reference1.1 in Appendix G may provide guidance on non-metallic materials selection

5.2.3.7 Thread sealants

The oxygen user shall contact the oxygen supplier, providing operating pressure and temperature data, and ask for guidance on material suitable for oxygen service. The sealant vendor should give specifications including at least the maximum service pressure and temperature for the material delivered. PTFE products (tape) can be used according to their individual specifications. See 4.3.
Reference1.1 in Appendix G may provide guidance on non-metallic materials selection.

5.2.3.8 Dust traps and dead ends

The risk of ignition of bulk metallic material 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, adequate design or operational procedures must be developed.

In particular, consideration must be given to lines in stand-by service such as by pass 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. 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. Special attention will be given to manual valves design, as they are locally operated by personnel.

Metallic material 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-metallic material selection requirements are described in 4.3.

5.3.2 Valve functions

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

- Isolation valves
- Process control valves
- Emergency-shutoff valves
- By-pass valves
- Vent valves
- Safety relief valves
- Check valves

5.3.2.1 Isolation valve risks

There are two risks 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.
- Rapid downstream pressurization and temperature rise due to adiabatic compression.

The high velocity, turbulence, and rapid pressurization risks can be avoided by the use of a bypass system to equalize pressure across the isolation valve before it is opened. By-pass 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 must be operated without significant pressure differential by using a bypass system or a specific operating procedure. The downstream pressurization rate shall be controlled to prevent the risk of adiabatic compression.

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

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

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

5.3.2.3 Throttling or process control valves

Throttling or process control valves include those for pressure control, flow control, by-pass or safety relief.

They are defined as valves that control flow or pressure. Depending on the function necessary, pressure control valves might throttle flow continuously, might allow for slow opening or closing, or 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 is not only present in the trim and body of the valve but is considered to extend to the downstream piping for a length of a minimum of 8 pipe diameters.

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 shut-off 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 will experience excessive velocities and momentary turbulence upon closing. Normally these valves are treated as throttling valves.

5.3.2.5 By-pass valves

Bypass valves are normally piped from immediately upstream to immediately downstream of manual isolation valves. Depending on the process design, a by-pass system may be required for certain process control or emergency shut off valves. They are installed for the purpose of providing pressure equalization across an isolation valve. Once pressure equalization is established, the isolation valve may be safely opened. Bypass valves are also used to slowly pressurize a downstream system to mitigate excessive velocity and rapid pressurization risks. Controlled, slow pressurization requires the use of a throttling flow-control-style valve. Due to their flow-control function, bypass valves are categorized as throttling or process control valves. Although classified as process control valves, bypass valves are normally manually operated valves. Typically, they are globe valves that experience impingement and high velocity turbulent flow throughout the valve body.

Bypass valves shall be designed according to the following criteria:

The by-pass system shall be sized to achieve pressure equalization within an acceptable period.
To minimize the amount of particles that might collect in the by-pass line, the by-pass pipe shall be connected into the main pipe at or above the centreline (see Figure 3).

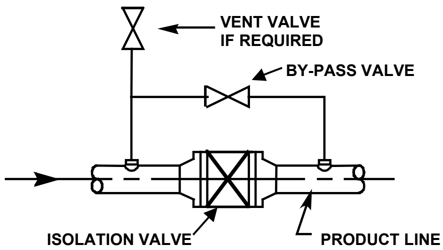

Figure 3: By-pass installation

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 shall be based on Impingement Velocity Curve in Figure 1 (for upstream piping see 5.2.3.3 and for downstream piping see 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 safety relief valves. 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 can be equipped with gear operators to assure slow opening.

5.3.3.2 Butterfly valves

Butterfly valves, when open, operate with the valve disc 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 disc, however, is directly in the flow stream and is considered as an impingement site.

Butterfly valves are inherently quick opening. This leads to concerns about adiabatic compression and temperature rise, especially for any elastomers in the valve or downstream piping system.
Butterfly valves can be equipped with gear operators to assure slow opening.

5.3.3.3 Gate valves

When gate valves are fully open, the flow through the valve is considered smooth. The body is considered as a non-impingement site whereas the gate is treated 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 equalized across them using a by-pass 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

Pressure relief valves by nature experience high velocity across the trim. There will 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 can 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 body and trim.

Pressure relief devices shall comply with national or international standards, such as ASME VIII “Boiler and Pressure Vessel Code” (Appendix G, reference 6.4).

5.3.3.6 Check valves

Check valves, by virtue of their design, contain components that will always be in the flow stream. The disc, plate or piston of a check valve is considered to be an impingement site. 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 must therefore be regarded as potential sources of ignition energy and, possibly, particle generation. Care must be taken to insure that the thickness of moving or impacting components in the flow stream is adequate and not less than those indicated in Appendix D. However, except for unusual circumstances, good design practices tend to achieve low-pressure drop, which also tends to keep velocities below the level at which impingement becomes a concern.

5.3.4 Valve seals and packing

The oxygen user shall contact the oxygen supplier for guidance on seal and packing materials suitable for oxygen service (see 4.3). Information on compatibility of non-metallic seal and packing materials may be found in Appendix G, references 1.1 and 6.10.

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 metallic 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
- Mixing of oxygen and non-compatible oil or grease, for instance in gearboxes or angled valve wheels. If such equipment is used, suitable arrangements, such as distance pieces open to the atmosphere, must be provided to prevent migration of oil or grease down the spindle into the oxygen system

5.4 Equipment

Special in-line pipe components, including filters, strainers, flow measuring devices, thermowells, silencers and flexible connections are described in the following paragraphs. The vast majority of in-line components experience impingement flow, and their materials should be selected on the basis of the information given below.

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 will be on the outside of the cone with the cone projecting upstream. Commonly used mesh sizes are between 30 to 100 corresponding approximately to a 500 to 150 micron particle size capture.

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 combustion resistant material, such as nickel, bronze or Monel. The use of materials with relatively low combustion resistance, such as stainless steel mesh, is not recommended.

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 1 and in Appendix D.

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 maximum allowable working pressure as determined by the setting of the pressure relief valve. 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 filer or strainer operation in reverse flow. The piping and valve requirements discussed for filters in 5.4.2.6 also apply to strainers.

5.4.2 Filters

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

5.4.2.1 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, might 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.

5.4.2.2 Filter element material

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

- fibre-glass or woven glass without organic binders
- woven or sintered nickel
- brass, bronze, or Monel 400.

5.4.2.3 Glass fibre filter elements

If filter elements are fitted with non-metallic 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.

5.4.2.4 Filter buckling pressure

Collapse of filter elements due to high differential pressure can lead to accidents. The element must either be able to withstand total line pressure when completely clogged or a pressure differential indicator with an alarm should be installed (see 5.4.1.1).

5.4.2.5 Filter housing

Housing material selection shall be determined by the application of impingement and non-impingement criteria and reference to the Velocity Curves shown as Figures 1 and 2.

5.4.2.6 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 ahead of the discharge block valve. Filters should not be equipped with valves for in-service back blowing, since this entrains a collection of particulate matter at very high velocity. By-pass 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, e.g. at process shutdowns where only low flow rates are used.

5.4.3 Flow-measuring devices

5.4.3.1 General requirements

Flow meter systems should be located remotely from other equipment and piping, preferably out-doors. Manual block and by-pass 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 D, or meeting the criteria of the Impingement Velocity curve shown in Figure 1. 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 user's requirements. Filtration is generally installed upstream of moving element meters.

5.4.3.2 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 D should be used.

5.4.3.3 Moving element flow measuring devices

The design and selection of moving element flow measuring devices must 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 which 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 over pressuring, over speeding, reverse flow, and excess flow. As there may be some additional considerations or simplifications, every case should be individually and carefully analyzed 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 which 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. This 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 authorized. Renewal or checking of the lubricant shall be made by personnel authorized by the user.
- Remote indication: meters having integral flow indicators or totalizers should be designed, so that they can be read at remote location without approaching the meter.
- Over-speed 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.

5.4.4 Bursting discs

Caution is required with regard to the use of bursting discs 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 shall be made of exempt material. 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.

5.4.5 Insulating joints

An insulating joint is essentially made up of two pipe elements separated by a dielectric 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. If, in the interior of a pipeline a continuous deposit of dust connects the two 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 dielectric properties and comply with the provisions in 4.3.

Insulating joints using standard flanges shall include the following features as minimum requirements:

- The insulating gaskets, bolt washers and sleeves shall be compatible with gaseous oxygen under the conditions of service.
- The dielectric strength of the gaskets, bolt washers and sleeves will depend on vendors' specifications and purchasers requirements but typically will be in the order of 10 kV/mm.
- Insulating flanges should be installed in the horizontal plane (i.e. a vertical pipe run) to minimize 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^{O} from the vertical. Gaskets should not be recessed. 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).
- Impressed current potentials should be limited to a value that cannot create a spark or localised heating across joint gaps or other locations where metal surfaces at different electrical potentials are separated by an insulating material.

If proprietary insulating joints of the monoblock type are to be used the following important features merit consideration:

- The dielectric material and internal gas seals shall be compatible with gaseous oxygen under the conditions of service.
- The dielectric material shall also be non-permeable with respect to gaseous oxygen at the service conditions.
- The dielectric strength of the insulating material should typically be in the order of 10 kV/mm.
- Insulating joints of the monoblock 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.
- It is also important that joints are adequately supported and correctly installed.

See also 4.5.2, 4.5.4 and 7.4.3.

5.4.6 Flexible connections

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

For pipelines 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.

5.4.7 Miscellaneous equipment items

5.4.7.1 Noise reduction devices

Shells, baffles and diffusers of vent silencers shall be entirely of metallic and/or concrete construction. The metallic material shall be corrosion resistant and in accordance with the Impingement Velocity Curve shown as Figure 1. 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.

5.4.7.2 Other accessories

Any other accessory which may come into contact with oxygen shall be constructed from material selected in accordance with the Impingement Velocity Curve. For their non-metallic components, materials that meet requirements of 4.3 shall be selected.

Common accessories are:

- Pressure sensors and indicators
- Pneumatic control devices
- Thermowells
- 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 D should be considered.

Dial gauges should be provided at the rear with blow out plugs or bursting discs 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 paragraphs 4.3 and 5.5. All pressure sensors and indicators should be clearly marked for oxygen service (e.g. by a visible inscription «Oxygen, no oil or grease»).

5.4.8 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:

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

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, it shall be selected from lists of lubricants that have been found acceptable for use with oxygen such as lubricants listed in Appendix G, reference 6.10). The ASTM document in Appendix G, reference 1.1. is also a pertinent information source. 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 has 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 must 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.

6 Cleaning

6.1 General requirements

6.1.1 Cleaning strategy

Cleaning of a pipeline system can be accomplished either by pre-cleaning all piping before installation and maintaining the clean condition during construction, by completely cleaning the pipeline system after construction, or by a combination of the two. It is both impractical and impossible to fully inspect a system for cleanliness after construction and final cleaning; it is therefore necessary that a detailed written procedure, including the sequence for construction and cleaning, be well established and carefully followed throughout the project. The piping system design must be compatible with cleaning, construction and pressure testing methods to be used. A high degree of visual inspection for cleanliness should be applied throughout the material preparation and construction stages.

6.1.2 Standard of cleanliness

A system is considered to be clean for oxygen service when internal organic, inorganic, and particulate matter has been extensively removed. Removal of contaminants such as greases, oils, thread lubricants, dirt, water, filings, scale, weld spatter, paints, or other foreign material is essential. See 6.6.3 for guidance on acceptance criteria.

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
- Solvent washing*
- High pressure detergent cleaning
- 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	To ensure freedom from obstruction
Foam (or soft pig)	Dewatering
	Removal of fine, loose debris and dust
Rubber disc 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 will be fabricated from materials that might not be totally compatible with oxygen, particularly those made of foam or rubber. It is therefore 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 be achieved by a high velocity gas purge (see 6.3.7 and 6.4.6). 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 will minimize 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: Solvents prohibited by the Montreal Protocol must not be used. Refer to relevant national, European or US regulations.

6.1.4 Pipeline components

Equipment such as tees, valves, check valves, insulation joints, regulators, meters, filters and other fittings will normally be purchased as pre-cleaned 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.

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 recognized 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 paragraph 7.3 for further information on welding requirements.

6.1.6 Pressure testing

The pipeline shall be subject to either a pneumatic or a hydrostatic pressure test at the pressure required by the code to which the pipeline has been constructed. The preference is for a pneumatic test (see 7.3.3). Whichever test method is selected, it shall be conducted at a convenient point in the overall pipeline construction programme to suit project requirements and to minimise the likelihood of costly rework. For further details on pressure testing see paragraph 7.6.1.

6.1.7 Installation of pipeline equipment

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

6.2 Specification and manufacture of line pipe material

6.2.1 General requirements

All essential requirements for the specification and manufacture of the line pipe which have a direct bearing on the cleaning process should be formally submitted to the pipe supplier as part of the full technical specification for the purchase of the line pipe. The origin and quality control of the purchased line pipe 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 EN 10208-2 (Appendix G, reference 6.1) or API 5L specification (Appendix G, reference 6.3) or other codes as defined in the project specification as a result of purchasers requirements, national regulations, or other reasons. The material composition should generally be in accordance with the aforesaid codes and the manufacturers normal standard for line pipe. However, for pipe which is to be pre-cleaned before installation, it is desirable that the manufacturing process should not include steps that will generate heavy deposits of mill scale on the internal surfaces of the line pipe (see 6.2.4).

6.2.3 Manufacturing process

The line pipe shall be manufactured using either the High Frequency Induction (HFI) or Electric Resistance Welding (ERW) or Submerged Arc Welding (SAW) process. Seamless rolled pipe can also be used. Line pipe manufactured by other processes should not be used without the prior approval of the purchaser. The purchase order issued to the pipe manufacturer or stockist shall prohibit the application of preservatives, such as paint, varnish, or lacquer, on the internal surfaces of the line pipe.

6.2.4 Heat treatment

Heat treatment for either the longitudinal weld (normally carried out as part of the continuous HFI or ERW or SAW production process) or the pipe body should be such that the finished line pipe 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 line pipe shall, as part of the manufacturing and quality control process, carry out a hydrostatic test 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 EN 10208-2 (Appendix G, reference 6.1) or API 5L (Appendix G, reference 6.3), unless dictated otherwise in the project specification as a result of the purchaser's requirements.

6.3 Pre-cleaned piping

6.3.1 General

All 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 pre-cleaned internally either at the manufacturer's works before delivery or local to the site. The method used for pre-cleaning 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

Line pipe undergoing pre-cleaning for oxygen service should be fabricated in a manner that permits visual inspection along its whole length and, if necessary, re-cleaning 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 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)
- 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 transmission line piping as a result of the introduction of water during a hydrostatic test. However, if pneumatic testing is not acceptable for any reason, pipelines shall be subject to a hydrostatic test (see 6.1.6).

6.3.4 Internal surface finish

The pre-cleaning process, including blowout, aims to achieve, as a minimum requirement, an internal surface finish in accordance with ISO 8501-1, Specification B SA2 (reference 5.8) or equivalent. The pre-cleaning and blowout can be carried out at the manufacturer's works (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 pre-cleaning 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 line 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, can be placed inside each length of line pipe to minimise corrosion. If a desiccant is used, it should be held in a container system which can be firmly secured to the inside of the plastic caps to guard against the container being inadvertently left in the pipe during installation. The total number of desiccant bags used may be checked and documented for reference during the installation at site. Any small-bore tappings in the pipe shall be sealed by metal or plastic plugs.

6.3.6 Maintaining cleanliness

For line pipe that has been cleaned before delivery to site, no further cleaning of the pipe sections need be carried out before installation unless visual inspection at site reveals that, for whatever reason, the cleanliness of the piping has been compromised. In this event, the affected line pipe sections shall be re-cleaned either on or local to the work site in accordance with an approved procedure. During the installation of the pipeline the internal surfaces of the line 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) which, among other requirements, must include all of the following:

- Keeping pipe trenches free of water and flammable material, particularly in the area of welding and where there are open-ended sections of line pipe.
- Sealing 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 about 0.1 bar gauge.
- Visual inspection of the line pipe before every closing weld to be made by an authorised person. Formal records of the results should be maintained for future reference.
- Maintaining the cleanliness of inert gas purging devices (e.g., lances, temporary seals).
- All propelling media, gases and the system for applying them during any type of cleaning operation to be clean and oil-free so that they are not a source of contamination.
- Construction personnel shall wear reasonably clean, non-oily work clothes and, as far as is practical, shall keep their hands free of oil, grease, and excessive dirt.

During the construction period, the pipeline will at times be open to atmosphere and will experience some degree of internal surface corrosion due to this exposure. At the completion of construction, 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.

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

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

In general, the use of lubricants shall be prohibited on either pipelines or valves intended for oxygen service. If for any reason lubricants are deemed to be necessary for oxygen wetted parts, they must be fully oxygen compatible and used only with the prior approval of the purchaser. See paragraphs 7.4.2 and 7.4.4.

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

6.3.7 Final cleaning

Final cleaning shall be performed at a convenient point in the overall construction programme to suit project requirements. The cleaning procedure will depend on a number of factors including, among others, risk of contamination during construction, nature of potential contaminants, method used for pressure test and 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 system. Attention is drawn to the risks associated with those solvents and cleaning agents which are non-flammable in air but exhibit a flammable range in oxygen (see IGC Document 33/97 or AIGA 012/04, Appendix G, reference 3.5 for information on flammability limits). If chemicals, solvents or detergents have been used for cleaning it is therefore important that any liquid residues are completely drained or otherwise removed from the system prior to commissioning. See paragraph 6.1.3 for a summary of available cleaning methods.

6.3.8 Leak testing and blowout

The completed pipeline, without equipment, can be leak tested with dry, oil-free air or nitrogen at the system design pressure following which it can be blown out. Valves, orifice plates, strainers, filters and other items of pre-cleaned 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) sufficient to substantially remove residual particulate matter. The effectiveness of the high velocity gas purge can be 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 effectiveness of the gas purge operation.

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

6.4 Post-installation cleaning

6.4.1 General

All line pipes should be installed with sections of pipe that are generally in accordance with paragraph 6.2. Otherwise there are no other special requirements. It is important, however, to ascertain the likely condition of the piping (e.g. degree of mill scale) as delivered from the stockist or manufacturer's works to ensure that the proposed cleaning method is capable of achieving the desired standard of cleanliness. See 6.3.1 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 ISO 8501-1, Specification B SA2. The piping 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 pipeline every effort should be made to minimise the ingress of contaminants (e.g. oil, grease, soil, debris, and runoff water). See paragraph 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 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 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.
- Inspection of end sections of internal bore by ultraviolet light (UVA) to verify the absence of oil or grease.
- Inspection of wipes (if taken) by bright white light and ultraviolet light (UVA) to verify the absence of oil or grease.

6.5.2 UVA-light examination

When UVA-light examination is required, all samples and openings shall be inspected by a suitable UVA-light source to verify that there is no evidence of hydrocarbon contamination. A slight discoloration of the sample is acceptable providing that the sample does not exhibit fluorescence when subjected to UVA-light examination. The following criteria shall generally apply to the selection of the UVA-light source to be used for the fluorescent detection of hydrocarbon contaminants on pipe surfaces or wipes:

- The light wavelength shall be in the range 250–400 nm.
- The light source shall be a spotlight using either a mercury vapour or halide lamp, together with a suitable filter, that provides a light intensity of at least 5.0 mW/cm^2 at 30 cm. Normally, UVA light sources using fluorescent tubes are not suitable for this application and should be avoided.

In most cases UVA-light examination will provide a reliable indication as to the extent of hydrocarbon contamination in a pipeline (see 6.6.3). However, it should be recognised that not all oils and greases fluoresce under UVA light. If for any reason such materials have been used either in the manufacture, long term storage, fabrication or construction of the line pipe then other detection methods might be necessary.

6.5.3 Acceptance criteria

Reference should be made to IGC Document 33/97 or AIGA 012/04, Section 4, CGA G-4.1, Section 10 and ASTM G93-96, Sections 9 and 10 for guidance on threshold detection limits and cleanliness acceptance criteria.

6.5.4 Remedial action

If at any stage during the pre-cleaning 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.

6.5.5 Sealing, purging and monitoring

Following the pipeline inspection and acceptance of the standard of cleanliness, the pipeline will be sealed at all open ends with either welded caps or blind flanges and purged with dry, oil-free air or nitrogen (dew point no higher than -40°C) 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 gas to about 0.01 MPa (1.5 psig). The pressure shall be monitored on a regular basis and maintained in this condition until the pipeline 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 Construction

7.1 General Criteria

The total installation of the pipeline, including testing and cleaning, should be undertaken by a reputable 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 pipeline is installed. The detailed construction programme, including the sequence of testing and cleaning procedures, shall be defined to suit specific project requirements. The design of the pipeline 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. Reference should be made to 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 off-loading, storing, installation, 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 line pipe shall be fabricated and/or installed in accordance with approved drawings. Installation of the line pipe shall include all manual valves, special piping items, control valves, relief valves, in-line 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 might be required should be agreed with the purchaser prior to the work being performed.

7.2 Construction plan

A formal construction plan should be developed which 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 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.
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 paragraph 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 must 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:

- By using the 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 will in itself 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.
- By using the Manual Metal Arc (MMA) welding technique, also known as the 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 Qualifications

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.
- The absence of backing rings facilitates the use of pigs for cleaning operations.

- 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 pre-cleaned 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 can be relaxed provided systems are in place to ensure removal of such devices before the cleaning operation.

7.3.5 Welding requirements for materials

The welding of carbon steel, stainless steel, and Monel shall be conducted in accordance with the relevant piping code. See also 6.5.3.

7.4 Assembly and installation

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 minimized. Piping must 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-metallic parts are used, non-metallic materials must be chosen according to 4.3. 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 rinsed with a compatible solvent or rejected.

Gaskets must be correctly sized to ensure that no part of the gasket projects beyond the inner wall of the pipe into the flowing gas stream. The use of gasket sealants shall be avoided to prevent extrusion of the sealant material into the pipeline system.

The re-use 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 re-made 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 pail may be available for washing nuts, bolts and, if necessary, gaskets just prior to installation. If so desired, a suitable lubricant, as defined in the project specification, can 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 must be exercised through formal procedures and rigorous supervision to insure oxygen-wetted surfaces are not contaminated and that the lubricant is not mistakenly assumed to be oxygen compatible.

Alternatively, lubrication 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, in special circumstances, bolt loads are specified, the contractor should use bolt-tensioning equipment to achieve the correct bolt loading. If torque values are specified, the contractor can use torque wrenches via the nuts to develop the necessary bolt load. The use of torque wrenches might dictate the use of a suitable lubricant on the bolt threads. If no bolt loads or torque values are specified, bolts shall be tightened sufficiently, 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 monoblock 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 and correctly installed in accordance with design drawings and good construction practices. See also 4.5.2, 4.5.4 and 5.4.5.

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 which 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 pressure relief valves and other pressure relief devices:

- Apart from those required for construction and testing purposes, no pressure relief valves or other pressure relief devices 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.

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 must be removed before the 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 cleanliness are being observed. After completion of construction, the pipeline 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, include those to verify the following:

- Pipe concentricity
- Specified wall thickness
- Internal cleanliness
- Protective coating integrity
- Absence of mechanical damage e.g. gouges, dents etc.
- Joint preparation
- Welding fit-up
- Welding
- Absence of arc burns
- Review of X-ray examination

7.6 Non-destructive testing

7.6.1 Pressure testing

If permissible, the strength test should be conducted pneumatically using dry, oil-free air or nitrogen to minimise the possibility of contamination (see paragraph 6.3.3). The test shall be carried out in accordance with the code to which the pipeline has been designed and constructed. Adequate safety precautions to minimise the potential consequences of a pressure release must 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 must be assessed and appropriate precautions taken.

If it is not permissible to carry out a pneumatic strength 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 deoxygenating agent and passivation agent can 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 pipeline system for any longer than necessary, particularly if sub-zero 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 pipeline should then be dried either by purging with dry, oil-free air or nitrogen to achieve a maximum dew point of minus $30^{O}C$ or by a recognised vacuum drying process using oxygen compatible vacuum pumping apparatus.

Dry, oil-free air shall have a dew point of $-30^{O}C$ or lower at 1.013 bar and a hydrocarbon/particle content of less than 1 mg/m^3 (see IGC Document 33/97, Appendix G, reference 3.5).

In the event that welding is required for repairs, pipe tie-ins or final closing welds the relevant piping code might 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 (see 7.6.1). Socket weld and fillet weld joints can be suitably tested with X-ray but may be examined using other non-destructive examination in accordance with the applicable code. For socket and fillet welds, dye-penetrant testing is an acceptable alternative to X-ray examination.

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

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

7.7 Documentation

The following documents relating to the construction and installation of the pipeline 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.
- Other reports and certificates required by local and/or national authorities, the relevant piping code and the project specification.

In addition, for underground pipelines:

- Holiday test report (report on pinholes or defects in the external coating)
- Cathodic protection and electrical isolation report.

8 Design and construction of 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. Typical arrangements are shown in Appendix A, Diagram 1.

8.2 Design brief

A design brief summarising the basic requirements (Process Definition and P & I Diagram) 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
- site requirements, including interaction with surrounding plant.

A Hazop study and/or Risk Assessment may need to be considered with the design brief.
An example of a complete process control station showing possible components is shown in Appendix A, Diagram 2.

8.2.1 Emergency shut-off valves

Emergency shut-off valves (ESOV) 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 , low pressure or rate of decay of line pressure. See also paragraph 5.3.2.4.

8.2.2 Isolation valves

(See 5.3)
Isolation valves are normally of gate, ball, or butterfly type design and should be operated in the fully open or fully closed position. They should not be operated in the throttling or regulating mode.
Where required to minimise adiabatic compression or particle impingement, a method of slow pressurisation should be provided. This can be achieved by a small manual bypass valve in exempt material or by a specific design of the valve. Valves may be manually or automatically operated. In the case of automatic operation however, the operating circuit shall be designed so that it is not possible to open such a valve before the upstream and downstream pressures have nearly equalised.

8.2.3 Filters and strainers

(See 5.4.1 and 5.4.2)
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) which may be entrained in the gas stream.

For high purity applications (e.g. electronics) more stringent filtration levels (typically less than 5 µm) may be specified.

8.2.4 Flow meters

(See 5.4.3.)
The invoice meter measures accurately 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 comprise the following:
- pressure transmitter
- temperature transmitter
- differential pressure transmitter

- mass flow computer

8.2.5 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.

8.2.6 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.

8.2.7 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 pressure relief valve.

8.2.8 Pressure relief and vent valves

(See 5.3.2.6 and 5.3.3.5)
Where required, a pressure relief device is installed downstream of the pressure controllers to protect the system against the abnormally high pressure that would be experienced under failure conditions.
The pressure relieving devices 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.

8.2.9 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
- 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 (see Appendix G, reference 6.6).
For designs in copper and cupro-nickel only, the allowable design stress shall be obtained by reference to a specific design code, such as BS 1306 (reference 6.2) or ASME B 31.3 (reference 6.6).
Electrical and instrument installations shall be designed and installed in accordance with the relevant international or national standard (see reference 5.7).

8.4 Materials

Due to the many unavoidable restrictions and variations in gas velocity within the pipework and components, (e.g. meters, valves and filters), the designer must carefully evaluate pressure and s under operating conditions. Exempt materials shall be used, where necessary to meet the requirements of Chapter 4.

Only lubricants formally approved for oxygen service shall be used (see paragraph 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 or screens

8.5.1 Barrier requirements criteria

Where compliance with the Velocity Curves (Figures 1 and 2), 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 paragraph 4.1.2), personnel exposure, siting (see paragraphs 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 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 apply.

- The barriers must protect personnel and, if so desired, adjacent equipment from hazards that occur during an oxygen combustion fire. They must 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 metallic fire. However, it must also be acknowledged that oxygen promoted metallic fires may 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 and qualification tests. An example of a potential validation test for an arbitrary set of selected conditions or requirements follows. One way of validating suitable materials is to perform testing with a PGE, Oxylance or equal oxygen lance. 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 inches) from the barrier material for a minimum of 3 seconds. The recommended lance should be 1.85cm (0.75 inch) nominal pipe diameter, fed with gaseous oxygen at a pressure between 0.8 and 1.5 MPa (100 and 200 psig). The barrier should also be able of withstanding the breech jet load on the barrier surface caused by the pressurized oxygen release. This jet load may be calculated by the following formula:
  $F = 1.017*PD^2 - 0.81*D^2$, with F jet load in daN, D pipe diameter in cm, P nominal gas pressure in bar (a)
  Or
  $F = 0.997*PD^2 - 11.54*D^2$, with F in lbs, D in inches and P in psia.
  It is also assumed that the breech jet load will be distributed on a circular wall surface of a diameter 7 times the pipe diameter.

- Barrier materials should be non-flammable, such as concrete, reinforced masonry or insulation reinforced with metallic 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 will prevent any molten metal splash from being deflected past the barrier.
- Vertical barriers open to the sky or building roof are acceptable.
- The barrier should preferably be at least 30 cm (12 in) away from any component having an oxygen fire potential.
- Special attention should be given to barriers located in the area adjacent to bends, by-pass and emergency shut-off valves and related piping.
- Barrier height should be at least 2.5 m and block any line of sight view of the equipment from walkways, permanent platforms or public buildings within 15 meters. 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).
- Barriers shall be constructed such that maintenance personnel and operators can work safely. In cases where there are two control stations to ensure continuity of oxygen supply, a barrier should be placed between the two stations.

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 include:

- operator controls, including instrument air valves and pressure reducers
- instrument readouts and equipment on which maintenance must be made during operation
- emergency shutdown switches
- check valves (unless individually protected with its own barrier)
- emergency shut-off valves (unless individually protected with its own barrier)
- 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 and such that 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, above-ground 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 above-ground 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 unauthorized 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:

- The stored energy level in the system.
- The 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
- 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 $P*D^2$ where P is the normal maximum operating pressure (bars) 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: $P*D^2 > 3000$, $P > 4$, $D > 2.5$.

Category 2: $P*D^2 < 3000 > 1500$, $P > 4$, $D > 2.5$.

Category 3: $P*D^2 < 1500$, $P > 4$, $D > 2.5$.

For stations intended for isolation or metering purposes only, 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 this table are the 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 a 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 Authorized Inspector.

8.9 Installation

All pipes and components shall be cleaned, degreased and prepared before installation and scrupulous cleanliness maintained thereafter (see chapter 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 after testing.

8.10.2 Post installation

Completed installations shall undergo a pneumatic test with dry, oil-free nitrogen or dry, oil free air, 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
- safety considerations

A Responsible Person shall be appointed to control all aspects of the commissioning procedure.

8.11.1 Safety

Only authorised personnel should be allowed in the vicinity of the station during commissioning. The Responsible Person shall be responsible for the co-ordination and control of the commissioning and shall ensure that the Customer and all personnel are properly briefed. Normally a commissioning programme and procedure will be 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:

- P & I D

- 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
- satisfactory operation and adjustment of:
    - meters
    - flow Controllers
    - spill valves
    - pressure controllers
    - safety valves (if fitted)
    - safety shut-off valves (if fitted)
    - shut-off valves
    - safety devices, alarms and trips

8.11.3 Filters

Initially on a new process control station, due to high velocity test and purge s 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 operations.

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 suit 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
- Completion of items defined under the «Planned Preventative Maintenance» system.

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

9 Operation, monitoring and maintenance

9.1 General safety instruction

- Before performing work on oxygen pipeline systems, a safety work permit should be issued. Guidance on work permit systems may be found in publications such as IGC Document 40/02 or AIGA 011/04 on “Work Permit Systems” (Appendix G, reference 3.6).

- Smoking is forbidden in stations and within a safety distance of 5 meters (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 on oxygen pipelines systems is not permitted
- The 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.
- As for other 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

As well as having the usual work safety knowledge, personnel who operate and maintain oxygen systems must also have special knowledge of how to handle oxygen and the potential hazards that are involved. They must be well acquainted with the location of the pipelines, the stations and the control equipment. All the operating and safety procedures must be available to the personnel.

Sub-contractors personnel must also be informed about or have access to all the relevant safety information.

Hands, work clothing, gloves and shoes must be free of lint and fibres. Above all they must be clean 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 shut-off valves, which might not be designed for use in throttling mode. An isolation valve not fabricated from exempt materials may only be operated after minimizing the pressure differential by the use of a by-pass valve or other specific procedures. Provisions must 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 previous definition, the valve then is defined as a process control valve. Best practice is to install warning signs on systems not fabricated from exempt material.

9.1.3 Welding and cutting work

Any welding on in-service oxygen pipelines could cause localized 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 during connection work
- welding on cathodic protection bolts using a specific bolt welding unit as explained below.

A process qualification must be made beforehand in order to ensure that little or no heat is generated on the inside of the pipeline during the short time the bolt is being welded on. This work requires special equipment and procedures; it may only be carried out under the supervision of highly experienced and trained personnel. The process qualification should 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 done when the oxygen line is out of service, if possible.

9.1.4 Oxygen enrichment and deficiency

Work shall only be carried out in well ventilated areas where normal ambient air is available.
The following should be adhered to:

- more than 21 % by vol. (Oxygen enrichment)
- less than 21% by vol. (Oxygen deprivation)

The ambient air must 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 must be checked and calibrated at regular intervals.

9.1.5 Shut down / start up of pipelines

Written procedures are required for shut down / start up and maintenance of pipelines. The personnel involved in the work, including contractors, must be informed of the specific risks related to oxygen and the tasks to be performed.

Authorization for these activities by a responsible person must be given as follows:
- prior to starting maintenance work, after shut-off procedures are completed
- prior to the repressurizing the pipe, 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, which 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 shut-off mechanism for maintenance work.

A positive shut-off is required if major work such as cutting and welding is being carried out. This shut off 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
- Closing a valve and placing a sealing balloon (bubble) inside the pipe with an intermediate bleed valve is a procedure that may be used, if there are no other possibilities.

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

Continuous monitoring of the oxygen concentration must be made.

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

9.1.6 Venting and pressure relief

- Venting:

Large quantities of oxygen must 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 operating in oxygen enriched atmospheres are particularly dangerous.
Venting should not take place directly beneath high voltage overhead lines.

- Pressure relieving:

When the pressure is being relieved, a auxiliary valve in throttling mode may be installed downstream of the actual blow-out 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 (Refer to sections 5.3.2.3 and 5.3.2.6 on valve materials).

9.1.7 Purging

Nitrogen or dry air, free of oil and grease, must be used to purge oxygen from the pipeline. A purging program, including all branches must be followed in order to avoid leaving any oxygen pocket in the pipeline system.

When using nitrogen, it must 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 (fasteners, connecting pieces etc.) must be clean and free of oil and grease.

9.2 Commissioning pipelines 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 drying (if the pipeline has been subjected to a hydrostatic test), the pipeline can be put in service. If possible, new pipelines must be blown through with a large quantity of nitrogen using as large an outlet as possible so as to remove dust from the pipeline (see also 6.3.7 and 6.4.6).
When commissioning starts, the pipeline must first be purged with oxygen so that 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 pipeline has been purged and all the purging points have been closed, the pipeline can be pressurised, using a by-pass, 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 must 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 laid down in work instructions.

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

9.4 Information to third parties, work adjacent to pipelines and update of documents

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 accidents out of three 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, must be followed.

These regulations usually require:

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

In 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 issue 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
- 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 which occurred when work was performed.

9.5 Specialised Surveys

In addition to the routine monitoring of cathodic protection system potentials, consideration should be given to investigating the integrity of the pipeline coating system and other faults, which may reduce the effectiveness of the cathodic protection (C.P) system.
This can be achieved by the use of specialised survey techniques, such as.

- Pearson survey.
- Current attenuation survey.
- Close interval potential survey.

These investigations can be undertaken at 5 to 10 year intervals, depending on the particular pipeline and the type of cathodic protection system applied. It is common practice to compare the results of such surveys with those obtained immediately following installation.

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.

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 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. Procedures must 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 procedure, however, the following subjects should be considered when compiling such procedures.

10.1.1 Liaison with Public Authorities and other Consultees

The effective handling of a pipeline incident will often require the co-operation of public authorities (e.g. 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, drawings of control stations including location of isolating 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 (e.g. telephone, radio, e-mail and/or fax) should be identified. Clear instructions for dealing with emergencies must be established and formalised.

10.1.4 Notification of an Incident

The incident may 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 Alerting Procedure

The control centre must alert the engineer and 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 shutdown 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 must 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, e.g. 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 Form

Details of the incident should be compiled and recorded on the form required by the legislative 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 must be installed in accordance with applicable standards and specifications, such as NACE Standard RP0177 (Appendix G, reference 6.12).

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

Particular care must 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 polarization 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 self-extinguish after a few seconds, but the mass of oxygen released may create an oxygen enriched atmosphere.
- Combustion in oxygen enriched air, which can be dealt with using conventional fire fighting methods, after the supply of oxygen has been cut off.

The effects of a fire can be minimised by cutting off the oxygen supply by actuating a shutdown system, see 10.6.3.
Fire extinguishers containing suitable extinguishing materials should be installed in a safe and easily accessible location in pressure reducing and flow metering stations. Emergency vehicles must also be equipped with fire extinguishers. All fire fighting equipment must be maintained in good working order.

If safety showers are available, they must be fitted with a frost proof water supply.

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. Fires on persons or their clothing should be extinguished using water.

Persons who have been in oxygen enriched air must not come into contact with ignition sources (cigarettes, welding torches, sparks etc.) and immediately leave the area. These people must undo or loosen their clothing and ventilate it for at least 15 minutes 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 must be adapted to the situation.

- Rapid risk assessment
- Warn personnel on site
- Leave the danger zone
- Bring the equipment into a safe condition (emergency shut-off, turn off using valves etc.).
- Notify the fire brigade and police if necessary
- Notify supervisors and the emergency crew
- Give first aid to injured persons
- 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 may immediately lose consciousness.

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

The rescuer must 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 must immediately be given first aid, such as artificial respiration or administration of oxygen, until a doctor arrives.

10.5 Accident and damage report

If a pipeline accident 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 accident, the material involved and the consequences of the accident, such as a secondary ignition, injury to people and damage to equipment or property.
The cause of the accident/damage should be determined and remedied. A typical method for investigating oxygen pipeline accidents is described in ASTM G145:"Standard Guide for Studying Fire Incidents in Oxygen Systems", (see Appendix G, reference 1.14.)

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 (P.I.M.S.). 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 subject headings.

10.6.1 Notification to Authorities and Consultation on Routing

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

10.6.2 Design and construction

Overall design and construction practice is 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 which relate to the particular product to be transmitted are applied

10.6.3 Shutdown Systems

Shutdown may be manual or automatic. Shutdown devices (e.g. emergency shutoff valves) may be actuated by a leak detection system or by sensing high flow, low pressure, or rate of decay of line 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 pressure relief device 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.
- Product purity: to ensure any product which 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 is also distributed to "one call" systems, a single point of contact where information on all pipelines and services can be obtained - (where applicable).
- Regular patrols of the pipeline by foot or aerial survey to search for unauthorised interference. (See also 10.6.10).

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 programmes are,

- routine testing of cathodic protection system
- visual leak check on above-ground 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
- check that all pipeline marking devices are in place

10.6.7 Major Accident 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, audit/review may be prepared (dependant upon the perceived extent and nature of the major accident hazards presented by the pipeline and local regulations and practice).

10.6.8 Emergency Planning

An emergency plan is prepared so that 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 must receive training appropriate to their role in such an event. Any special protective clothing and equipment that might 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

Plans and documentation illustrating the route of the pipeline must be deposited with the local government authority planning department, landowners and other parties who may have an interest in the pipeline (e.g. 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 section 4.5.

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 Accident Reporting

This is normally included in the legislative requirements of individual Member States or local authorities.

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

Appendix A: Typical arrangements for Pipelines Systems

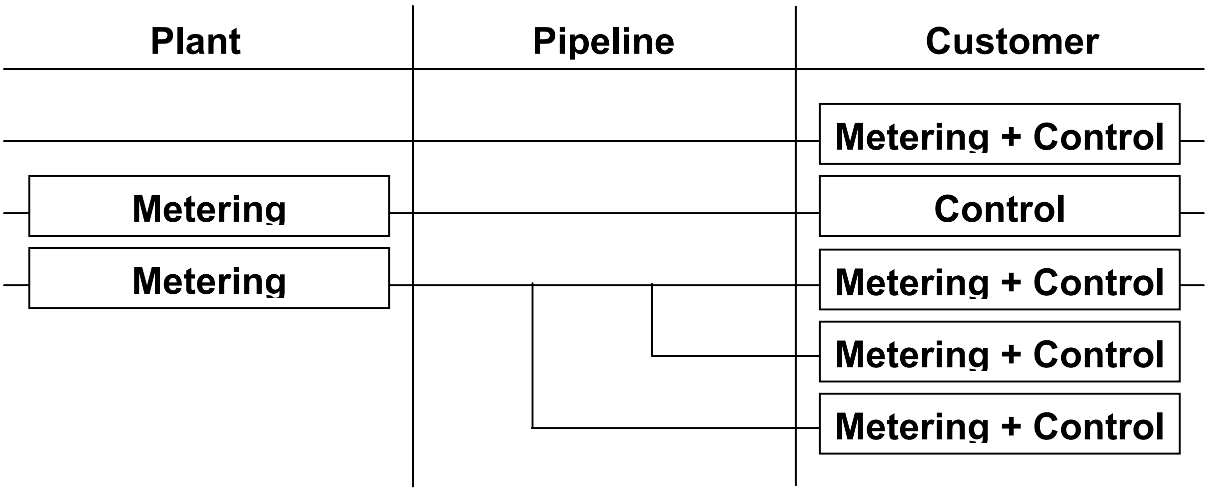

Diagram 1 : Typical transmission and distribution piping systems

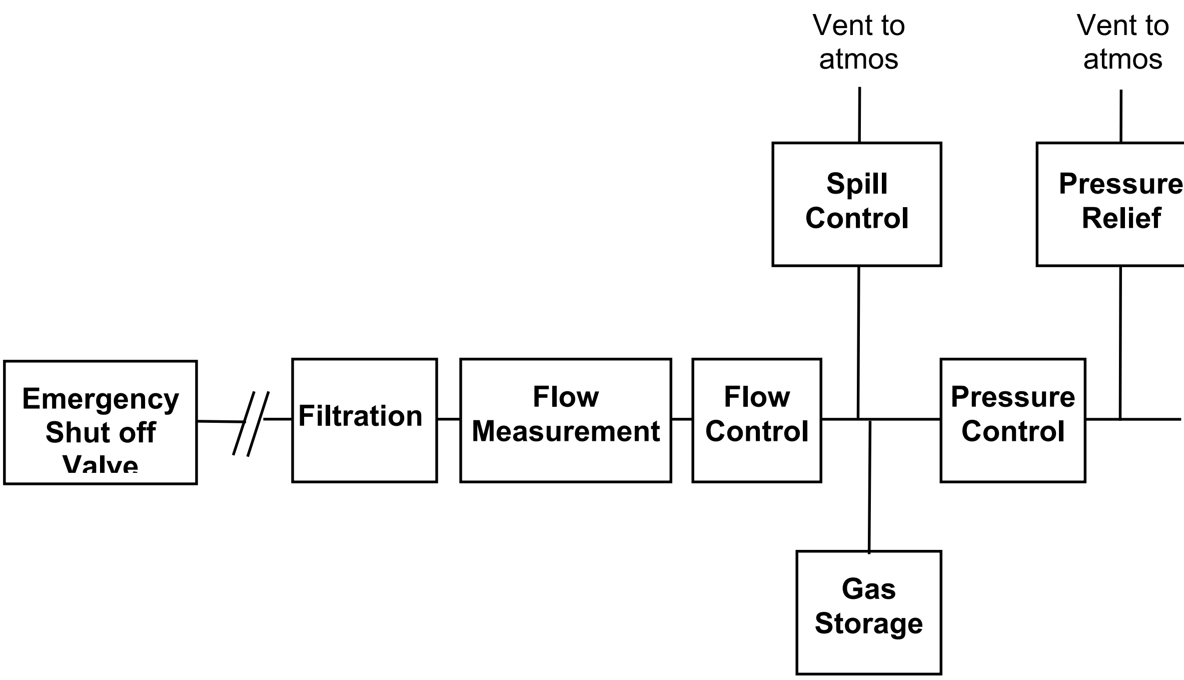

Diagram 2 : Basic components of process control

Note: Items shown in Diagram 2 are not always used or required

Appendix B: Description of Promoted Ignition Combustion Test Method

1 Criteria

In this test method (in Appendix G, see reference 1.7. and bibliography 7), the test specimen is ignited in an oxygen atmosphere by a promoter. 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. Reference 7.4 in Appendix G describes the Promoted Ignition- Combustion transition Curve in considerable detail. 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.

2 Specimen Configurations

The most common specimen in use in Promoted Ignition-Combustion Tests is the rod configuration with a nominal diameter of 3.2 cm (0.125 in) and length ranging between 10 and 15.3 cm. However, in making flammability assessments, diameters greater or less than 3.2 cm (0.125 inch) may be utilized. Technical papers on promoted ignition-combustion testing which describe various test specimens are found in references 1.15 through 1.23.

3 Promoter

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

4 Oxygen Purity

Oxygen atmospheres used in flammability tests can be chosen to suit potential applications. The bulk of published data involves high purity 99.7% oxygen. However, metals flammability data obtained with substantially lower oxygen purities exist. Premixed cylinder blends or point of use blends both have been utilized in flammability experiments.
Previously cited references should be consulted on this test parameter.

5 Test Vessels for Promoted Ignition-Combustion Testing

5.1 General

There are two types of vessels used in metals promoted ignition-combustion testing which 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 Oxygen-Index (O.I.) apparatus. Descriptions of this testers are found in Appendix G, references 7.1-7.6, 7.9-7.12, 7.18- 7.25.

5.2 Static Tester

Static testers have generated data over the 3.55 MPa (500 psig) to 34.5 MPa (5000 psig) 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.

5.3 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 minimized using this approach.

5.4 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 Appendix G, reference7.4. Three distinct zones known as upper shelf (minimal specimen consumption), transition zone and lower shelf (substantial to complete specimen consumption) may be observed.

Design criteria by which a material is exempt from velocity limitation can be based upon the upper shelf e.g., a maximum burn length of 3 cm within which combustion is arrested or the lower shelf where complete burns of 10-15 cm long specimens can occur. Exemption pressures in this document which are based upon upper shelf data and the cited burn criteria incorporate a significant safety factor when compared to the lower shelf pressures.

It is necessary to test at least 3 to 5 test specimens at each test pressure. Use of smaller specimen numbers may be misleading; particularly if combustion arrest occurs. Reference 7.2 in Appendix G is also of significance relative to ranking methods.

Appendix C: Table of Nominal Alloy Compositions & Ranges

MATERIAL TYPE OR ALLOY	EN-MAT.NO.	UNS NO.	NOMINAL COMPOSITION RANGE
Brass Alloys (1)		2.0380	Various 55-85 Cu, 15-44 Zn, 1-3 (Sn, Pb, Fe)
Cobalt Alloys			
Stellite 6	Stellit 6	R30006	55.5Co, 29 Cr, 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)
Copper	2.0090	C10100 C10200	99.9+Cu
Copper-Nickel Alloys	2.0882	C70600 C71500	67-87 Cu, 10-31 Ni, 1-2 (Fe, Mn, Zn)
Ferrous Castings (Non- Stainless)			
Gray Cast Iron	0.6030	F12801	3C, 2Si, 0.8Mn, Bal. Fe
Nodular Cast Iron	0.7040	F32800	3.6C, 2.7Si, O.4Mn, Bal. Fe
Ni Resist Type D2	0.7673	F43010	20Ni, 3C, 2SI, 2Cr, 1Mn, Bal. Fe
Ferrous Castings, (Stainless)			
CF-3(2)	1.4308	J92500	19.5Cr, 10Ni, 2Si, 1.5Mn, Bal. Fe
CF-8(2)	1.4308	J92600	19.5Cr, 10Ni, 2Si, 1.5Mn, Bal. Fe
CF-3M	1.4408	J92800	19Cr, 11Ni, 3Mo, 1.5Si, 1.5Mn, Bal. Fe
CF-8M(3)	1.4408	J92900	19Cr, 11Ni, 3Mo, 1.5Si, 1.5Mn, Bal. Fe
CG-8M(4)	1.4439	J93000	20Cr, 12Ni, 3Mo, 1.5Si, Bal. Fe
CN-7M(5)		N08007	21Cr, 29Ni, 4Cu, 3Mo, 1.5Si, 1.5Mn, Bal. 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-276	2.4819	N10276	56Ni, 12Cr, 13.5Mo, 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, Bal. Fe
304L	1.4301/1.4306	S30403	19Cr, 9Ni, 2Mn, 1Si, Bal. Fe
316	1.4401/1.4404	S31600	17Cr, 12Ni, 2Mn, 3Mo, 1Si, Bal. Fe
316L	1.4401/1.4404	S31603	17Cr, 12Ni, 2Mn, 3Mo, 1Si, Bal. Fe
321	1.4541	S32100	18Cr, 11.5Ni, Ti 5XC min., Bal. Fe
347	1.4550	S34700	18Cr, 11.5Ni, Nb 8XC min., Bal. Fe
410	1.4006/1.4024	S41000	13Cr, 1Mn, 1Si, Bal. Fe
430	1.4016/1.4742	S43000	17Cr, 1Mn, 1Si, Bal. Fe
17-4PH(6)	1.4542/1.4548	S17400	17Cr, 4Ni, 4Cu, 1Si, Bal. Fe
X3 Ni Cr Mo 13-4	1.4313	S41500	13Cr, 4.5Ni, 1Mo, 1Si, Bal. Fe
Carpenter 20 Cb-3	2.4660	N08020	35Ni,20Cr,3.5Cu,2.5Mo, Bal. Fe
Tin Bronzes	2.1080	Various	85-89Cu, 5-11Sn, 5-10 (Zn, Pb, Ni)

Notes:

(1) Aluminum Brasses not included
(2) Cast Analogs of 304L/304 stainless steel
(3) Cast Analogs of 316L/316 stainless steels
(4) Cast Analog of 317 stainless steel
(5) Alloy 20
(6) Age Hardened Condition

Appendix D: Table of Exemption Pressures and Minimum Thicknesses

ENGINEERING ALLOYS	MINIMUM THICKNESS	EXEMPTION PRESSURE*
Brass Alloys**	None Specified	21 MPa (3000 psig)
Cobalt Alloys		
Stellite 6	None Specified	3.6 MPa (500 psig)
Stellite 6B	None Specified	3.6 MPa (500 psig)
Copper**	None Specified	21 MPa (3000 psig)
Copper- Nickel Alloys**	None Specified	21 MPa (3000 psig)
Ferrous Castings, Non Stainless		
Gray Cast Iron	3.18 mm (0.125")	0.27 MPa (25 psig)
Nodular Cast Iron	3.18 mm (0.125")	0.45 MPa (50 psig)
Ni Resist Type D2	3.18 mm (0.125")	2.2 MPa (300 psig)
Ferrous Castings, Stainless		
CF-3/CF-8,CF-3M/CF-8M,CG-8M	3.18 mm (0.125")	1.4 MPa (200 psig)
CF-3/CF-8,CF-3M/CF-8M,CG-8M	6.35 mm (0.250“)	2.0 MPa (290 psig)
CN-7M	3.18 mm (0.125")	2.6 MPa (375 psig)
CN-7M	6.35 mm (0.25")	3.6 MPa (500 psig)
Nickel Alloys		
Hastelloy C-276	None specified	5.3 MPa (750 psig)
Inconel 600	None specified	6.9 MPa (1000 psig)
Inconel 625	3.18 mm (0.125")	8.7 MPa (1250 psig)
Inconel X-750	None specified	6.9 MPa (1000 psig)
Monel 400	None specified	21 MPa (3000 psig)
Monel K-500	None specified	21 MPa (3000 psig)
Nickel 200	None specified	21 MPa (3000 psig)
Stainless Steels, Wrought		
304/304L, 316/316L, 321, 347	3.18 mm (0.125")	1.4 MPa (200 psig)
304/304L, 316/316L, 321, 347	6.35 mm (0.250")	2.0 MPa (290 psig)
Carpenter 20 Cb-3	3.18 mm (0.125")	2.6 MPa (375 psig)
410	3.18 mm (0.125")	1.8 MPa (250 psig)
430	3.18 mm (0.125")	1.8 MPa (250 psig)
X3 NiCrMo 13-4	3.18 mm (0.125")	1.8 MPa (250 psig)
17-4PH (aged)	3.18 mm (0.125")	2.2 MPa (300 psig)
Tin Bronzes	None Specified	21 MPa (3000 psig)

* Exemption Pressure is the maximum pressure not subject to velocity limitations in high purity oxygen (nominal 99.7 %) where particle impingement may occur.
** Cast and wrought Mill Forms.
Note: This list does not include all possible exempt materials. Other materials may be added based on the results of testing as described in 4.2.1.

Appendix E: Table of Safety Distances (without barriers) for Oxygen Control and Isolating / Metering Stations

Nature of Exposure	Category 1 stations	Category 2 stations	Category 3 stations	Category 4 stations
Above ground pipeline (flammable fluid) without close proximity of mechanical joints (see 8.6).	15m	6m	2m	2m
Buried Tank (flammable fluid)	5m	2m	2m	2m
Pressure vessel, (non-flammable fluid) with P*V > 200 bar.m3 water capacity (P*V >100000 psi.ft^3)	5m	3m	3m	2m
Flammable product storage	8m	5m	2m	2m
Liquid hydrogen storage	15m	15m	15m	15m
Transformer station	15m	6m	3m	2m
Administrative Building with openings or air conditioning intake owned by customer	10m	8m	8m	2m
Public Building	15m	10m	10m	2m
Public road/railway/car park	15m	10m	6m	2m
Internal road/ railway	3m	3m	3m	2m
High tension electric cable (above ground)	10m	6m	5m	2m
Boundary of user's property	15m	10m	2m	2m
Internal car park	15m	6m	2m	2m
Flame and/or spark producing activities. For smoking restrictions see 8.6.	15m	8m	3m	2m

Notes:

1. Category 1 Stations: $P*D^2 > 3000$, P > 4 bars, D > 2.5 cm.
   Category 2 Stations: $P*D^2 < 3000 > 1500$, P > 4 bars, D > 2.5 cm.
   Category 3 Stations: $P*D^2 < 1500$, 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.

Appendix F: Example of Preventive Maintenance Program

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

a. Pipeline systems

Aerial Inspection 1)		**Checking interval**						
		1 Month	¼ Year	½ Year	1 Year	2 Year	3 Year	When required
	Underground pipelines		x					
	Overground pipelines		x					
On-foot inspection								
	Underground pipelines	x 2)			x			
	Overground pipelines	X 2)			X			
	Leak test R							x
	Inner pipeline inspection							X
	Effect of mining (subsidence)							X

1) Aerial inspections are used for long pipelines
2) If there are no aerial inspections

b. Slide valve shafts and stations

On-foot inspection		**Checking interval**						
		1 Month	¼ Year	½ 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. Anticorrosion systems

Checking		**Checking interval**						
		1 Month	¼ Year	½ 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			

d. Safety equipment in the production areas

Equipment checking for preventing								
Unacceptable pressures		**Checking interval**						
		1 Month	¼ Year	½ 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								
		1 Month	¼ Year	½ 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								
		1 Month	¼ Year	½ Year	1 Year	2 Year	3 Year	When required
	Restrict quantity of escaping gas		X					

e. Checking for station safety equipment

		Checking interval						
		1 Month	¼ Year	½ Year	1 Year	2 Year	3 Year	When required
	Safety shut-off valves, shut-off 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		**Checking interval**						
		1 Month	¼ Year	½ Year	1 Year	2 Year	3 Year	When required
	External medium-controlled slide valves				X			
	Manually operated valves				X			
	Display instruments					X		
Checking of electrical lightning protection earthing systems		**Checking interval**						
		1 Month	¼ Year	½ Year	1 Year	3 Year	5 Year	When required
	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	¼ Year	½ Year	1 Year	2 Year	3 Year	When required
	Detecting losses				X			

Appendix G: References and Bibliography

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1.1 G63 Standard Guide for Evaluating Materials for Oxygen Service
1.2 G72 Standard Test Method for Autogenous Ignition Temperature of Liquids and Solids in High -Pressure Oxygen-Enriched Environment
1.3 G74 Standard Test Method of Ignition Sensitivity of Materials to Gaseous Fluid Impact.
1.4 G86 Standard Test Method for Determining Ignition Sensitivity of Materials to Mechanical Impact in Pressurized Oxygen Environments.
1.5 G88 Standard Guide for Designing Systems for Oxygen Service.
1.6 G93 Standard Practice for Cleaning Methods for Material and Equipment Used in Oxygen-Enriched Environments.
1.7 G94 Standard Guide for Evaluating Metals for Oxygen Service.
1.8 G114 Standard practice for Aging Oxygen-Service Materials Prior to Flammability Testing.
1.9 G122 Standard Test Method to Evaluate the Effectiveness of Cleaning Agents
1.10 G124 Test Method for Determining the Combustion Behavior of Engineering Materials in Oxygen-Enriched Atmospheres.
1.11 G126 Standard Terminology Relating to the Compatibility and Sensitivity of Materials in Oxygen Enriched Atmospheres.
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1.13 G128 Standard Guide for the Control of Hazards and Risks in Oxygen Systems.
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3 European Industrial Gases Association /Asia Industrial Gases Association

3.1 IGC 4/00: Fire hazards of oxygen and oxygen enriched atmospheres
AIGA 004/04: Fire hazards of oxygen and oxygen enriched atmospheres

3.2 IGC 8/ 76: Prevention of accidents arising from enrichment or deficiency of the oxygen in the atmosphere

3.3 IGC 10/ 81: Reciprocating compressors for oxygen service

3.4 IGC 27/ 01: Centrifugal compressors for oxygen service

3.5 IGC 33/97: Cleaning of Equipment for Oxygen Service
AIGA 012/04 Cleaning of equipment for oxygen service

3.6 IGC 40/90: Work Permit Systems
AIGA 011/04 : Work Permit Systems

4 Compressed Gases Association

4.1 CGA G-4: Oxygen
4.2 CGA G-4.1: Cleaning equipment for oxygen service
4.3 CGA G-4.3: Commodity specification for oxygen
4.4 CGA G-4.6: Oxygen compressor installation and operation guide
4.5 CGA P-8: Safe practices guide for air separation plants
4.6 CGA TB-12: Design considerations for nonmetallic materials in high pressure oxygen supply systems
4.7 CGA 2000: Directory of Cleaning Agents for Oxygen Service
4.8 CGA G-10.1, Commodity Specification for Nitrogen

5 International and European Standards

5.1 EN ISO 11114-2 “Transportable Gas Cylinders - Compatibility of Cylinder and Valve Materials with Gas Contents – Part 2 : Non-metallic materials”.
5.2 En ISO 11114-3 “Transportable Gas Cylinders - Compatibility of Cylinder and Valve Materials with Gas Contents – Part 3 : Autogeneous Ignition Test in Oxygen Atmosphere
5.3 EN 1797-1 “Cryogenic Vessels – Gas Material Compatibility – Part 1: Oxygen Compatibility”
5.4 EN 12300 ”Cryogenic Vessels – Cleanliness for Oxygen Service”
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5.6 ISO 13847 “Petroleum and natural Gas Industries – Pipeline Transportation Systems – Welding of Pipelines”
5.7 BS IEC 61508 (EN 61508 in draft form): “Functional Safety of Electrical/ Electronic/Programmable Electronic Safety Related Systems”
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5.12 EN 13445 Unfired Pressure Vessel
5.13 EN 13480 Metallic Industrial Piping

6 National Standards and Requirements

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6.3 API SPEC 5L “Specification for Line Pipe”
6.4 ASME VIII “Boiler and Pressure Vessel Code”
6.5 API STD 1104 “Welding of Pipelines and Related Facilities”
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