DESIGN, MANUFACTURE, INSTALLATION, OPERATION, AND MAINTENANCE OF VALVES USED IN LIQUID OXYGEN AND COLD GASEOUS OXYGEN SYSTEMS

Doc 200/17

Revision of Doc 200/15

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As part of a programme of harmonization of industry standards, the European Industrial Gases Association (EIGA) has issued the publication *Design, manufacture, installation, operation, and maintenance of valves used in liquid oxygen and cold gaseous oxygen systems*. This has been jointly produced by members of the International Harmonization Council.

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

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2	Scope change to include customer station bulk storage tank systems
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5	Additional requirements added
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7.2.3	Clarification of customer station valves in customer station service
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Note: Technical changes from the previous edition are underlined

1 Introduction

This publication has been prepared by a group of experts in industrial gases technology or oxygen equipment representing oxygen manufacturers and is based on technical information and experience currently available.

The use of incompatible materials, unsuitable lubricants, improper cleaning and/or ingress of impurities, and procedural failures have been identified as root causes of a number of severe incidents that occurred over the past few years involving liquid oxygen valves with concentrations greater than 90 mol % of oxygen. This indicates the need for continual improvement in the fundamental knowledge of design, material selection, manufacturing, cleaning, installation, operation, maintenance processes, and storage related to valves in liquid oxygen service. This is necessary for liquid oxygen valve specifiers, suppliers, and manufacturers as well as those who clean, assemble, install, operate, and maintain these valves.

In order to avoid similar incidents with potentially fatal consequences, requirements for cold oxygen systems are outlined in this publication.

The information contained in this publication only applies to new installations designed after the publication of this document and not to existing installations. However, the information contained in this publication may benefit existing installations or those in the project phase. Furthermore, to the extent that they exist, national laws may supersede the practices included in this publication. It should be noted that all local regulations, tests, safety procedures, or methods are not included in this publication and that abnormal or unusual circumstances could warrant additional requirements.

The industrial gases industry has demonstrated that personnel who are involved in the design, selection, manufacturing, handling, cleaning, installation, and maintenance of valves in cold oxygen service require training in these respective areas.

2 Scope

This publication covers isolation valves, control valves, check valves, pressure relief valves, drain, and vent valves in air separation units (ASUs), their backup and storage piping system, and customer station bulk storage tank systems. It addresses the design, material selection, manufacturing, cleaning, installation, operation, and maintenance of oxygen service valves operating at temperatures less than –30 °C.

Valves in warm service connecting instrumentation devices are excluded from the scope of this publication. Some of the principles discussed in this publication may be used for other cold oxygen applications.

3 Definitions

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

3.1 Publication terminology

3.1.1 Shall

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

3.1.2 Should

Indicates that a procedure is recommended.

3.1.3 May

Indicates that the procedure is optional.

3.1.4 Will

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

3.1.5 Can

Indicates a possibility or ability.

3.2 Technical definitions

3.2.1 Burn resistant metals or metal alloys

Metals or metal alloys that, after being subjected to an ignition event, either will not burn or exhibit burn quenching behaviour, resulting in minimal consumption under specific process conditions that the metal experiences.

3.2.2 Cold oxygen

Liquid, supercritical fluid or cold gas with a temperature less than –30 °C and an oxygen concentration greater than 23.5 mol%.

3.2.3 Non-metallic material

Any material, other than metal, or any composite material in which the metal constituent is not the most easily ignited component and for which the individual constituent cannot be evaluated independently (see ASTM G63 *Standard Guide for Evaluating Nonmetallic Materials for Oxygen Service* [1]).[1]

3.2.4 Valve manufacturer

Organization that manufactures a valve assembly and is responsible for its design.

3.2.5 Valve specifier

Individual or organization that has responsibility for defining technical and/or procurement requirements for oxygen valves and their actuation systems, where applicable.

3.2.6 Valve supplier

Organization that supplies a complete oxygen valve. This can be a valve manufacturer or a third-party.

4 Oxygen properties, hazards, and hazard analysis and risk assessment

4.1 Oxygen properties

Oxygen, which is essential to life, is colourless, odourless, and tasteless. The normal concentration in air is approximately 21% by volume.

The presence of an oxygen-enriched atmosphere cannot be detected by human senses. Oxygen also does not produce any physiological effects that could alert personnel to the presence of oxygen enrichment. Increasing the oxygen concentration of the air at atmospheric pressure does not constitute a significant health hazard.

At atmospheric pressure, liquid oxygen boils at –183 °C and has a slight blue colour.

Oxygen is heavier than air. It can accumulate in low lying areas such as pits, trenches, and underground cavities or rooms. This is particularly relevant when there is a cold oxygen spill. In that case, the generated cold gaseous oxygen is three times heavier than air.

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

4.2 Oxygen hazards

Oxygen is not flammable but supports and accelerates combustion. Oxygen concentrations greater than 23.5% create fire hazards but not asphyxiation hazards. Flammable materials, including some materials that are normally relatively non-flammable in air, burn very rapidly in high oxygen concentrations. As concentrations increase greater than 23.5% oxygen, ease of ignition of clothing increases dramatically. Once ignited by even a relatively weak ignition source such as a spark or cigarette, clothing can burst into flames and burn rapidly. Greater than 40% oxygen, the fibres on clothing and body hair and oil are subject to flash fire when ignited, which spreads rapidly over the entire exposed surface.

Personnel should not be exposed to oxygen-enriched atmospheres because of the increased risk of fire. Areas where it is possible to have high oxygen content shall be well ventilated. Vents shall be piped outside of buildings or to a safe area. Where an oxygen-enriched atmosphere is possible, special precautions shall be taken such as installation of oxygen analysers with alarms, ensuring a minimum number of air changes per hour, implementing special entry procedures, or a combination of these procedures. Warning signs shall be posted at all entrances to alert personnel to the potential hazard of an oxygen-enriched atmosphere. For additional information on oxygen hazards, see EIGA Doc 04, *Fire Hazards of Oxygen and Oxygen Enriched Atmospheres* [2].

4.3 Oxygen hazard analysis and risk assessment

The three elements necessary for an oxygen valve fire to occur are an ignition source, oxygen, and a flammable material (fuel). Since oxygen is assumed to be present in all liquid oxygen or cold gaseous oxygen systems, it is important to have a clear understanding of any potential ignition sources and mechanisms present in the system as well as good knowledge of the flammability properties of the materials present in the valve.

A risk assessment and oxygen hazard analysis shall be carried out by personnel with knowledge and training in the field of oxygen compatibility and familiarity with relevant CGA, EIGA, American Society for Testing and Materials (ASTM), and other applicable standards. This assessment shall be done for a defined valve model. If this model is used again for the same process applications, the assessment does not need to be repeated unless the design has changed.

The risk assessment should consider that active ignition mechanisms can occur due to inadvertent causes (for example, failure to remove or prevent contamination) and can be different between steady state operation and transient conditions or process upsets, including those in which gaseous oxygen can be present.

An oxygen hazard analysis is a method used to evaluate the risk of fire in an oxygen system. It assesses the probability of ignition or consequence of ignition (ignition versus sustained burning based on operating conditions). It can be used to select materials for new designs or to evaluate the compatibility of materials in existing valves. In general, acceptance criteria for materials in a given application depend on two key factors, ignitability and flammability. Various processes for oxygen hazard analysis have been published over the years with different steps to assess the probability of ignition and sustained combustion.

The oxygen hazard analysis process includes the following steps as shown in Figure 1.

a) Assemble required information and resources:

- Application conditions (oxygen concentration, pressure, temperature, etc.) with particular attention to transient conditions (i.e., cooldown) and worst-case scenarios (for example, valve failure) of the oxygen system in which the valves are used;
- References of valves used in similar operating conditions (see 13.1.2);
- Assembly and component drawings, materials of construction, and flammability data for materials;
- Procedures used during manufacturing, cleaning, installation, operation, and maintenance; and
- Experienced personnel/team familiar with relevant industrial guidelines (CGA, EIGA, ASTM, and other applicable standards).

b) Evaluate the flammability of materials in application pressure and minimal cross sectional thickness.

c) Evaluate probability of ignition based upon contributing factors present:

  - Review potential for contamination;
  - Review type and location of non-metals;
  - Review type and location of metal trim and determine location of thin sections on trim and valve body/bonnet;
  - Assess and document location of potential ignition mechanisms (such as friction, mechanical impact) and possible kindling chain, particularly with respect to location of non-metals and thin metal sections; and
  - Consider operational history of existing valve models under known operating conditions for example, stainless steel valves in customer station applications.

d) Evaluate potential consequences of a fire on personnel, equipment, and operations.

e) Identify mitigation steps to reduce probability of ignition or eliminate or mitigate risk of ignition/kindling chain and hazards to personnel, equipment, and operation. These steps include:

  - Ensure the design and manufacturing process allows for cleaning of all components to the required specifications;
  - Avoid the use of lubricants where possible. Where lubricants are used, ensure they are compatible in oxygen service (see 6.4);
  - Eliminate or minimize mass of non-metal component(s);
  - Use non-metals with a higher auto ignition temperature (AIT), higher mechanical impact resistance, and lower heat of combustion;
  - Use burn-resistant alloys suitable for the operating conditions;
  - Design so metal components are at a thickness that is burn resistant and suitable for the operating conditions;
  - Design to protect non-metals by avoiding contact with direct flow;
  - Design to protect exposed non-metals by encapsulating in metal as much as possible;
  - Change operating parameters for transient/worst-case scenarios; or
  - Mitigate consequences by using barriers or isolating the component from personnel.

f) Document results of oxygen hazard analysis, including specific design drawings, bill of materials, cleaning documents and certifications, recommendations, resulting design and/or process changes, hazards identified, and mitigation steps.

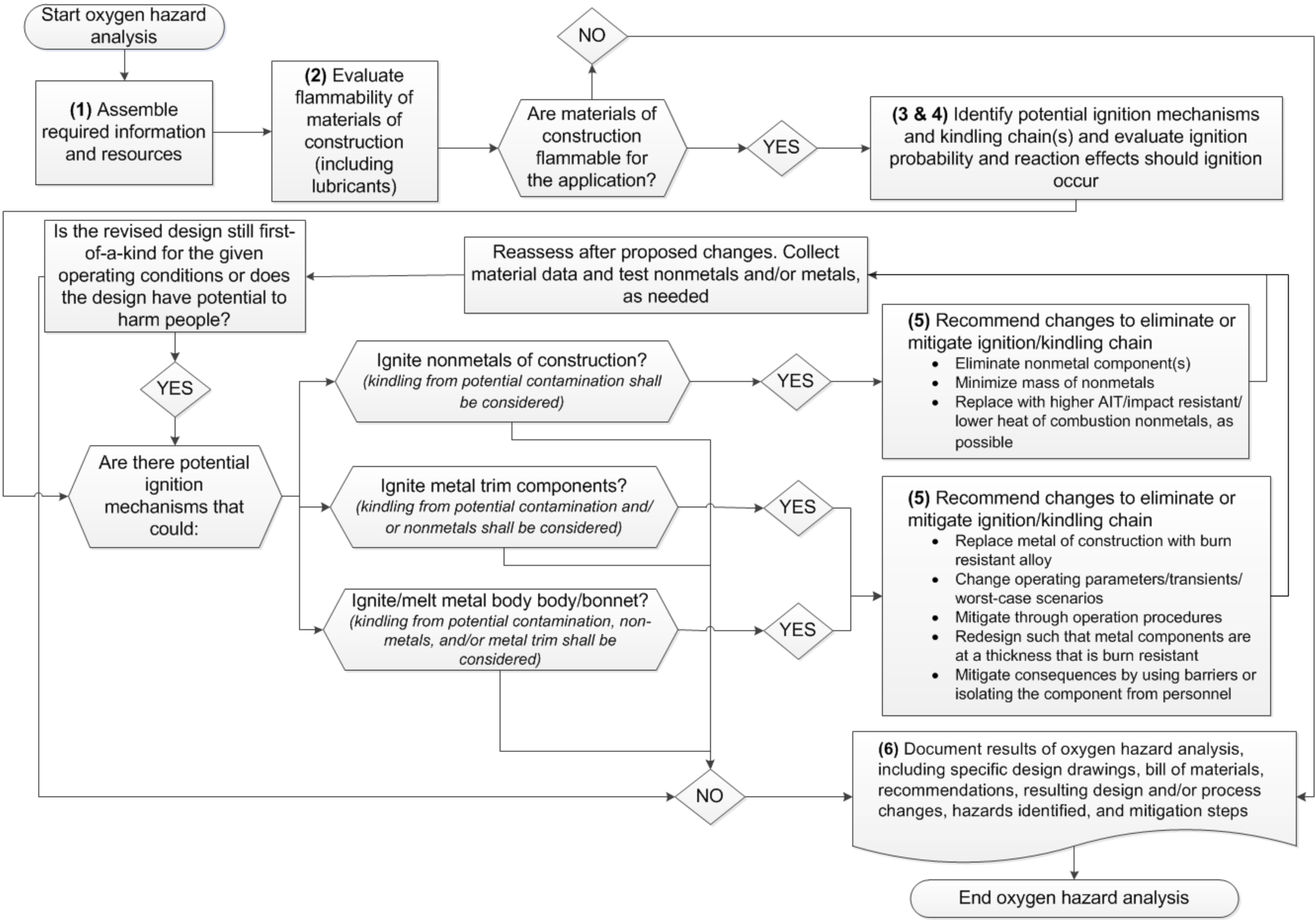

Figure 1—Flowchart showing an oxygen hazard analysis

5 Kindling chain, ignition mechanisms, and contributing factors

5.1 Kindling chain and ignition mechanisms

The most common ignition mechanisms (thermal energy sources) are the result of improper system or component cleaning, improper operation, or improper maintenance. System parameters such as oxygen concentration, pressure, gas velocity, and temperature are factors influencing ignition mechanisms and propensity for material ignition and combustion.

In a kindling chain, an easily ignitable material ignites (such as contamination in the system or a non-metallic component) and the energy released from this combustion ignites a more ignition resistant material, which in turn ignites an even more ignition resistant material (such as a metallic component). The kindling chain process is a function of each material's inherent minimum ignition energy requirement, heat of combustion, and heat transfer (thermal conductivity) characteristics. The combustion propagation rate of a material, once ignited, becomes a factor of its chemical composition and physical and mechanical properties including thickness and surface area to mass ratio. The kindling chain is minimized by ensuring the system is cleaned for oxygen requirements and that the metals and non-metals present have a low probability for ignition and combustion propagation, if ignited (see EIGA Doc 13, *Oxygen pipeline and piping systems*) [3]. Design features such as heat sinks and fire stops can also help mitigate ignition and combustion propagation via efficient heat transfer mechanism.

Figure 2 is a representation of a generic kindling chain showing successive ignition and combustion from what typically are the easiest to most difficult to ignite components in a valve. The energy gap shown can be defined as the difference in the maximum baseline thermal energy generated during operation and the thermal energy required to ignite the most flammable component or contaminant, if present. Also, shown in Figure 2 are example strategies and approaches for two risk mitigation methods that can be used in conjunction with one another. These are:

- Reduce the probability of ignition by eliminating ignition mechanisms where possible; and
- Increase the burn resistance of valve components in order to disrupt successive ignition/combustion (i.e., break the kindling chain) to both decrease the probability of metal combustion and impact severity of an event in a valve.

5.1.1 Kindling chain

Contamination is a common link in the kindling chain. Contamination sources include but are not limited to:

- dirt, debris, particles, hydrocarbons (hydrocarbon lubricants, machining oils, etc.), entering a valve during assembly or maintenance;
- residues such as cleaning agents, dirt, or debris remaining in a valve due to improper cleaning;
- lubricants or thread sealants that migrate into the oxygen wetted area from threads or from accessories such as actuators and gearboxes;
- contaminated compatible lubricant (metallic particles and hydrocarbons);
- metallic flakes and particles formed during assembly;
- particulates originating from breakdown of seals, valve friction, shearing metal pieces, cavitation, degradation of non-metallic components, and migration of impurities from gaskets, packing, and seat material;
- items accidentally dropped into the system by personnel; and
- environmental contamination from improper, unprotected storage.

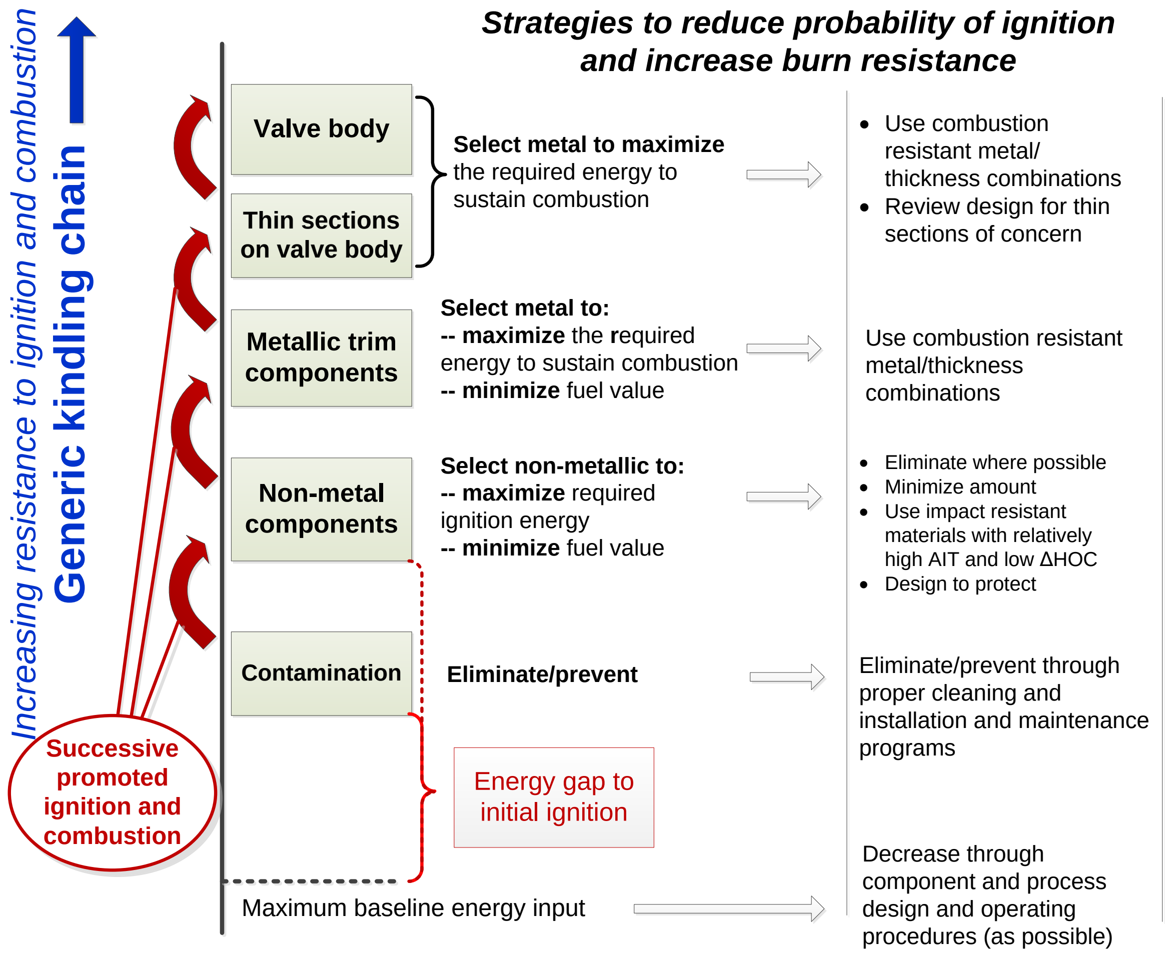

Figure 2—Generic kindling chain

5.1.2 Ignition mechanisms

The following are some common ignition mechanisms.

5.1.2.1 Frictional heating

Frictional heating can occur between stationary and moving parts, that is with relative motion, and can occur with both metallic and/or non-metallic materials. This can be due to poor design or when gaps or clearances become reduced during operation. This can also produce particles. Frictional heating is a consequence of surface finish, shape, ability to dissipate heat, size, and valve type. Frictional heating is one of the most active ignition mechanisms in cold oxygen systems and this grows as pipe diameters or pressures increase.

5.1.2.2 Particle impact

Particle impact is considered an unlikely ignition mechanism in liquid oxygen. Although some high pressure gaseous oxygen incidents have been attributed to particle impact, there are no known liquid oxygen incidents that have been attributed to particle impact. The main barriers to ignition by particle impact are low velocities in liquid oxygen and the low operating temperature. In addition, credit may be taken in systems where any particles in the liquid oxygen are removed. For example, by pump inlet filters leaving the pressurized cold oxygen systems particle-free. Therefore, particle impact is more of a hazard for cold gaseous oxygen.

During transient conditions, such as the cooling down or warming up of a cold oxygen system or during upset conditions, vaporized oxygen is present in the system. In this case, potentially flammable particulate contamination can ignite and kindle target metals by impingement at high gaseous oxygen velocities.

5.1.2.3 Mechanical impact

Heat is generated from the transfer of kinetic energy as a result of a single or repeated impact of non-metal or metal resulting from vibration, a quick closing valve, or a chattering check or relief valve. This mechanism was identified as the energy source for many liquid oxygen incidents including when two-phase conditions were present leading to the ignition of non-metallic materials used for valve seats or seals. Direct mechanical impact on bulk metal alone is not considered to be credible for ignition of most metals.

5.1.2.4 Dry boiling and pool boiling

By their nature, liquid oxygen systems face the additional risk of hydrocarbon accumulation wherever boiling of liquid oxygen occurs. However, this ignition mechanism is more related to process and system design and not directly related to cold oxygen valves.

5.1.2.5 Adiabatic compression

Heat is generated when a gas is rapidly compressed from low pressure to high pressure. Ignition by adiabatic compression is usually considered as non-active in liquid oxygen. It can be active in transient conditions such as the cooldown or warm-up sequence of a cold oxygen system. This can be sufficient to reach the AIT of non-metallic materials and organic contaminants directly exposed to the adiabatic compression and to ignite these materials. This ignition mechanism is more relevant with quick opening valves.

5.1.2.6 Electrical arcing

Electrical arcing from a power source with sufficient energy to ignite the material receiving the arc-lightning strikes and electrical surge of non-grounded system could cause ignition when it arcs to a metallic flammable material.

5.1.2.7 Static discharge

Ignition can occur when a static charge discharges with enough energy to ignite the material receiving the discharge or exposed to the discharge energy. Static discharge is more likely to occur in a dry environment, which is the case in cold oxygen systems.

5.2 Contributing factors

The following factors in combination with ignition mechanisms in 5.1 can influence the probability and/or severity of an incident:

- Personnel exposure in the immediate vicinity of a cold system when started, shut down, or in operation;
- Oxygen leak leading to upset conditions (for example, oxygen enrichment, dry boiling, and high velocity);
- Rapid vaporization/flashing, cavitation;
- Mechanical failure/rupture of a component of a valve;
- Excessive vibration resulting from incorrect internal valve clearances, improper assembly, or excessive piping loads;
- Contamination of any kind (that can be present or introduced into the system) due to inadequate cleaning, residual contamination from cleaning agents/cleaning process, contaminated soft goods and/or lubricants, post cleaning testing such as hydro testing, packaging, site assembly, and maintenance procedures;
- Mechanical stress due to sudden temperature changes;

- Deficiencies in surface quality of functional valve parts; or
- Not following operating or maintenance procedures.

6 Material selection

The information from the publications referred to in this section should be used to apply the burn resistant method as shown in Figure 2.

6.1 Selection of metallic materials

The metallic material shall be suitable for the mechanical service including resistance to cold embrittlement.

The ability to ignite and sustain combustion of metallic components in any given oxygen application is a function of several process and design related factors including, but not limited to:

- concentration, pressure, velocity, and temperature of the oxygen;
- component geometry and dimensions;
- ignitability and combustion characteristics of the metal itself;
- close proximity to non-metals (one possibility for the presence of an ignition mechanism and kindling chain from non-metal to metal); and
- ignition mechanisms likely to be present.

Metal properties and conditions affecting potential ignitability and flammability include:

- thermal conductivity;
- heat of combustion;
- mass and its geometry (thick versus thin);
- oxygen concentration and pressure;
- presence of gaseous versus liquid oxygen; and
- flow conditions before and after ignition.

Typical metallic materials for cold oxygen valve components, where ignition mechanisms are present, include:

- brass;
- bronze;[2]
- cobalt alloys;
- copper and copper alloys;
- copper nickel alloys;
- nickel and nickel alloys; and
- austenitic stainless steels.

Other base material alloys may be used for valve bodies in low purity or low pressure oxygen applications; however, specific knowledge and expertise are required for the use of other base material alloys.

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[2] Aluminium bronze is not typically used. See EIGA Doc 13 [3].

6.2 Metallic material ranking

ASTM G94, *Standard Guide for Evaluating Metals for Oxygen Service* provides guidance for selecting metallic materials for oxygen service [4]. Some of the data listed in ASTM G94 are based on ASTM G124, *Standard Test Method for Determining the Combustion Behavior of Metallic Materials in Oxygen-Enriched Atmospheres*, which provides a test method for comparing the flammability characteristics of metallic materials in gaseous oxygen [4, 5]. In this test, sample rods of a metal are intentionally ignited at a specific oxygen concentration, temperature, and pressure and then compared against burn/no-burn criteria. The test can also be used to show the relative flammability characteristics of a specific metal at different thicknesses.

However, the ASTM G124 test method does not provide criteria for relating the data to the suitability of a metal for use in any specific oxygen application (i.e., warm or cold oxygen), or design configuration [5]. The data does provide a useful basis for selecting metallic materials based on their relative flammability behaviour in gaseous oxygen, in the event any ignition mechanism becomes active.

NOTE—Based on the thermal energy required to raise a metal's temperature to its ignition temperature, the local environment around the ignition point is likely to become gaseous oxygen. If combustion occurs and continues, the burning region is also likely to remain in gaseous oxygen due to the combustion energy release rapidly vaporizing the surrounding liquid oxygen.

ASTM G124 data can provide some guidance in alloy selection from a combustion propagation standpoint based on test conditions in warm gaseous oxygen [5]. ASTM G124 test data should be carefully considered if used as a reference for metallic material evaluation for cold oxygen applications [5]. First and foremost, it is imperative that selection of suitable metallic materials for cold oxygen applications take into account the function of the valve and the mechanical properties required for valve components for the specific cryogenic application.

Operating in liquid oxygen service provides an additional safety margin against ignition due to cryogenic temperatures compared to cold gaseous oxygen service.

6.3 Selection of non-metallic materials

Non-metallic materials are widely used for bonnet gaskets, valve seats, seals, valve packing, and similar components of valves to reduce friction and to minimize gas or liquid leakage. Many non-metals are flammable in cold gaseous oxygen or in liquid oxygen even at low temperature and low pressure and concentrations greater than 23.5%. The main factors affecting their ignition and fire propagation are the pressure, temperature, and oxygen concentration.

In a kindling chain, the non-metallic component is often the link that promotes the ignition of the metallic material just adjacent and in intimate contact with it. Therefore, the heat of combustion of the non-metal component and its mass are important parameters to consider.

The suitability of any non-metallic material shall be evaluated for the full design temperature and pressure ranges.

Precautions shall be taken to avoid contamination during the manufacturing process of non-metallic materials. Contamination can be introduced from high pressure hydraulic systems or other machining processes. Changes in materials used during the manufacturing process shall be evaluated before use to ensure new hazards are not introduced.

The following steps shall be considered and confirmed by the valve manufacturer for valves containing non-metallic materials:

- Minimize the quantity of non-metals used;
- Evaluate possible ignition with kindling chain and take account of heat dissipation in the design by embedding the non-metallic part in an adequate mass of burn resistant metal (where necessary) that will act as a heat sink;

- Avoid locating non-metals directly in the gaseous or liquid oxygen stream, where possible; and
- Prevent excessive friction or mechanical impact of the non-metallic component.

There is no defined pressure threshold above which non-metallic components are no longer allowed. However, the greater the pressure is, the more caution is required for the use of non-metallic materials. Data for mechanical impact tests are only published for liquid oxygen at ambient pressure.

The consistency of composition of non-metallic components can vary especially for plastics, elastomers, and compound material.

The selection of non-metallic materials for valves requires two steps. First, verify the mechanical and chemical suitability, flexibility, etc., (other than oxygen compatibility) of selected non-metallic material based on design and operating conditions (including transient conditions). Second, determine the ignitability and burn resistance of the material in cold oxygen. This can include AIT, mechanical impact test in liquid oxygen, and minimum pressure leading to ignition by adiabatic compression if the non-metallic material can be exposed to adiabatic compression and energy released when burning (heat of combustion).

In practice, it is usual to consider a minimum AIT of 300 °C (572 °F) at a minimum test pressure of 103 bara (1500 psia) according to ASTM G72, *Standard Test Method for Autogenous Ignition Temperature of Liquids and Solids in a High-Pressure Oxygen-Enriched Environment* or at 120 bara according to EN 1797, *Cryogenic vessels. Gas/material compatibility* or ISO 21010, *Cryogenic vessels. Gas/material compatibility* [6, 7, 8].

For valves operating in liquid oxygen service, the non-metallic material shall pass a mechanical impact test in liquid oxygen. For more information concerning test methods and list of non-metallic materials, see ASTM G63, ASTM G72, EN 1797, ISO 21010 , M034-1, *List of nonmetallic materials by BAM Federal Institute for Materials Research and Testing,* ASTM G86, *Standard Test Method for Determining Ignition Sensitivity of Materials to Mechanical Impact in Ambient Liquid Oxygen and Pressurized Liquid and Gaseous Oxygen Environments*, and ASTM D2512, *Standard Test Method for Compatibility of Materials with Liquid Oxygen (Impact Sensitivity Threshold and Pass-Fail Techniques)* [1, 6, 7, 8, 9, 10, 11]. The test and appropriate test report shall be completed by a referenced laboratory[3] according to International Organization for Standardization (ISO), Federal Institute for Materials Research and Testing (BAM), or ASTM standards. Existing and valid test reports can be used if the type and origin of the non-metallic material have been verified. Special consideration shall be given if only the base material has been tested and not the final product configuration (for example, braided packing). Although a base material could have been successfully tested, it might not pass the test when fabricated into the final product configuration.

6.4 Specific requirements for lubricants and locking compounds

All valve components which are subjected to cold oxygen (i.e., wetted or in the flow path) shall be designed to function without lubrication between moving parts. Valve components that are exposed to oxygen (for example, seat, stem, and plug) should be designed for assembly and workshop testing without any lubrication being required. In specific cases where lubricants and locking compounds are required for assembly, their use and type shall be approved by the valve specifier and the amount shall be minimized. Removal of lubricants after assembling may not be possible. The type and location of lubricant and locking compounds used shall be indicated on the valve drawing.

Oil lubricants are very difficult to contain because of their low viscosity. They can migrate along the stem of a valve through valve packing, tight clearances, and through seals including valve stem extensions for cryogenic service. Lubricants and greases suitable for oxygen service are generally halogenated chlorotrifluoroethylene (CTFE) and perfluoropolyether (PFPE) fluids, which are thickened with silicon oxide or polytetrafluoroethylene (PTFE). Many oxygen-compatible lubricants are hydrophilic and provide no corrosion protection as compared to hydrocarbon-based lubricants. Experience and testing have demonstrated that oxygen compatible greases do not provide the same level of lubrication as hydrocarbon-based greases. Many failures have occurred due to corrosion caused by the atmospheric

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[3] Examples include CTE (Air Liquide Blanc-Mesnil, France), BAM (Berlin, Germany) and WHA International, Inc. (Las Cruces, NM, USA)

moisture. It should be noted that in cryogenic conditions lubricants are likely to freeze and cement valve parts together.

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

- AIT greater than or equal to 400 °C at the maximum operating pressure in gaseous oxygen or at 103 bara in case the maximum operating pressure is lower than 120 bar;
- The lubricants pass the mechanical impact test in liquid oxygen at ambient pressure, as determined by an acceptable test method (for example, by ASTM G86 or ASTM D2512 [10, 11]); and
- The lubricant passes a pneumatic impact test in gaseous oxygen at a test pressure of at least 50 bar greater than the maximum operating temperature, as determined by an acceptable test method (for example ASTM G74, *Standard Test Method for Ignition Sensitivity of Nonmetallic Materials and Components by Gaseous Fluid Impact* [12]).

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

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

Assessment of lubrication migration from the gearbox is especially important for valve design where part of the stem is exposed to the internal oxygen because of rising stem movement, for example, globe and gate valves. The motion of the stem during operation increases the risk of external contamination such as hydrocarbon greases to be transported through the packing of the valve over multiple operations (see 5.1.1, 7.2.4.3, and 7.2.4.4).

The risk of this type of migration shall be considered based on maximum environmental temperatures that could decrease the viscosity of the grease and increase the probability of migration along the valve stem.

7 Design philosophy

7.1 General system design

The safe design and operation of a cold oxygen system depends on various factors that can influence each other. This section describes the principal hazards associated with cold oxygen systems and the manner in which these hazards can be minimized by good design practices.

An oxygen hazard analysis of valves as described in 4.3 shall be followed for the given valve operating range and model. Results of such an analysis shall be documented and re-assessed if the operating range or valve model changes. This analysis can be reflected in company standards and procedures. All the design principles described assume sufficient cleanliness as described in Section 8.

The design of all parts shall allow for an approved cleaning process (see Section 8).

7.2 Valve design

7.2.1 General

Valves shall be manufactured in accordance with this publication and for the specified oxygen valve applications. Materials of construction and the physical design of the valve shall be selected considering all the normal, maximum, and upset operating conditions as well as startup and shutdown conditions to which the valve can be subjected.

The valve specifier shall provide specifications and perform a design review. The valve manufacturer shall make available the design documentation (for example, drawings, bill of materials, material test reports, etc.) to accomplish the review. Components within the flow stream shall meet the following requirements.

If the valve has an integral metallic seat, any hard-facing coatings shall be in accordance with 7.2.5. All parts of the valve shall be designed to allow disassembly for oxygen cleaning.

Anti-static features to limit static electricity accumulation as well as electrical continuity through the valve shall be integrated into the design.

The valve should be designed with stem extension, where necessary, so the gland packing remains at ambient temperature while in operation to prevent oxygen leakage. To allow for good insulation, the radial clearance between valve stem and extension tube shall be minimized.

The assembly of the valve stem into the bonnet and bonnet extension can scratch the surface finish of the valve stem. Scratches on the valve stem can influence sealing ability and can increase the risk of contaminant migration, especially for rising stems, for example, gate and globe valves. The internal shoulders of the bonnet, bonnet extension, packing gland, etc., shall avoid sharp edges and be deburred to reduce the risk of stem scratching.

Testing (for example, long term cycle testing, leak testing, etc.) may be specified for new valves/designs that have not been previously qualified in liquid cryogenic service. Test procedures shall be agreed upon between the specifier and the manufacturer.

Where used, stem bearings (radial/axial) that are exposed to the flow stream or wetted shall meet the mechanical wear resistance requirements of the valve design to reduce ignition potential caused by mechanical overstressing or friction from parts physically rubbing or galling.

Internal metallic components can contribute to kindling and act as a fuel; so, specific characteristics such as burn resistance and heat of combustion of the metallic materials are key factors. There are two basic approaches that can be used in tandem to help reduce the risk of an ignition/combustion event inside a valve.

- Minimize the energy available to promote and kindle non-metal-to-metal and direct metal ignition combustion. This includes cleaning, minimal use of non-metals, minimal use of thin components, parts using best evaluated non-metallic materials in terms of oxygen index, AIT, heat of combustion, electrical continuity, internal metallic components selection regarding minimum thickness, and avoiding thin sections on pressure containing parts; or
- Maximize the energy threshold needed for ignition combustion of internal metallic components and pressure containing parts (valve body). In practice, this involves the use of metallic components whose chemistry and geometry (surface area to mass) are considered burn resistant for specific service conditions (oxygen concentration, pressure, and temperature).

Work processes are needed for each of the following:

- material specification and design features for non-metallic components, internal metallic components, and valve body; and
- oxygen cleanliness during manufacturing, assembly, transportation, installation, and maintenance.

7.2.2 Isolation valves

Isolation valves are designed to operate in either the fully closed or the fully open position but never in a throttling mode. Customer station isolation valves are typically used in throttling service (see 7.2.3). If the operating pressure is greater than 3 bar, they shall only be operated with a differential pressure of less than or equal to 0.3 bar unless designed for throttling service or an oxygen hazard analysis and risk assessment is carried out.

In cold oxygen service, particularly during system cooldown and startup, isolation valves opened with a high differential pressure across the seat can experience:

- high velocity and turbulence through the valve during its opening, possibly resulting in cavitation or two phase condition;

- frictional heating and/or mechanical impact of internal components due to severe vibration; or
- rapid downstream pressurization and possible temperature rise due to adiabatic compression.

These hazards can be minimized by the use of:

- A bypass system (see 7.2.3.1); or
- Specific operating procedure to equalize pressure across the isolation valve before it is opened as well as for the system cooldown; or
- An isolation valve that is designed using the criteria for throttling valves.

Valve tightness is applicable in one direction only. The installation direction should be indicated on the valve body, process and instrument diagrams (P&ID), and/or piping assembly drawings. The leak tightness of the valve shall be type tested at cryogenic temperatures.

7.2.3 Throttling valves

Valves that operate at differential pressures and can be operated in all positions between fully closed and fully open are regarded as throttling valves. In general, valves used on customer station tanks and similar liquid storage tanks are called isolation valves but are designed for throttling service. Throttling valves shall follow the burn resistance method for material selection (Section 6) as these can be subject to high differential pressures and high velocities resulting in a higher risk potential for ignition.

Throttling valves can be automated or manually operated and include those used for pressure control, flow control, and bypass valves. These normally include globe, eccentric plug butterfly, ball valves, and regulators.

Throttling valves do not require a bypass system for pressure equalization.

Other examples of throttling valves include vent valves, bleed valves, pressure relief valves, drain valves, and other valves operated under high differential pressures.

7.2.3.1 Bypass systems for pressure equalization

For cold oxygen systems operating at pressures greater than 3 bar, a bypass system shall be installed for each isolation valve unless the isolation valve is designed for throttling service or operating procedures can be used to equalize pressure (within 0.3 bar) across the isolation valve before opening. A bypass system is normally piped from immediately upstream to immediately downstream of an isolation valve. A bypass system is used to slowly pressurize upstream or downstream piping system to mitigate risks associated with the excessive mechanical loading on the isolation valve, high fluid velocity and rapid pressurization.

A bypass system shall be designed according to the following criteria:

- Throttling valve (for example, a globe valve is used as bypass valve to achieve controlled pressurization);
- Bypass valve is sized to allow pressure equalisation within an acceptable time period;
- Bypass line is connected into the main pipe at or higher than the centreline;
- Bypass valve is installed at a high point to avoid dry boiling (see Figure 3); and
- Bypass line materials of construction are burn resistant or selected based on an oxygen hazard analysis and risk assessment.

In addition, the bypass system should be designed so that vibrations are minimised as flow induced vibration can be a source of ignition.

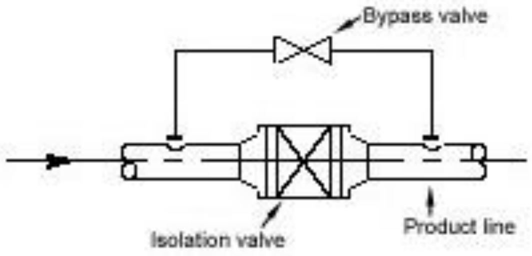

Figure 3—Example for a bypass system

7.2.3.2 Emergency shutoff valves

Emergency shutoff valves are usually automated, operate in the fully open position, and are normally closed only in the event of an emergency. The valve can experience momentary high velocities, high mechanical load, and turbulence during closing. Emergency shutoff valves shall be treated as throttling valves and are normally of butterfly, globe, or ball type.

7.2.3.3 Vent and drain valves

Vent and drain valves can experience high velocity and impingement and are usually treated as throttling valves. Because these valves can operate in warm gaseous oxygen or cold oxygen, an oxygen hazard analysis and risk assessment shall be performed to determine if the valves should follow this publication's material selection method or be designed as part of a warm gaseous oxygen system (see EIGA Doc 13 [3]).

7.2.4 Valve types

7.2.4.1 Ball valves

When fully open, ball valves operate with the ball out of the flow stream. When this valve is partly open, thin edges of the ball are exposed to the flow stream. See Figures 1 and 2 for material selection.

Ball valves are inherently quick opening, which leads to concerns about adiabatic compression and temperature rise, especially for any elastomers downstream in the piping system. Ball valves may be equipped with gear operators to ensure slow opening. Ball surfaces should not be plated as the plating can scrape off and create an ignition source. Welded overlays or coatings should be used instead of plating. Overlay or coating of ball surfaces shall comply with 7.2.5. In addition, ball valves shall be designed with internal pressure relieving features to avoid pressure build up from liquid or cold gaseous oxygen trapped in the ball cavity. Bidirectional isolation design shall not be specified since it compromises the internal pressure relieving feature.

7.2.4.2 Butterfly valves

When open, butterfly valves operate with the valve disk in the flow stream.

In case of reverse flow, the seat groove can become a thin part in the flow stream area and needs to follow the described burn resistance method. See Figure 2 for selection and design of internal metallic parts.

The shaft to bonnet or shaft to body bearing/bushing should be a metallic design and shall be designed to meet the mechanical requirements at maximum pressure differential across the valve disk.

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

7.2.4.3 Gate valves

Gate valves shall not be used as throttling valves for cold oxygen applications. In a limited pressure and size range typically found on customer station tanks, gate valves have been successfully used in throttling service and may be used provided they meet the requirements in 7.2.3. An internal pressure relieving feature shall be provided if necessary to avoid pressure buildup from liquid trapped between the wedge and the body.

Pressure equalization shall be established between the inlet and outlet of a process gate valve prior to opening.

The shaft to bonnet bearing/bushing should be a metallic design and shall be designed to meet the mechanical requirements at maximum pressure differential across the valve wedge.

Gate valves shall be metallic seated with a soft or metallic seal according to application and tightness requirements. The integral metal seat and seal material (if any) shall meet the specific metallic material selection criteria.

Gate valves designed with part of the stem wetted by oxygen when closed and exposed to the external environment when open, should be reviewed for risk of external contaminant migration through the stem seals (for example, packing).

7.2.4.4 Globe valves

Globe valves are commonly used in cold oxygen on-off (open-closed) or throttling applications and can be manual or automated. The trim design varies with specific valve manufacturers but it can have a relatively thin section fitted with non-metallic inserts to minimize leakage. Sometimes, for high differential pressures, cage trims are used that are usually of thin section and provide sites for debris to be trapped and create friction. In this case, the trim of the globe valve shall be designed for a higher burn resistance.

Globe valves designed with part of the stem wetted by oxygen when closed and exposed to the external environment when open, should be reviewed for risk of external contaminant migration through the stem seals (for example, packing).

7.2.4.5 Pressure relief valves

Pressure relief valves in cold oxygen service will experience warm gaseous relief during initial opening and high velocities 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. Specific metallic material selection as described in Section 6 can be used for both nozzle and poppet trim, which are considered impingement sites unless other mitigating measures are in place. Ignition can also occur due to mechanical issues such as chattering.

If particles are present, there will be impingement on the exhaust part of the housing and outlet piping. When performing an oxygen hazard analysis and risk assessment on pressure relief valves, the potential for contamination, plugging, or backpressure of the exhaust vent shall be considered under all expected operating conditions.

For pilot operated pressure relief valves, the pilot valve is exposed to oxygen and shall be designed accordingly.

7.2.4.6 Check valves

Check valves contain components that are always in the flow stream and can be subjected to mechanical impact. The material selection of the disk, plate, piston, hinge, or spring of a check valve shall be evaluated according to the material selection process in Section 6. The components of check valves are designed to impact with each other and shall be considered as potential sources of ignition energy.

The internals of the valve should avoid using small components. Check valves should be sized, selected, and installed to minimize chatter.

7.2.5 Hard facings and burn resistant coatings

Facings such as welded overlay with hardening and/or burn resistant metallic material coating are acceptable.

The material of welded overlay, metallic coating, and the final metallurgical bonding shall meet the expected operating conditions. The factors to be considered include the thickness and burn resistance of a coating, plating, or welded overlay, and its adherence to the substrate. In the case of coatings and platings, the hazard is disintegration and particle generation that can result in contamination of the oxygen flow stream and/or reduced burn resistance. Overlay welding and/or metallic coating shall be agreed upon between the valve manufacturer and valve specifier.

7.2.6 Actuators and gearboxes

The valve manufacturer shall specify the type and location of the lubricant used for external equipment requiring lubrication such as gear operator or hand lever. The actuators and gearbox shall be designed to prevent lubricant leakage and subsequent migration to the process. For example, this can be done by providing a sealed gearbox and a distance piece open to the atmosphere. If the stem is mounted vertically or at an angle towards the valve, ensure that a device such as a deflector plate is used to prevent leakage down the stem into the packing area.

In rare cases, oxygen can be used as an instrument gas supply. These systems have specific design requirements due to the presence of oxygen. The instrumentation materials such as volume booster or quick exhaust and actuator materials shall follow the oxygen material selection guide lines defined by EIGA Doc 13 [3].

8 Valve cleaning for oxygen service

In addition to good design and material selection for the valves used in cold oxygen service, organic and inorganic contaminants including oils, greases, thread lubricants, fibres, rust, dirt, filings, and other foreign material shall be removed from the valves and the associated piping. This is in order to reduce risks of ignition and combustion propagation. See CGA G-4.1, *Cleaning Equipment for Oxygen Service* and EIGA Doc 33, *Cleaning of equipment for oxygen service* for guidance on oxygen service cleaning [13, 14].

8.1 Valve cleaning strategy

Valves shall either be specified or purchased cleaned for oxygen service, or cleaned before use applying a process approved by the valve specifier. When specified and purchased as cleaned for oxygen service, this requirement shall appear on all purchase orders for the valves. The manufacturer's or third-party vendor's cleaning procedure, cleaning agent specified, and the quality control procedure shall be reviewed and accepted by the valve specifier. The valve specifier shall ensure initial and periodic inspections and audits of the manufacturer's/third-party vendor's facilities including the cleaning and quality control procedures. The cleaning process shall be qualified for each valve type.

The cleaning strategy is an essential part of valve manufacturer qualification (see 13.1.2).

The geometry of the valves to be cleaned shall be considered while selecting a cleaning method so that cleaning, rinsing, purging, and drying can be planned to ensure that all surfaces are cleaned and any cleaning agent residue is completely removed. The valve manufacturing and machining processes shall be so the required cleanliness can be achieved. Machining chips, burrs, etc. shall be eliminated. In addition to cleaning the normally oxygen wetted surfaces of a valve, other areas of the valve that could come into contact with oxygen in case of damage to the valve internals shall also be cleaned for oxygen service. As it is often difficult to ensure adequate cleaning of inaccessible areas of the valves, individual valve components shall be cleaned before assembly. Care shall be taken to ensure valve parts are not contaminated during assembly.

The use of solvents as cleaning agents is an alternative to aqueous cleaning agents. Some solvents are incompatible with non-metallic parts of the valve such as the valve seat. Some solvents can be absorbed by the non-metallic materials and render a compatible material non-compatible and create a flammability hazard. Properties of the non-metallic parts can also change leading to problems such as valve leaks. These shall be considered when selecting the solvent.

Once cleaning is completed, all cleaning agent residues shall be removed.

If the valves need to be cleaned in the field, for example after maintenance, the valves shall be cleaned by trained and qualified personnel. Contractors cleaning valves shall be qualified by the valve specifier for oxygen cleaning. Care shall be taken on those parts of the valves with hidden cavities or areas inaccessible for inspection. Precautions described in this section shall be followed during field cleaning of the valves.

All cleaning inspection and assembly activities until packing, including activities in the field, shall take place in a designated area for clean work.

8.2 Cleanliness inspection

Regardless of the cleaning method used, inspection to verify and document cleanliness is required. Cleaned parts and/or valves shall be inspected by qualified personnel. Failure to pass inspection requires recleaning and re-inspection. It should be noted that some contaminants do not fluoresce under ultraviolet light and cannot be detected during inspection using ultraviolet light. See CGA G-4.1 and EIGA Doc 33 for guidance on inspection procedures [13, 14].

Recleaning activities usually require the disassembly of the valve and can require a return to the manufacturer.

8.3 Standard of cleanliness

A valve is considered to be clean for oxygen service when organic, inorganic, and particulate contamination have been removed to the level specified. See CGA G-4.1, EIGA Doc 33, ISO 23208, *Cryogenic vessels—Cleanliness for cryogenic service*, and ASTM G93, *Standard practice for cleaning methods and cleanliness levels for material and equipment used in oxygen-enriched environments*, for guidance on threshold detection limits and cleanliness acceptance criteria [13, 14, 15, 16].

8.4 Packaging, storage, and handling

Once a valve or part has been cleaned and inspected, it shall either be used immediately or packaged and labelled to prevent recontamination during storage, transportation, and prior to installation and commissioning.

Care shall be taken to ensure that cleaned parts are not recontaminated during assembly or packaging once they have passed inspection. Tools used for assembly or installation shall be cleaned to prevent them from contaminating the parts. If there is any question regarding cleanliness, inspection of the valve is required and cleaning carried out, if necessary.

Parts and/or valves that are not immediately used after cleaning and inspection shall be sealed in new, clean plastic bags or appropriate containers. Individual pieces should be packed in separate bags. Precautions to be taken include:

- New plastic sheeting may be used on valves in place of separate bags, as necessary;
- Protective covering shall not leave a residue;
- Openings on valves shall be sealed with clean caps, plugs, or blind flanges;
- Small valves, parts, gaskets, fittings, etc., shall be packed or bagged in plastic bags and sealed for protection from contamination;
- Do not use any adhesives on oxygen valves. The adhesive in waterproof cloth (duct tape) is not oxygen compatible and is difficult to remove; and
- All protective caps, plugs, blinds, and other packaging shall be kept in place until final assembly or installation.

Packaged parts cleaned for oxygen service shall be labelled as “CLEANED FOR OXYGEN SERVICE” and should indicate the number of desiccant bags, if any, that have been put inside the packaging. The number of desiccant bags indicated on the label shall be removed before installation of the valve or part.

Valves or parts in damaged or opened packages or having illegible labels shall be re-inspected and recleaned if necessary.

Oxygen service cleaned valves and parts shall be stored in an area designated for oxygen service cleaned parts. These shall be segregated from valves and parts that have not been cleaned for oxygen service.

8.5 Records

Records of oxygen service cleaning inspections shall be made available to the valve specifier by the valve manufacturer or the third-party cleaning vendor. When a valve is cleaned in the field, the contractor responsible for the cleaning shall prepare and submit records to the owner. When cleaned by qualified owner personnel, they shall follow internal company policy and procedures. See CGA G-4.1 and EIGA Doc 33 for guidance on record keeping [13, 14].

Cleanliness inspection records shall be part of the plant documentation.

9 Site installation

Cold oxygen piping and piping components shall be cleaned for oxygen service before installation and cleanliness shall be maintained thereafter. If any contamination occurs during installation, recleaning and inspection are required. Care shall be taken that all traces of the cleaning agent have been removed from the system as the cleaning agent could have accumulated at low points and dead ends. Piping system installation shall be carried out by contractors approved in their particular discipline (for example, mechanical, civil, instrumentation) in accordance with the design drawings and specifications. Procedures in accordance with the work instructions of the manufacturer shall be made available to technicians and supervisors.

Valves cleaned for oxygen service shall be installed in the clean piping system. Blowing out of the system can occur after the valves are installed. The geometry of the valves shall be reviewed to ensure that particles remaining in the piping cannot accumulate in cavities inside the valve during the blowing operation. For example, valves with cages can trap the particles being blown out. Such valves should be installed only after completing the blowing operation or recleaned after completing the blowing operation. Alternatively, valve internal components can be removed during the blowing operation provided oxygen cleanliness is maintained and verified before their re-installation.

Valves shall be installed in the correct direction. Directional arrow markings are typically present on the valve body or stem. It is not always obvious to the valve installer(s) whether the arrow indicates the direction of normal flow or the direction of pressure against which the valve shall seal when in the closed position. This can be opposite of the normal flow direction. The directional arrows shall be interpreted by the construction supervisor(s) (for example, from piping isometrics or P&ID). This information shall be provided to the installer(s).

Liquid oxygen valves shall be installed with the stem having at least a minimum slope of 15º upwards from the horizontal orientation with the valve body at the lowest point. The valves shall not be installed with the stem in the horizontal orientation to prevent accumulation of hydrocarbons in the valve due to dry boiling of liquid oxygen. Trycock valves may be regarded as gas valves.

The following shall be considered for site installation of valves:

- Ensure that the specified valve has been delivered by checking purchasing documents;
- Check that the packaging is intact;
- Segregate oxygen equipment and maintain packaging integrity during storage;

- Supervised handling of the valves is only by personnel trained for oxygen equipment installation to avoid issues such as early unpacking, recontamination by greasy fingers, dust, mechanical damage during installation, etc.;
- Before installation, qualified personnel shall inspect the valves at both the inlet and outlet ends and at all accessible points to verify the cleanliness of the oxygen wetted surfaces;
- Correct torque and bolting protocols for all bolting of valves, piping, and accessories;
- Gaskets - cleanliness, storage, types for different pressure applications;
- As preparation for welding or brazing, heat sensitive parts such as soft seats or bonnet assembly should be removed when close to the heat source;
- Quality check procedure for correct reassembly, especially alignment of gearbox or actuator;
- Process of site construction/site machining—cleanliness and all standards are kept;
- Cleaning before commissioning—blowing out procedures, avoid contamination from the piping system; and
- Small valves are sometimes fitted to the process line using a threaded connection. It shall be confirmed that the thread sealant material is compatible for oxygen service at the operating temperature range and at the maximum service pressure. Minimal amounts of thread sealant shall be applied to prevent extrusion of the sealing material into the process. For acceptable thread sealant materials, see 11.3.5.

10 Operations

10.1 Personnel

In addition to being trained in work safety knowledge, personnel who operate and maintain oxygen systems shall also have specific training and understanding of oxygen safety requirements (see Section 12).

All the relevant operating and safety procedures shall be available to operations personnel. Subcontractor’s personnel shall be informed about, and have access to all the relevant safety information.

Operations personnel shall work with clean hands and work clothing (uncontaminated by oil, grease, or dirt). Items contaminated when used for other services such as automotive maintenance or fuelling shall not be used in oxygen service (for example, clothing and gloves).

10.2 Isolation, drain, and vent valves

Operational personnel shall receive instructions about the use of isolation, drain, and vent valves to prevent inappropriate use.

Isolation, drain, or vent valves that are not designed to be opened with high differential pressures in oxygen service that could be opened by mistake shall be labelled with a warning sign prohibiting opening under high pressure. A lockout/tagout (LOTO) process should be in place for these valves.

10.3 Pressure relief valves

An operating procedure shall be in place that gives guidance to the operator should they observe the following phenomena of pressure relief valves in liquid oxygen systems:

- chattering/vibration;
- icing up; and
- leakage.

10.4 Pressurizing piping systems

Operating procedures shall define how to pressurize piping systems to avoid excessive mechanical loading or unacceptable temperature increase due to adiabatic compression (see Section 5). Provisions shall be made for determining the pressure difference across isolation valves regardless whether locally or remotely controlled.

10.5 Valve leaks

An operator site walk should include checks for any leaking valves. See Section 11 for safety precautions to be taken when dealing with leaks.

External leaks from liquid oxygen valves (seals or outlet piping) should be stopped as soon as possible to prevent damage to the surrounding equipment and surfaces by cryogenic fluids and possible oxygen-enrichment hazards in the immediate surroundings.

An internally leaking (passing) valve can also result in hydrocarbon accumulation due to continuous dry boiling within the valve or piping. This accumulation can lead to violent energy release and corrective action should be undertaken to resolve this situation (see Section 5). This also applies to a non-leaking dead end liquid oxygen valve that has lost its gas seal which normally results in icing up of the dead end valve. Periodic purging is required to prevent hydrocarbon accumulation.

Liquid oxygen leaking at the packing of valves is a common cause of ice buildup that should be avoided on valves in cryogenic service because it can impede valve operation and can stop the valve from fully opening or closing. A liquid oxygen leak at the packing of a valve can lead to oxygen enrichment in the environment.

Maintenance may be required for oxygen valves when there is:

- evidence of process media leaking through the packing and/or bonnet gasket;
- evidence of lubricants leaking from the gearbox or actuator along the shaft (packing); and/or
- icing up of valves due to passing through the seat or leaking through packing or gasket.

10.6 Shutdown and startup of piping systems

Written procedures are required for shutdown, startup, and maintenance of piping systems. The personnel involved in this work, including contractors, shall be informed of the specific risks related to oxygen and the tasks to be performed.

Authorization by a responsible person shall be given:

- prior to starting maintenance work and after shutoff procedures are completed; and
- prior to repressurizing, cooling down the pipe, when maintenance work is completed, and cleanliness for oxygen service has been verified.

No repair work shall be carried out on equipment and plant until a permit to work has been authorized. See EIGA Doc 40, *Work permit systems* [17].

11 Maintenance

11.1 General considerations

Personnel who operate and maintain oxygen systems shall be trained and understand oxygen safety requirements (see Section 12). They shall be familiar with the hazards and safeguards of the system they are maintaining. The valve manufacturer’s and/or owner’s maintenance procedures shall be available to maintenance personnel. Contractor personnel shall be informed about and have access to all the relevant safety information.

Maintenance personnel shall work with clean hands and work clothing (uncontaminated by oil, grease, or dirt). Items contaminated when used for other services such as automotive maintenance or fuelling shall not be used in oxygen service (for example, clothing and gloves).

When working on oxygen wetted surfaces, only clean hands or gloves that are free of lint, fibers, powder, and uncontaminated by oil or grease are allowed.

Before performing work on oxygen systems, a safety work permit should be issued or an equivalent safety procedure in place. Guidance on work permit systems can be found in publications such as EIGA Doc 40 [17].

Examples of precautions to be taken include:

- Open flames shall be prohibited in the safety zone;
- Hot work shall only be performed under written work permission;
- Ensure that all traces of oil and grease are removed;
- Cap open pipe ends when not working on the pipe; and
- Grounding of any equipment such as welding equipment onto oxygen piping systems while in operation (oxygen under pressure) is not permitted.

11.1.1 Equipment isolation

LOTO procedures shall be used with positive isolation as necessary when maintenance is undertaken on the oxygen system itself.

11.1.2 Management of change

A management of change (MOC) process shall be followed for any changes made, other than replacement in kind, to the piping system, gaskets, control system, valve internal parts, etc. See EIGA Doc 51, *Management of change* for guidance [18].

A MOC process shall also be followed for any changes in inspection, maintenance, or cleaning procedures.

11.1.3 Work on oxygen systems, handling leakage

The decision to repair any leakage while the system is in operation shall be based on a risk assessment. If the leak is liquid, a cryogenic hazard is present, and this shall be included in the risk assessment. Leakage most commonly occurs at flanges and valve glands. These may be addressed as follows:

- Flanges—If flange bolts are not excessively frosted, it is possible to manually retorque bolts (see 11.3.4 on cold torqueing). Only use hand tools; and
- Valve glands—If gland nuts can be safely accessed, tightening of the valve gland is possible.

Exposing personnel to an oxygen-rich atmosphere that will saturate their clothing and hair with oxygen can present a hazard if there is any source of ignition. Any person that is inadvertently exposed, or who considers that it is possible that some oxygen could have migrated into clothing or hair, should leave the area and avoid all sources of ignition until the oxygen dissipates (see EIGA Doc 04) [2].

11.1.4 Protecting open systems when valves have been removed

Open pipes or ports shall be protected with oxygen cleaned plugs, caps, or blinds. These should be controlled as listed items on a register so that they can all be accounted for when work is complete.

Rags and adhesive tape shall not be used inside pipework or on flange faces. Protected piping should have a dry oil-free nitrogen or air purge applied to ensure that debris cannot enter the piping and to prevent condensation. Care shall be taken when using purges in closed areas or in confined spaces such as valve boxes and coldboxes. Assume that purge gas will enter that space and label and barrier it accordingly against inadvertent entry by personnel. Asphyxiation hazards shall be managed by an appropriate work permit process (see EIGA Doc 44 *Hazards of inert gases and oxygen depletion* and CGA SB-2 *Oxygen-Deficient Atmospheres)* [19, 20].

11.1.5 Tools and workshop facilities

All tools used on oxygen valves shall be clean and free of grease.

A separate clean area shall be allocated for servicing oxygen equipment. Machining, welding, or other maintenance work not requiring oxygen cleanliness shall not be carried out in this area while maintenance is being carried out on oxygen equipment. Benches, tools, and vices used in this clean area shall be cleaned and hydrocarbon-free. Care should be taken when using lifting tools that could have been contaminated when used for other activities. Work surfaces should be covered with clean, lint-free cloth. The area is also likely to include a variety of equipment for oxygen cleaning, including solvent or detergent baths. These shall have appropriate fume extraction equipment.

If a functional or tightness test is needed, it shall be carried out using clean, dry, and oil-free air or nitrogen.

Clean clothing shall be worn when performing work on oxygen systems.

For further details, see CGA G-4.1 and EIGA Doc 33 [13, 14].

11.1.6 Quality control

Work shall be performed in accordance with approved work procedures or quality plan. If such procedures or plans are not available, prior to the start of maintenance the company or contractor shall submit a quality plan with hold and witness inspection points for approval by a qualified person. As a minimum, the quality plan shall cover the following points:

- Confirmation that all replacement parts meet the oxygen valve specifications;
- Confirmation that all parts are free of burrs, sharp edges, mechanical damage;
- Inspection for oxygen cleanliness (see 8.2); and
- Inspection and acceptance records shall be kept for the cleaned equipment (including piping) or assembly.

For further details of cleanliness inspection, see CGA G-4.1 and EIGA Doc 33 [13, 14].

11.2 Maintenance of valves

Repair procedures shall be available. Repair workshops shall be assessed and have their facilities qualified based on their ability to perform oxygen work and technician skills and knowledge.

Depending on size and time constraints, valves may be replaced rather than repaired.

11.3 Assembly and installation

11.3.1 Ensuring correct direction for valve re-installation

The direction arrow on a valve should always be noted upon removal. It is essential to re-install the valve in the same orientation.

11.3.2 Alignment

Before bolting up the valve, 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.

Overstress in the valve body shall be avoided as it can cause leaking or friction and can lead to a potentially hazardous situation.

11.3.3 Gaskets

Gaskets shall be installed in accordance with the design drawings. The use of gasket types or materials other than those defined in the project specification shall be prohibited unless approved by a person competent to assess the oxygen compatibility of the proposed material for the service conditions. Changes to the gasket specification shall undergo a MOC process (see 11.1.2). Gaskets should only be removed from packaging immediately prior to use. If the package is found open and contamination is suspected, the gaskets shall either be recleaned for oxygen service or rejected.

Gaskets shall be correctly sized and centred to ensure that no part of the gasket protrudes beyond the inner wall of the pipe into the flow stream. The use of gasket sealants shall be avoided to prevent extrusion of the sealant material into the pipeline system. The reuse of any gasket is prohibited.

Gaskets for oxygen systems should not be hand cut from sheet because they are difficult to clean and can have ragged edges which could protrude into the flow stream.

Care shall be taken when cleaning the flange surface to ensure that any debris created does not enter the pipework.

Gaskets, nuts, and bolts shall be visually inspected to ensure that they are clean and in good condition. PTFE-based coated bolts are ideal for obtaining the required torque for tightness. A lubricant as defined in the project specification may be applied to bolt, threads, and bearing faces of nuts and washers before bolts are inserted into flanges and tightened.

11.3.4 Cold torqueing of cryogenic valve flanges

It is sometimes necessary to retighten flange studs after first cooldown when valves are re-installed after maintenance. For this reason, valves that are installed in perlited or rock wool boxes or within external pipe insulation should not be re-insulated until after a cold test of the system. Valves should be checked for leakage before insulating.

11.3.5 Thread sealant including tape

Hydrocarbon contaminated PTFE tape or PTFE sealant is a potential root cause for incidents.

Only pure virgin PTFE tape or PTFE sealant is permitted. PTFE tape ordered to the following standards (or equivalent) have low residual lubricant content and are acceptable for liquid oxygen or gaseous oxygen service.

- EN 751, *Sealing materials for metallic threaded joints in contact with 1st, 2nd and 3rd family gases and hot water. Unsintered PTFE tapes* [21];
- BS 7786, *Specification for unsintered PTFE tapes for general use*; or [22]
- A-A-58092, *Commercial Item Description (CID), Tape Antiseize, Polytetrafluoroethylene* [23].

Other materials shall be tested in accordance with 6.3 and 6.4.

Thread tape should be used sparingly where required. No excess tape protruding into the process is allowed.

Thread sealant should be applied uniformly to cover the threads needed. No excessive amount of sealant is allowed.

11.3.6 Lubricants

Any lubricants used shall meet the requirements of 6.4.

11.3.7 Actuator and gearbox maintenance

The use of hydrocarbon lubricants in actuator and gearbox mechanisms is only permitted where originally specified by the actuator or gearbox manufacturer. Dangerous situations can occur if lubricants migrate into oxygen wetted parts. Ensure that safeguards remain in place to prevent any lubricant from migrating along the valve stem. See 7.2.4.

11.3.8 Valve handling

All valves shall be uniquely identified by identification tags, plates, or other similar permanent marking. This identification shall be durable and remain attached to each valve during maintenance. It is not permitted to interchange valves unless approved through an MOC process.

All valves shall be assembled, disassembled, and installed in accordance with the piping design drawings. All valves shall be handled in a way that maintains their cleanliness and prevents ingress of moisture, oil, dust, and other contaminants. It is essential to maintain bagged or blinded conditions until the moment of re-installation in the field.

Valves in oxygen service removed from piping during maintenance shall be segregated from valves in other service.

11.4 Spares

11.4.1 Source of spares

Spares produced by the original valve manufacturer are strongly preferred (i.e., original equipment manufacturer [OEM]). Where OEM parts are not available, all materials and especially soft goods shall be an exact replacement for the original unless approved through the MOC process. The modified parts or materials, or any change in source of the parts, shall be reviewed and approved by a person competent to assess oxygen compatibility.

CAUTION: *Some facilities have nearly identical valves that are not used in oxygen service but which could have different internal components including non-metals.*

Incorrect selection of spare parts between non-oxygen valve spare parts and oxygen valve spare parts is a potential root cause of incidents. Fires have occurred due to confusion in selection and use of spare parts. Spare parts approved for oxygen service shall be segregated from the non-oxygen service parts. Do not swap parts between non-oxygen service valves and oxygen service valves.

11.4.2 Ordering, packaging, and marking

Orders for materials for oxygen service should not be combined with those for other materials. If there is concern and/or uncertainty about their cleanliness, the materials shall be inspected and cleaned according to specified procedures. The materials should be delivered free from rust, scale, oil, and grease. See 8.4 for more details and information on packaging.

A component that is cleaned for oxygen service shall only be used at the service conditions for which it was ordered. Using it in different service conditions without a MOC process is not permitted as the part could be incompatible with the original valve. Approval from a company expert shall be obtained before using it in a different service condition.

11.4.3 Spare gaskets

Gaskets shall be stored and bagged with other oxygen components and only opened in the field when needed at the moment of installation (see 11.3.3).

11.4.4 Labelling

All packaging for spare parts used in oxygen service shall have a label indicating “CLEANED FOR OXYGEN SERVICE” (see 8.4).

11.4.5 Adequacy of preservation

Periodic warehouse checks of stored valves and or spare parts are recommended. The packaging shall be intact and the oxygen service labelling shall be present. If packaging is damaged or labelling is missing, recleaning or replacement is required.

11.5 Supervision and inspection

For the supervision and inspection of the maintenance activity the following is required:

- qualified supervision to approve contractor workshops, capabilities, methods, and cleanliness procedures;
- cleanliness inspection of valves being maintained; and
- supervision of installation of valve to ensure compliance with requirements (see 11.1).

11.6 Documentation

For quality documentation measures for valves and spare parts, see Section 13.

11.7 System restart after maintenance

11.7.1 System blowout after major maintenance

Cleanliness can be divided into two distinct areas:

- free from hydrocarbons; and
- free of particulates.

Hydrocarbon cleanliness can only be achieved by rigorous attention to component, valve, and system build cleanliness as the maintenance is performed as previously described. Similar attention should be given to particulate cleanliness. However, it is important to be realistic. When working in the field, cleaning gasket faces or final installation of a valve between flanges, particulate can fall into piping, particularly when vertically orientated. Particulates are not always visible and not easily removed. Accordingly, it is recommended that any oxygen system that has been opened for maintenance is blown out with clean, oil-free and dry air or inert gas (for example, nitrogen) wherever possible. This is the only real proof test for particulate cleanliness in many real-life situations.

Care shall be taken when using inert gas due to risk of asphyxiation.

11.7.2 Excluding personnel from the area of startup of equipment

Personnel should be excluded from the startup area of equipment as far as practical when re-commissioning systems that have been opened and/or subjected to maintenance.

12 Training

All personnel working with oxygen systems shall be trained in oxygen system safety hazards. These personnel can include operations and maintenance personnel, engineering, procurement, construction, contractors, commissioning and startup, contracting and procurement, warehousing staff, inspection staff, valve manufacturers/suppliers, and design organisations.

12.1 Training scope and elements of the training programme

The following training topics shall be applied to personnel involved in oxygen systems according to job function.

12.1.1 Potential hazards

Potential hazards and safeguards related to cold oxygen should be included in the training. It is recommended to present examples about incidents.

Site operational procedures relating to oxygen valves and all the relevant operating and safety procedures shall be available to operations personnel.

12.1.2 Cleaning and cleanliness for oxygen service

Training for cleaning and cleanliness for oxygen service shall be developed according to CGA G-4.1 and EIGA Doc 33, [13, 14]. Tools and clothing shall be clean for working on oxygen equipment.

12.1.3 Oxygen compatibility of materials

Personnel shall be trained that only approved materials (spare parts, supplies, etc.) shall be used (see 11.4.1).

12.1.4 Valves handling

Maintenance personnel shall be trained on how to handle oxygen valves to ensure cleanliness between site delivery, storage, and installation. For details, see Sections 9 and 11.

12.1.5 Assembly

The training shall follow the valve manufacturer's assembly and installation guidelines. For spare part handling, see 11.4.

12.1.6 Training records

Training records shall be kept and competency shall be assessed.

13 Quality assurance, quality control measures for valves and spare parts

Quality control needs to be a joint effort between the valve specifier, valve manufacturer, and where appropriate, the construction company and maintenance company. The required quality can only be achieved if a common understanding of what needs to be done is established. Third-party inspectors may be used to verify quality systems.

As a minimum, the following items shall be considered in a joint review:

- Qualification of the manufacturer (for example, audit) to demonstrate their capability in the field of oxygen equipment;
- Product inspections;
- Proof of quality documentation of the valve manufacturer;
- Validation of quality system and design process of the valve manufacturer;
- Definition of responsibilities for quality for the valve manufacturer and for the valve specifier;
- Review of the valve specification for its suitability for the service intended. Ensure that the valve manufacturer understands and follows the specification requirements (for example, cleanliness and oxygen capability);
- The valve manufacturer shall notify the valve specifier of any changes in parameters affecting the valve quality and safety (material, assembly, cleaning, etc.) using the MOC process;
- Proof of quality of construction phase (goods inwards, storage, installation, documentation); and
- Qualification and competence of personnel.

13.1 Valve manufacturer control

13.1.1 Valve manufacturer quality control

Manufacturing should follow standard acceptable quality control guidelines to ensure repeatable manufacturing processes that produce a product compliant with the applicable specifications.

13.1.2 Valve manufacturer qualification

The valve manufacturer shall be qualified to manufacture and provide service according to the valve specifier's requirements.

Such a qualification should include:

- Reference list indicating experience with oxygen service;
- Effective and operable quality management system capable of meeting customer technical specifications and requirements;
- MOC process in place;
- Resource management/human resources – training/competences for oxygen service;
- Lessons learnt from operations, maintenance, design, and manufacturing;
- Principles for selection of non-metallic materials (bearings, gaskets, packings, lubricants);
- Principles for selection of metallic materials (springs, pins, washers);
- Principles of validation of the cleaning process (qualification, cleanliness verification process, cleaning room/area organization, quality of sub-supplier material);
- Process for validation of the valve design (see 7.2);
- Cascading of quality measures to sub-suppliers;
- Assembling sequence, procedure, working environment for assembly process;
- Material traceability (type of metallic/non-metallic material is used in which particular valve);
- Standard documentation (cleanliness certificate, inspection test plan, installation and maintenance instruction, packaging procedures and preservation, labelling, and marking); and
- The surface finish and roughness (Ra) shall be established at least for machined components and controlled according to ISO 4287, *Geometrical Product Specifications (GPS) -- Surface texture: Profile method -- Terms, definitions and surface texture parameters or applicable national or international standard* [24].

A shop tour is recommended to follow the processing of oxygen valves, with the focus in particular of the entire oxygen cleaning and assembly processes.

Qualification may be repeated in case of changes in organization, quality requirements, and new products.

13.1.3 Change in manufacturing process

When the valve manufacturer decides to make a change in the manufacturing process of a specific order (for example, a change in material, assembly, cleaning, or packaging) the manufacturing shall be stopped. This change shall be documented and notification sent to the valve specifier to seek approval before manufacturing resumes. For valves made for stock (mass produced), changes made shall be reflected in the part number and/or documentation.

13.1.4 Technical review

The valve specifier shall determine the type of design review required. The valve specifier should check the valve manufacturer's documentation prior to the commencement of manufacturing.

This includes:

- design drawings;
- material; and
- inspection and test plan.

If a type approval was previously carried out (meaning a specific valve model was tested, see 7.2) and the valve passed all quality criteria, an individual document review may not be necessary.

13.1.5 Inspection

To check the compliance with the specifications and quality requirements, inspection of purchased or overhauled valves shall be carried out. The frequency of inspections can vary with experience gained from earlier inspections. Inspections should be carried out at different stages of the valve manufacture or overhaul process and not only after the work is finished. The inspection may occur independently or be part of an audit or the qualification process.

13.1.6 Final documentation

Documentation shall be made available by the valve supplier for verification by the valve specifier including:

- certificates of compliance;
- cleanliness, assembly, and leak checking records;
- material test report and/or certificate; and
- maintenance, installation, storage, and operating instructions.

This documentation shall be retained by the valve supplier.

13.1.7 Packaging and shipping

Valves shall be packed and tagged after testing and stored in a clean, dry location until shipped.

13.2 Construction site management

Construction personnel (company or contractor) are responsible for following all specifications and shall acknowledge that they understand the specification requirements for cleanliness and oxygen compatibility.

In installations where the work will be performed by company employees (technicians), company policies as well as the following requirements shall apply.

13.2.1 Construction contractor qualification

The contractor shall be qualified to install valves according to valve specifier's requirements. This process mainly consists of:

- material receiving process;
- material storage; and
- installation.

13.2.2 Material receiving

In addition to site receiving material procedures, site receiving and quality control assurance personnel shall also:

- check integrity of valve packaging and labelling; and
- check the packaging for visual indications of gross contamination (for example, liquids, rust) without opening the package.

If unsure of valve cleanliness, open the package and perform a visual cleanliness check. For this check, the valve does not need to be disassembled.

If the packaging is found opened or damaged, the valve shall be inspected to determine if recleaning is necessary before storage. This can either be carried out on-site or the valve will have to be sent back to the valve manufacturer.

13.2.3 Storage

Oxygen valves shall be stored in a designated area which is marked “cleaned for oxygen service” or equivalent.

13.2.4 Installation

Immediately before installation of valves a visual cleanliness inspection shall take place and shall be documented (see 8.2). Only valves without visible contamination shall be installed. For this inspection, the valve does not need to be disassembled unless contamination is suspected. Care shall be taken not to contaminate the valve during handling. Oil and grease shall not be used for the installation of oxygen valves.

14 References

Unless otherwise specified, the latest edition shall apply.

[1] ASTM G63, *Standard Guide for Evaluating Nonmetallic Materials for Oxygen Service* www.astm.org

[2] EIGA Doc 04, *Fire Hazards of Oxygen and Oxygen Enriched* Atmospheres www.eiga.eu

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

[3] EIGA Doc 13, *Oxygen pipeline and piping systems*, www.eiga.eu

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

[4] ASTM G94, *Standard Guide for Evaluating Metals for Oxygen Service* www.astm.org

[5] ASTM G124, *Standard Test Method for Determining the Combustion Behavior of Metallic Materials in Oxygen-Enriched Atmospheres* www.astm.org

[6] ASTM G72, *Standard Test Method for Autogenous Ignition Temperature of Liquids and Solids in a High-Pressure Oxygen-Enriched Environment* www.astm.org

[7] EN 1797, *Cryogenic vessels—Gas materials compatibility* www.cen.eu

[8] ISO 21010, *Cryogenic vessels—Gas materials compatibility* www.iso.org

[9] M034-1, *List of nonmetallic materials compatible with oxygen by BAM Federal Institute for Materials Research and Testing* www.bam.de

[10] ASTM G86, *Standard Test Method for Determining Ignition Sensitivity of Materials to Mechanical Impact in Ambient Liquid Oxygen and Pressurized Liquid and Gaseous Oxygen Environments* www.astm.org

[11] ASTM D2512, *Standard Test Method for Compatibility of Materials with Liquid Oxygen (Impact Sensitivity Threshold and Pass-Fail Techniques)* www.astm.org

[12] ASTM G74, *Standard Test Method for Ignition Sensitivity of Nonmetallic Materials and Components by Gaseous Fluid Impact* www.astm.org

[13] CGA G-4.1, *Cleaning Equipment for Oxygen Service* www.cganet.com

[14] EIGA Doc 33, *Cleaning of equipment for oxygen service* www.eiga.eu

[15] ISO 23208, *Cryogenic vessels—Cleanliness for cryogenic service* www.iso.org

[16] ASTM G93 *Standard Practice for Cleaning Methods and Cleanliness Levels for Material and Equipment Used in Oxygen-Enriched Environments* www.astm.org

[17] EIGA Doc 40, *Work permit systems* www.eiga.eu

[18] EIGA Doc 51, *Management of change* www.eiga.eu

[19] EIGA Doc 44, *Hazards of inert gases and oxygen depletion* www.eiga.eu

[20] CGA SB-2 *Oxygen-Deficient Atmospheres* www.cganet.com

[21] EN 751, *Sealing materials for metallic threaded joints in contact with 1st, 2nd and 3rd family gases and hot water. Unsintered PTFE tapes.* www.cen.eu

[22] BS 7786, *Specification for unsintered PTFE tapes for general use* www.bsigroup.co.uk

[23] A-A-58092, *Commercial Item Description (CID), Tape, Antiseize, Polytetrafluoroethylene* http://quicksearch.dla.mil/

[24] ISO 4287, *Geometrical Product Specifications (GPS)--Surface texture: Profile method -- Terms, definitions and surface texture parameters* www.iso.org