



RECIPROCATING COMPRESSORS FOR OXYGEN SERVICE

AIGA 048/18

Revision of AIGA 048/12

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RECIPROCATING COMPRESSORS FOR OXYGEN SERVICE

As part of a programme of harmonization of industry standards, the Asia Industrial Gases Association (AIGA) has issued the publication AIGA 048 *“Reciprocating Compressors for Oxygen Service”*. This has been jointly produced by members of the International Harmonization Council and originally published as Doc 10 by European Industrial Gases Association (EIGA) as *“Reciprocating Compressors for Oxygen Service”*.

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). Each association's technical content is identical, except for regional regulatory requirements and minor changes in formatting and spelling.

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Amendments from 048/12

Section	Change
	<u>Editorial to align style with IHC associations</u>
	<u>Re-alignment to a more consistent format.</u>

Note: Technical changes from the previous edition are underlined

1 Introduction

Oxygen compression represents a special risk in that the compressor can burn violently. This publication defines design and operating parameters for reciprocating oxygen compressors. Compliance with this publication will reduce the likelihood of, and the hazards arising from, a fire in a compressor to be equal or lower than those commonly accepted in the air separation industry. There is less demanding technology in a reciprocating compressor than in a centrifugal one. Potential rubbing velocities, gas velocities and inventories are all lower. For these reasons more flexibility in design is allowed in a reciprocating compressor than in a centrifugal compressor as defined in the AIGA 071, *Centrifugal Compressors for Oxygen Service* [1].¹

This publication has made a significant contribution to the safe compression of oxygen primarily because the suppliers and users have fully and frankly shared their philosophies and experiences. It is recognised by the Working Group members that the feedback of operating experiences makes a powerful contribution to safe operation and design. This publication requires that all those who build and operate reciprocating oxygen compressors that have been specified to comply with this publication should contribute towards it by fully reporting the circumstances surrounding oxygen fires.

For the purpose of safe operation of the compressor and its auxiliaries, the user and the supplier shall establish full agreement on the possible and expected modes of compressor operation (for example, specified operating points, normal operating range, start-up and shut-down).

2 Scope

This publication applies to conventional ringed and labyrinth compressors in any geometric configuration having a crosshead and distance piece. Most operating experience exists in compressors greater than 500 Nm³/hr at pressures up to 8.5 MPa (85 Bar a) with oxygen purity of 90% or greater and with a maximum 10 ppm water (volume basis)². Additionally, experience suggests that at a discharge pressure below less than 0.2 MPa(2 Bar a) the likelihood of ignition is low and the consequence of ignition slight since the trapped inventory is small and fire is difficult to sustain at low pressures. This working group believes the publication can be applied to 10 MPa(100 Bar a) without further precaution.

The safe and reliable compression of oxygen using reciprocating compressors can only be achieved by the successful combination of many factors. This publication identifies and addresses the following factors:

2.1 Design of the compressor system

- robust and well proven compressor design;
- safe materials in critical areas;
- comprehensive instrumentation; and
- safety shutdown system.

2.2 Cleaning, preservation, and inspection

- correct and properly enforced procedures and well trained personnel.

2.3 Erection, testing, and commissioning

- trained erection personnel; and

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

² kPa and MPa shall indicate gauge pressure unless otherwise noted as (kPa, abs and MPa, abs) for absolute pressure or (kPa, differential or MPa, differential) for differential pressure.

- comprehensive testing programme to verify the design.

2.4 Operation

- trained personnel; and
- correct procedures.

2.5 Maintenance

- condition monitoring;
- planned preventive maintenance;
- trained personnel;
- personnel protection;
- identification of the hazard;
- safety barriers;
- location of the compressor; and
- emergency procedures

2.6 Other specifications

The compressor supplied shall be in conformity with all applicable rules, codes and regulations of the country of use.

2.7 Application of the publication

2.7.1 Oxygen purity

This publication applies to reciprocating oxygen compressors operating on dry gases containing greater than or equal to 90% oxygen, and less than 10 ppm water (volume basis).

2.7.2 Oxygen-enriched gases

Experience in compressing oxygen-enriched gases containing less than 90% oxygen is very limited at this time. In the absence of such experience or established data, the working group members recommend that this publication shall be considered for reciprocating compressors operating on oxygen-enriched gases and the degree of implementation shall be agreed between supplier and user.

2.7.3 Moisture

Experience in compressing oxygen-containing moisture is limited. Specific precautions need to be taken particularly with reference to the materials of construction. Additional requirements shall be agreed between supplier and user.

2.7.4 Discharge pressure

The requirements in this publication are based on the experience gained in the compression of oxygen up to 10 MPa(100 Bar a).

2.7.5 Suction pressure

Traditional experience is with compressor suction pressure of less than 0.2 MPa(2 Bar a). This is the application that has been considered when putting forward the best design of ancillary systems. However, if the compressor has an elevated suction pressure it is possible that some ancillary systems may need modification and appropriate risk assessment shall be made.

2.7.6 Driver

The majority of experience has been with the use of constant speed electric motor drivers. This publication has been written giving the best solution for this type of driver. However, where another type of driver (for example, variable speed electric motor requires a different solution) this has been identified in the publication (resonance, vibrations, and lubrication issues).

3 Definitions

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

3.1 Publication terminology

3.1.1 Shall

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

3.1.2 Should

Indicates that a procedure is recommended.

3.1.3 May

Indicates that the procedure is optional.

3.1.4 Will

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

3.1.5 Can

Indicates a possibility or ability.

3.2 Technical definitions

3.2.1 Hazard area

Area where an incident is most likely to occur and as a consequence is capable of causing danger and/or injury to personnel.

3.2.2 Maximum continuous speed of the compressor

Maximum permitted continuous rotating speed of the compressor.

3.2.3 Maximum operating temperature

Highest temperature, which can be measured anywhere in the main gas stream, under the most severe operating conditions. See 9.4.

4 Compressor design

4.1 Design criteria

4.1.1 Possible causes of an oxygen compressor fire

It is normally very difficult to precisely ascertain the cause of a fire in an oxygen compressor because the material at and around the ignition site is completely burnt up. Therefore, during the design and manufacture of a reciprocating oxygen compressor both active and passive safety measures shall be taken to guard against any of the following situations leading to ignition:

- mechanical rub, friction—improper design, clearances, vibrations, operating pressure, assembly errors, bearing failure, alignment, improper inter-cooling, start-up/shut down instability (may include shock, adiabatic compression);
- debris impact—screen/filter failure or improper mesh size, weld debris or slag, (friction/shock) maintenance debris, shot, sand;
- contamination—oil, faulty design of bearings/seals and/or faulty design of associated vents and drains;
- resonance;
- debris in dead areas; and
- cooling system—design the system to avoid concentrating ethylene glycol in the process arising from leakage.

4.2 General materials

4.2.1 Construction materials

When selecting materials of construction for an oxygen compressor, components that come into contact with oxygen shall have good oxygen compatibility. Materials that fulfil this criterion usually have the following properties:

- high ignition temperature;
- high thermal conductivity;
- high specific heat; and
- low heat of combustion.

4.2.2 Use of aluminium

Because of its high heat of combustion the use of aluminium shall be limited for oxygen wetted or potential oxygen wetted parts. However, aluminium will not sustain combustion at certain pressures and purities. One such condition for piston construction is up to 1.4 MPa with oxygen purity 97%. Anodized aluminium is also acceptable within the constraints above.

Materials (including copper alloys) containing more than 2,5% aluminium shall be considered as aluminium.

4.2.3 Non-metallic materials

Non-metallic materials shall be tested for their suitability for oxygen service. Information can be found in Code of practice M 034, *List of non-metallic material compatible with oxygen by BAM* [3] and ASTM G63 *Standard Guide for Evaluating Non Metallic Materials for Oxygen Service* [4]. This does not

preclude other methods of determining compatibility such as by other independent bodies, customers, and suppliers.

4.3 Compressor parts

4.3.1 Cylinders and cylinder liners

4.3.1.1 Cylinder and cylinder liner material

The following materials have proved satisfactory with regard to the criteria listed under 4.2

- grey cast iron;
- nodular cast iron;
- high alloy steel - cast or fabricated; and
- welding of cast-steel and fabricated steel casings is permitted if the execution and heat treatment are properly conducted.

4.3.1.2 Repairs

Any repair shall be agreed between supplier and user, with the appropriate procedure.

4.3.1.3 Sealing material

If non-metallic materials are employed for sealing the cylinders, they shall be oxygen compatible and agreed by the supplier and user. Liquid sealant shall be applied to prevent it from creeping and projecting into the inside of the compressor. If required, threads shall also be sealed by materials that are compatible with oxygen.

4.3.1.4 Anti-galling compound

If an anti-galling compound is applied to centring fits, bolts, studs, etc., only compounds compatible with oxygen shall be used. Compounds shall be mutually agreed by the supplier and user.

4.3.2 Distance piece

The distance piece and frame oil head shall be designed to positively prevent the contact of crankcase oil with the process oxygen stream. The distance piece should be longer than the stroke length to allow the fitting of a slinger ring. For horizontal compressors, a second compartment distance piece of the same design should be used.

The interior of each distance piece should be painted white to detect presence of oil or pollution. A piston rod slinger ring shall be provided to form a positive barrier against oil migration along the rod. Oil migration shall be checked for on a regular basis.

An open distance piece is recommended to prevent oxygen enrichment. A positive purging system using air or nitrogen may be provided to ensure oxygen enrichment is not possible. Oxygen concentration in the distance piece should be checked periodically only remotely from outside the barrier or hazard area. If distance piece covers are provided, for example in case of hostile or polluted environment, a positive purging system shall be provided (dry air or nitrogen) to ensure that oxygen enrichment is not possible; in this case the concentration of oxygen at the vent of the distance piece shall be checked periodically.

Care shall be taken to avoid oxygen-enriched gas from the distance piece entering the crankcase either by over pressurizing the distance piece or by creating a vacuum in the crankcase.

4.3.3 Cylinder valves

Compressor valves contain thin materials and represent a particular hazard. Although there are no established design and construction rules for these valves, the design and material selections listed below have proven successful in operation.

The maximum continuous rotating speed of the compressor is determined primarily by the valve life cycle. The maximum continuous rotating speed of the compressor shall not exceed 750 rpm.

4.3.3.1 Design of cylinder valves

Ported plate valves with damping plates should be used for oxygen applications. Valve size should be sufficient to keep pressure losses across the valve below 5% of nominal suction and discharge pressures. Valve lift should be designed to keep opening impacts below 3.5 m/s and closing impact below 1.3 m/s to ensure maximum lifetime and safety. Valve motion natural frequencies should not correspond to system pulsation frequencies since this can lead to rapid valve failure.

4.3.3.2 Materials for compressor valves

The following materials have proven satisfactory for compressor valves:

- valve seat and guard: X20Cr13, X5CrNi1810, AISI 305, AISI 410, JIS SUS 420;
- valve plate: X20Cr13, X5CrNiCuNb177, AISI 410, JIS SUS 630;
- valve springs: X5CrNiCuNb177, Nimonic, JIS SUS 304;
- centre bolt: martensitic stainless steel, JIS SNB7; and
- nut: austenitic stainless steel.

4.3.4 Pistons

Maximum mean piston velocity shall not exceed 4 m/sec for ringed piston, and 5 m/sec for labyrinth piston.

4.3.4.1 Piston rod

Suitable materials for pressure greater than 4.5 MPa(45 Bar a) include among others, K-Monel. Martensitic stainless steel can be used less than 4.5 MPa(45 Bar a).

If a piston rod coating is used, it shall be of a proven technology such as chrome plating, nitrided steel, or tungsten carbide coating.

4.3.4.1 Piston rings

Ringed, as distinct from labyrinth, compressors normally have piston rings to seal the gas and rider rings to carry the piston weight. The choice of ring material is important because the rubbing ring is itself a source of ignition and secondly wear of the rider ring can allow the metal piston to rub on the cylinder creating heat and a possible fire. Piston rings have successfully been made of polytetrafluoroethylene, PTFE, with one or some combination of the following fillers:

- glass fibre;
- lead powder;
- copper powder;
- bronze powder;

- graphite;
- molybdenum disulphide (MoS₂).

Strict quality controls shall be imposed on the piston ring supplier to ensure that manufacture is conducted with virgin materials and cleanliness appropriate to oxygen use. Rider ring specific loading should not exceed 35 kPa(0.035 Bar a) based on the diameter multiplied by rider ring width. Rider rings should not over-run valve ports by more than 30% of their width. To avoid piston to liner touches, a rod drop trip system should be installed on horizontal or Y type machines. The rider ring groove depth should be at least equal to 150% of the diametrical difference between the piston outer diameter and the cylinder bore.

Piston ring expansion springs shall not be used as they can break and cause an ignition source.

4.3.5 Packing case (stuffing box)

Due to the change in piston rod positions in the packing case as a result of rider ring wear, the packing case should be designed to avoid any contact with the piston rod when there is minimum clearance between the piston and the cylinder.

4.4 Compressor dynamic analysis, verification tests, and data to be provided

4.4.1 Introduction

NOTE This publication follows internationally recognised standards and practices.

Due to their physical nature any responding vibrations or pulsations that occur can always be related to forced, to self-excited, or to parameter excited vibrations. The sources of these vibrations and their effects on the compressor system shall be analysed by calculations, if they are expected to occur in the actual design.

4.4.2 Pulsations limits

Pulsation level shall not be higher than API 618 *Reciprocating Compressor for Petroleum Chemical and Gas Industry Services*, Design Approach 1, within the limit of the original equipment manufacturer's scope [5].

4.4.3 Vibration limits

For stroke of 250 mm and less, the vibration level shall not be greater than 12 mm/s root mean squared (RMS) on compressor, and 20 mm/s RMS on piping system.

For stroke greater than 250 mm, the vibration level shall not be greater than 20 mm/s RMS on compressor and piping with stress raisers (for example, a junction or an instrument connection) and 35 mm/s RMS on plain piping system.

4.5 Grounding

Care shall be taken to ground the electric drive motor correctly to prevent currents circulating through the compressor, which, experience has shown, can damage the bearings. The electrical continuity between all piping equipment shall be ensured with the appropriate devices.

5 Piping including filters

5.1 Pulsation and damping

Because of the dangers resulting from the fractures of pipes or other components, both mechanical vibration and gas pulsation shall be limited. Pulsation can be limited by either pipework design or by damping. Damping can be achieved by various methods (for example, capacities, orifices, and

vessels). The material used in any pulsation-damping device shall be suitable for use with oxygen at the pressure and velocities expected.

Care shall be taken to ensure cleanliness in the manufacture of damping vessels where the design incorporates internal components, such as partitions, impingement plates, and tubes that prevent complete visual inspection of all internal surfaces after completion of welding.

5.2 Process pipework

AIGA 021, *Oxygen Pipeline and Piping Systems* states that it does not apply to oxygen compressor units [6]. However, compressor process piping specification, fabrication, cleaning, and inspection shall follow the criteria shown in the publication.

5.3 Extent

The recommendations contained in this section shall be limited to the piping directly associated with the oxygen compressor and included within the oxygen compressor unit. In general terms, this is limited to the piping downstream of the suction isolating valve and includes the inlet filter system, all piping between the compressor and non-integral coolers, by-pass valves, and associated piping and discharge piping from the compressor through to the outlet shut-off valve.

5.4 Vents to atmosphere

Vent outlets shall be directed away from personnel and shall be located so that a concentration of oxygen is avoided. In the case of continuous vents, it is recommended that a dispersion calculation be carried out. The vent line is continuously exposed to the atmosphere and shall therefore be constructed of corrosion resistant material. The design of the pipework shall prevent the accumulation of water.

5.5 Special piping

Piping downstream of a recycle, vent, or relief valve shall be considered as a pressure let-down station. The use of stainless steel could be agreed between the supplier and the user in vent duties considering that they:

- operate infrequently and for a short duration; and
- have an atmospheric downstream pressure.

A type of pressure-reducing system which has proved satisfactory is the use of a matched combination of a valve plus a static pressure reducing device. This is typically either a multi-hole radial diffuser or a multi-plate axial diffuser. In this system, the pressure let down is shared between the valve and device and it is normally designed so that the velocity in the pipework downstream of the device is sufficiently low to permit the pipework to be made of carbon steel.

NOTE The velocity in the individual diffuser holes will be sonic and the materials used shall take this into account.

It is recommended that the valve and pressure-reducing device be bought as a matched pair from the same supplier.

Whatever solution is chosen, it shall result in a low noise and low vibration pressure reducing system.

The recycle system shall be designed to pass full flow, at all operating conditions up to the maximum continuous speed. This includes the point of entry to the main suction line and the main suction line itself.

The entry of the recycle stream into the suction line shall be upstream of the suction filter. In order to prevent damage to the suction filter, the distance between the entry point and the suction filter shall not be less than twice the diameter of the suction piping.

5.6 Bellows

Because of the vibration inherent to the reciprocating machine, bellows shall not be installed on oxygen piping.

5.7 Acoustic and thermal insulation

External acoustic and thermal insulation material, if used, shall be compatible with oxygen at atmospheric pressure. Care shall be taken to ensure that the pipe insulation is sealed against the ingress of oil vapour. The supplier and the user shall agree to the material used. Pipe internal insulation is not permitted by this publication.

5.8 Silencers

Silencers are forbidden in the recycle or inter-stage pipework. It is preferred that silencing of the suction is achieved by insulating the suction pipe but if this is not practical then the use of suction silencers is permitted. Suction silencers, if used, shall be located upstream of the suction filter. The silencer shall be manufactured using oxygen compatible materials and the design shall be such that the possibility of the internals breaking up is prevented.

5.9 Main suction filter

A filter shall be provided in the main suction line as close as practicable to the compressor inlet flange. It shall be installed before start-up and remain throughout the life of the compressor.

5.9.1 Rating

The filter rating should be 150 micron maximum.

5.9.2 Materials

The filter media should be manufactured from copper alloy or nickel alloy. Stainless steel shall not be used at pressures greater than 0.2 MPa(2 Bar a). If non-metallic materials are used they shall be oxygen compatible. In either case, materials used shall be approved by both supplier and user.

5.9.3 Design

The filter shall be designed to avoid failure of the filter element by:

- differential pressure caused by partial or total blockage;
- pressure pulsations; and
- abrasion by supporting elements.

5.9.4 Flow direction

The filter unit shall be designed so that all attachments that can come loose during operation (bolting, screening, etc.) are upstream of the filter elements so as to be contained within the elements should failure occur.

5.9.5 Precaution against installation errors

The filter unit shall be designed to prevent incorrect installation. An external indicator such as an arrow shall be provided to indicate the direction of flow.

5.9.6 Inspection

The filter element shall be easy to remove for inspection and cleaning. During removal, care shall be taken to retain all foreign particles.

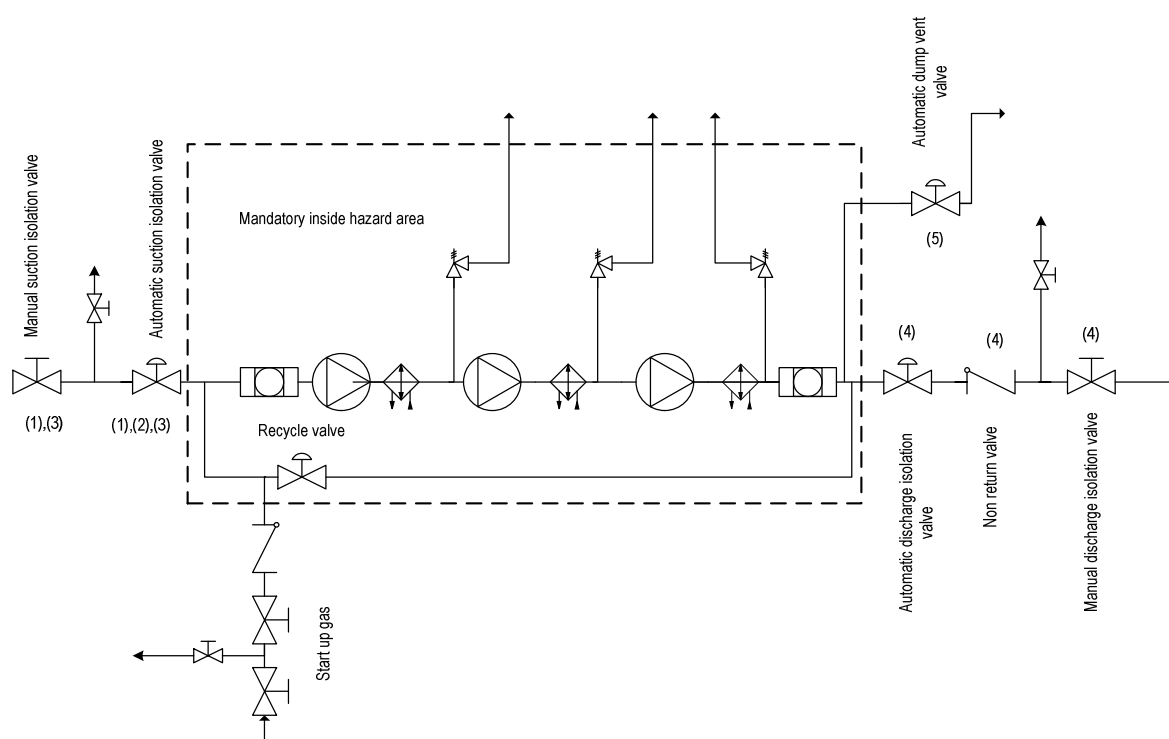
6 Valves

6.1 Isolation system

Isolation system (manual valves, automatic valves, and check valves) shall be according to Figure 1.

6.2 Safety relief valves

A full flow safety relief valve shall protect each stage of the compressor. Safety valves normally operate in critical flow conditions; therefore, care shall be taken of high velocities and requirements in 5.5 shall apply.



Notes:

- (1) Suction isolation valves are optional for low inventory cryogenic plants
- (2) Automatic suction isolation valve is optional if suction pressure is below 1 barg.
- (3) Suction valves are permitted for installation inside the safety barrier if adequate protection against fire blast is provided. Manual valves shall be provided with spindle extensions from inside to outside.
- (4) Discharge valves are permitted for installation inside the safety barrier if adequate protection against fire blast is provided. Manual valves shall be provided with spindle extensions from inside to outside. The valve arrangements can be changed depending on the installation.
- (5) Dump vent valve can also be installed in the hazard area.

General note: Other connections can be needed for operational purposes but not shown in the diagram as many options are possible.

Figure 1 Example of reciprocating oxygen compressor system flow diagram

7 Coolers

7.1 Scope of supply

It is recommended that the coolers be supplied by the compressor supplier as it is their ultimate responsibility to ensure that the entire compressor is constructed under clean conditions. The user is responsible for ensuring that the supplier has been given sufficient information about the water quality to enable the selection of correct materials.

7.2 Types of cooler

Any type of cooler can be accepted, provided that materials are oxygen compatible and that adequate cleaning can be achieved, see 10.4.

7.2.1 Design features—specific to coolers with gas in the shell

Coolers with gas in the shell design can have a higher potential for tube failures due to pulsation.

This type of cooler has “cooler heads” containing the water channels to tube bundle.

To ensure a positive inspection for oxygen cleanliness, they should have removable tube bundles.

7.2.2 Design features—specific to coolers with gas in the tubes

This type of cooler should be U type or have a single gas pass.

7.2.3 Design features common to both types of cooler

Care shall be taken that components (for example, bolts) are positively secured so as to avoid the danger of them coming loose and being carried into the oxygen stream.

The design shall minimize the risk of leaks between the oxygen and the coolant sides.

Care shall be taken to ensure that the cooler tubes are properly supported and are not susceptible to compressor or gas induced vibration. The tube supports and baffles shall be of a suitable design and materials to ensure that they do not damage to the tubes Experience has shown that the support material in contact with the tubes should be softer than the tube material

When the tubes are expanded into the tubesheets, the lubricant used shall be oxygen compatible.

7.3 Material selections that are common to both types of cooler—oxygen side only

The materials of the tubes and fins (if any) in contact with the oxygen shall be copper or copper alloy. Commonly used materials for tubes are admiralty brass or 90/10 copper nickel.

Commonly used materials for tubesheets are Muntz metal, naval brass, or carbon steel.

Tubesheets made from carbon steel may be used provided that impingement surfaces are avoided and cooling water quality is ensured to avoid corrosion problems (for example with closed circuits or appropriate water treatment).

Gasket material in contact with the oxygen stream shall be compatible with oxygen and agreed between the supplier and the user. Gaskets shall not protrude into the gas stream.

7.4 Establishment and maintenance of oxygen cleanliness—gas in shell type or gas internally finned tubes

One of the concerns with this type of cooler is the oxygen cleanliness of the cooler bundle because:

- It requires special equipment to clean it after assembly or reclean it if it becomes contaminated; and
- There is not a simple way of checking its cleanliness in the field.

Use of this type of cooler shall be agreed between supplier and user.

7.5 Establishment and maintenance of oxygen cleanliness—gas in bare tube type

It is easy to establish oxygen cleanliness in this type of cooler, because the oxygen side of tubes are straight and smooth and the gas header can be detached for easy cleaning and inspection.

No special cleaning equipment is needed and this type of cooler is easy to check for oxygen cleanliness in the field.

7.6 Vents and drains

Suitable means shall be provided to vent all high points and to drain all low points on the waterside.

It shall be possible to check for cooling water leaks prior to starting and thereafter if the compressor is stopped with cooling water circulating. If the oxygen side drains can be operated on oxygen then they shall be led into a well-ventilated area.

The minimum size of drain connections should be 20 mm and equipped with a full bore valve. Vent and drain connection could run in critical flow conditions. Therefore, care shall be taken of high velocities and associated risks.

7.7 Closed circuit cooling system

Closed circuit cooling systems are often filled with water containing up to 50% ethylene glycol or propylene glycol. Both ethylene glycol and propylene glycol are flammable and will concentrate if leaked into an oxygen system and the water evaporates. Members have good experience with closed circuit systems having 50% glycol but when systems have all low points checked for leakage. Incidents have occurred when leakage was undetected in the system.

8 Lubrication oil system

8.1 General

Parts requiring operator attention or on-line maintenance should be outside the enclosure. Lubricating oil pipes within the hazard area shall be kept as short as possible and be routed clear of oxygen pipework where possible. The number of joints shall be kept to a minimum and, where their use is unavoidable, they shall be easily accessible and located to avoid the possibility of lubricating oil dripping onto pipework or other equipment.

8.2 Pumps

A mechanically driven main oil pump that provides adequate lubrication during run down, caused by total loss of power, is the method preferred for motor driven units.

8.3 Oil heater

The surface area of the oil heater, if provided, shall be such that no local over heating or cracking of the oil can occur. The oil heater shall not have any active heating surface that is not immersed in the oil. Provisions shall be taken to avoid exposing heating surfaces dry.

8.4 Crankcase vents

Crankcase vents if provided shall be piped away from the hazard area. See 4.3.2

9 Controls and instrumentation

The capacity control shall be designed, manufactured and operated with consideration given to the prevention of a fire. Systems having a capability of dust accumulation or metallic friction or shocks should not be used. The use of this system shall be agreed between supplier and user.

9.1 General

Protective controls and instrumentation shall be provided for every oxygen compressor in accordance with but not necessarily limited to those described in the following paragraphs. The minimum alarm and trip requirements are given in Table 1. All measurements required to be taken while the compressor is in oxygen service shall be capable of being read without entering the hazard area.

The trip system may be executed by computer software provided that the reliability is not less than the equivalent hard-wired system.

The speed of the tripping system should be as fast as possible. Therefore, the slowing down of the system to avoid trips due to transient voltage dips, etc., should be kept to an absolute minimum commensurate with the engineering of a reliable system.

Any fluid used in a pressure transducer that is in contact with oxygen shall be oxygen compatible.

A "first up" alarm system is recommended.

Electrical pressure switches directly actuated by oxygen shall be of a design avoiding contact between the oxygen and switching element. Electric, pneumatic, or hydraulic power failure of any system or mandatory trip shall actuate the respective controls in a failsafe manner.

Table 1 Minimum instrumentation of oxygen compressors

Function		Indicator	Alarm	Trip	Interlock
1.0	Oxygen				
1.1	Compressor suction pressure (after filter)	Σ	Lo	Lo	
1.2	Compressor final discharge pressure	Σ	-	-	
1.3	Gas filter differential pressure	Σ	(Hi)	-	
1.4	Compressor suction temperature	Σ	(Lo)	-	
1.5	Temperature of main gas stream at each process stage outlet (See 9.4).	Σ	Hi	Hi	
2.0	Cooling water system				
2.1	Main supply flow	(Σ)	(Lo)	-	(Lo ¹)
3.0.	Bearings and lube oil system				
3.1	Oil filter differential pressure	Σ	-	-	
3.2	Pressure after filter and cooler	Σ	Lo	Lo	
3.3	Temperature in supply manifold after the oil cooler	Σ	(Hi)	(Hi ²)	
3.4	Oil level	Σ	Lo ³	-	
4.0	Vibration system		(Hi)	Hi	
5.0	Miscellaneous				
5.1	Rod drop indicator (non-vertical cylinders)		(Hi)	(Hi)	
-	= Not required				
Σ Hi, Lo	= Mandatory				1. Interlock to prevent start-up
(Σ), (Hi), (Lo)	= Recommended				2. Trip on high temperature in supply manifold d after the oil cooler is recommended for unattended plant
					3. Recommended for units with oil heaters or units that have a splash lubricated crankcase

9.2 Recycle system

Cooling is required if recycle oxygen can cause excessive temperature in the compressor.

9.3 High oxygen temperature protection

Compressor failures are generally associated with gas temperature rise. Monitoring the gas temperature from each stage can indicate potential trouble. Fast response sensors should be installed in the oxygen path at each process stage suction and discharge. They should be positioned as close as possible to the valves and before the first elbow if any.

The measurement and indication of each stage temperature shall allow for the compressor to be tripped at pre-set levels. The tripping temperatures will be related to and in excess of the maximum normal operating discharge temperature experienced. However, maximum normal values recommended are: 170°C (338 °F) for ringed compressors and 200°C (392 °F) for labyrinth compressors.

9.4 Vibration

Compressors shall be provided with a vibration shut down system.

9.5 Compressor isolation and venting

In the event of a trip, the compressor unit shall be quickly isolated from the rest of the oxygen system. A means of venting the oxygen shall be provided.

9.6 Manual isolation and vent valves

A manual isolation valve shall be provided in the suction pipework to the compressor and a non-automatic isolation valve shall be provided in the discharge pipework.

9.7 Non return valve

A non-return valve shall be installed in the discharge pipework of each compressor. This valve should be downstream of any recycle branch. A non-return valve of the same basic design as the compressor stage valves is recommended. Swing type non-return valves shall not be used.

Non-return valves shall be marked with an arrow to indicate correct direction of flow.

9.8 Automatic isolation valves

In addition to the suction and discharge isolation valves, automatically actuated fast-acting isolation valves shall be installed in the discharge pipework and also in the suction pipework when the normal suction pressure is greater than 0.1 MPa(1 Bar a). These valves shall be designed to close on every routine shutdown or trip, and on instrument air failure or electrical failure, see Table 2.

9.9 Automatic vent valves

To limit the duration and extent of any fire that occurs, automatic venting shall be considered. For example, an automatically actuated fast-acting vent valve may be installed in the delivery between the final stage cylinder discharge flange and the non-return valve. This valve should open on every routine shutdown and trip on instrument air failure or electrical failure to quickly and discharge the bulk of gas contained in the compression system to atmosphere. Experience with such a system is very limited but it is considered that to be effective there should be a substantial pressure fall in a few seconds. In case of a compressor trip due to an emergency, the primary consideration should be to isolate the compressor from the oxygen supply and immediately dump the oxygen inventory so that the pressure in the entire compressor system falls to 0.1 MPa(1 Bar a) in not more than 20 seconds. To achieve this, automatic and quick operation of isolation and vent valves is normally required.

For large compressors, a vent valve at an intermediate stage may be required in addition to the discharge vent valve. For machines with a normal final discharge pressure less than 2 MPa(20 Bar a) and with an inventory of oxygen below 10Kg (measured from inlet of suction strainer to discharge isolation) an automatic vent system is not necessary.

It is considered that for a low inventory, low-pressure system the consequences of a fire are small and any system breach is likely to depressurize the system in less time than a dedicated dump system would take to operate.

Table 2 Failure modes and operating speeds of system valves

Valve duty	On compress or shutdown	On loss of electrical signal	On loss of motive power	Speed of action
Automatic suction isolation valve	Shut	Shut	Shut	10 s maximum
Automatic discharge isolation valve	Shut	Shut	Shut	10 s maximum
Dump vent	Open	Open	Open	2 s maximum auto reclose after depressurization

NOTES

1. The relatively slow closing of the isolation valves is to ensure that the dump vent valves have opened first. This is desirable to prevent the safety relief valves from opening.
2. The failure mode and operating speed of the recycle valve is not related to safety

10 Oxygen cleaning

10.1 Introduction

Compressors can be shipped from supplier's works either as fully assembled, tested and oxygen clean units, or as separate components to be erected on site. The latter implies pipework to be site fabricated.

Any combination between the two previous extremes is also possible.

10.2 Extent of oxygen cleaning

The criteria cleaned for oxygen service shall apply to:

- All parts that come in contact with oxygen; and
- Systems that supply gas to the oxygen compressor (for example, start-up gas) to the extent that the gas supplied is free of particles and hydrocarbons.

10.3 Responsibility

Whatever the extent of prefabrication there shall be a designated person responsible for ensuring that the compressor is correctly built. On request, the supplier shall provide an experienced oxygen compressor erector who will be in charge of the unit until it is handed over to the user. It can be seen however that, if units or subassemblies are brought to site cleaned, tested and sealed, then the

designated person's responsibilities include verification that the supplier's and major sub-supplier's work has been carried out.

10.4 Inspection and cleanliness standards

Cleaning methods and acceptance criteria to be followed shall be those shown in AIGA 012 *Cleaning of Equipment for Oxygen Service* [7]. This section is a summary of the requirements.

10.5 Preservation of oxygen cleanliness during shipping and storage

10.5.1 Equipment

All equipment sent to site that has been cleaned for oxygen service shall be protected against contamination and corrosion. A label stating, "cleaned for oxygen service" shall be visible from outside the package. The size and complexity of the equipment being shipped dictates the appropriate method of preservation. Some methods of preservation are listed in the following sections.

10.5.2 Individual components

Individual items such as pistons, cylinder valves, regulators, filters, etc. which are being shipped separately shall be protected, either by sealing within a strong clean plastic bag or for smaller components by vacuum wrapping.

NOTE If the component requires protection against rusting then the plastic bag shall contain bags of desiccant with a colour change additive to detect moisture.

10.5.3 Subassemblies that can be made pressure tight

10.5.3.1 Rust protection not required

Subassemblies that do not require protection against rusting shall have their openings sealed with full-face gaskets of oxygen compatible material and substantial covers of wood or metal. Plastic plugs or gaskets secured with tape are not permitted. For example, gas in shell cooler with a stainless steel shell.

10.5.3.2 Rust protection required

Subassemblies that require protection against rusting shall have their openings sealed with gaskets and metallic covers. Their integrity shall be demonstrated before leaving the suppliers' works by leak checking against a small internal pressure. All spaces shall be blown out with dry oil free air or nitrogen before the subassembly is sealed.

Rust protection can be provided by one of the following means:

- Bags of desiccant, which contain colour change additive to detect moisture, shall be attached to the inside of appropriate opening covers and elsewhere within the subassembly as required. The number and position of the desiccant bags shall be painted on the subassembly exterior;
- Pressurising the subassembly with dry oil free nitrogen. The subassembly shall be fitted with a pressure gauge and have a notice painted on it warning that it is pressurised; and
- Colour change type moisture detectors shall be fixed to the inside of selected opening covers to give confirmation that the preservation measures have been effective.

10.5.4 Arrival on site

When oxygen cleaned components and subassemblies arrive on site, the preservation arrangements shall only be altered/broken with the approval of the designated person.

If the preservation is found not to be intact and if the moisture detectors, if fitted, have changed colour then the subassembly shall be opened for inspection and recleaned until the designated person is satisfied that the equipment is "cleaned for oxygen service".

11 Compressor installation

11.1 Hazard area

It is necessary to consider a number of pertinent factors when determining whether or not an area should be classified as a hazard area such as:

- specific equipment service conditions of pressures, temperatures, gas velocities, purity and contaminants;
- compressor and other system equipment design factors such as type, size, materials of construction, operating speed, internal clearances and type of seal system;
- history for equipment of similar design and operating conditions;
- extent of safety monitoring and shutdown devices that provide early detection of problems before equipment failure;
- proximity of oxygen equipment to personnel walkways, work areas, and other equipment; and
- plant operator's standards, local government requirements, or other specific requirements.

The hazards that can result from a compressor fire are:

- jets of molten metal;
- projectiles;
- flash;
- blast and overpressure; and/or
- energy release in the crankcase or in the distance piece.

It is the responsibility of the user to specify the extent of the hazard area on a case-by-case basis.

NOTE The term hazard area should not be confused with electrical hazardous area classification.

11.2 Enclosure of the hazard area by a safety barrier

In most instances, the hazard produced by a reciprocating oxygen compressor is such that the resultant hazard area would be so large as to be impracticable unless its extent is reduced by enclosing the compressor within a safety barrier. It is recognised that the extent of the hazard area is specific to the size and pressure of each application.

If the user proposes not to enclose the hazard area within a safety barrier, the user shall analyse the hazard, shall determine the extent of the hazard area, and shall demonstrate that the required safety criteria can be met without the use of a barrier.

Barriers shall be installed when the discharge pressure is greater than 2 MPa(20 Bar a). However, in current practice, most users have adopted a 0.4 MPa(4 Bar a) limit. National regulation(s) may require a safety barrier for less than 0.4 MPa(4 Bar a).

11.3 Access to the hazard area

When the compressor is operating on oxygen, access to the hazard area is not permitted without specially written procedures and warning notices to this effect shall be posted. Maintenance access panels shall be closed. Routine visual inspection shall be done remotely through approved safety windows or by using cameras or other devices.

Before entering the hazard area, after the compressor has been shutdown or changed over to dry, oil-free air or nitrogen, the atmosphere within the enclosure shall be analysed to ensure that it is safe to enter. In case of nitrogen, warning signs of possible oxygen deficiency shall be posted. It is recommended that the oxygen concentration be between 19,5% and 23,5%. Continually monitor the atmosphere for oxygen deficiency or enrichment when personnel are within the area.

11.4 Equipment location

11.4.1 Equipment within the hazard area

Equipment that shall be located within the hazard area includes:

- compressor;
- compressor gas coolers, pulsation dampeners, and inter stage piping;
- throttling valves and downstream piping to the first elbow or tee (for example, recycle valve);
- the first elbow in each pipe to and from the compressor, cylinder, or pulsation dampeners; and
- piping components subject to sonic flow velocities or high velocity impingement.

11.4.2 Equipment outside the hazard area

Equipment and instrumentation that require operator attention when the machine is in operation shall be located outside the hazard area. This would include:

- all operator controls;
- all instrumentation readouts;
- alarms and shut-down indicators;
- emergency shut-down devices;
- separate lube oil reservoir; and
- all valves requiring manual adjustment while the unit is operating on oxygen service.

11.4.3 Equipment either within or outside the hazard area

Some equipment may be located either within or outside the hazard area.

11.4.3.1 Automatic isolation valves

Power operated isolation valves and the discharge non-return valve shall be protected from the effects of a fire so that they will function correctly and thus cut off the supply of oxygen and put out the fire. The required protection can be achieved by either putting the valves outside the hazard area or by putting them inside the hazard area with their own shields.

11.4.3.2 Emergency vent valves, purge valves, relief valves

Refer to Figure 1.

11.4.3.3 Driver

The electric motor drive should be located outside the hazard area. However, if the motor is located within the hazard area, it is recommended that the following precautions be taken:

- If the motor is fitted with hydrodynamic bearings, then oil migration from the bearings should be prevented;
- The safety barrier ventilation should be arranged so that air from outside the enclosure is drawn across the motor to ensure that in the event of an oxygen leak a concentration build up around the motor is not allowed to occur; and
- The driver and/or gear shall be designed so that oil vapour is vented to outside of the hazard area.

11.4.3.4 Service pipes and electric cables and junction boxes within the hazard area

If it is not possible to avoid the routing of service pipes, junction boxes, and cables through the hazard area then they should be protected against fire as far as practicable.

11.4.3.5 Lubricating oil system

The lubricating oil system can be located inside or outside the hazard area. The number of connections shall be minimized to prevent leaks in the oil piping within the enclosure.

11.5 Safety barrier

11.5.1 Purpose

The primary purpose of a safety barrier is to prevent injury to personnel. It has a secondary function in that it lessens damage to adjacent equipment. A safety barrier achieves the previous by preventing flames, jets of molten metal, or projectiles from penetrating or collapsing the barrier in the event of an oxygen fire, which can cause burn through of any of the oxygen containing equipment within the hazard area.

11.5.2 Responsibilities

It is the responsibility of the user to design and specify the safety barrier. The supplier shall supply any necessary information as required.

11.5.3 Nature of burn through

11.5.3.1 Likely burn through positions

The majority of fires start in areas of high pressure or gas velocity, therefore the area around the cylinders or recycle valve are likely sites. "Burn through" is most likely to occur at places close to the potential ignition point where the gas pressure is high and the thermal mass small therefore the primary risk areas are:

- compressor cylinders and suction /discharge valves;
- compressor distance piece;
- packing box;

- first elbow in the process pipework immediately upstream and downstream of the compressor flanges;
- recycle valve and its associated outlet pipe and the first downstream bend;
- pulsation dampeners and coolers;
- drain and vent connections; and
- piping around safety valves.

11.5.4 Results of burn through

11.5.4.1 A jet of flame and molten metal

This will burn through equipment, on to which it impacts directly, unless this equipment is of large thermal mass or is protected by a fire resistant heat shield. The safety barrier shall also be strong enough to withstand the impact of the jet.

11.5.4.2 A spray of molten metal

Accompanying the jet is a widening spray of molten metal, which spatters equipment over a wide area.

11.5.5 A blast and overpressure effect

This is caused by the release of high-pressure gas and will cause the barrier to collapse unless it has been allowed for in the design. Normally the barrier is designed to withstand a certain overpressure and a sufficient vent area is provided to ensure that the design overpressure is not exceeded. This is a particularly difficult design problem in the case where the safety barrier is also an acoustic shield.

11.5.6 Strength and burn through criteria

The safety barrier shall withstand the force resulting from the impact of a jet of molten metal issuing from a hole burnt in the compressor or pipework, hitting the safety barrier, plus the overpressure due to the release of the stored inventory of the oxygen. This requires calculation on a case-by-case basis because it varies with the size and the discharge pressure of the compressor. The minimum force that the barrier shall be able to sustain is 2 kPa(0.02 Bar a) projected over the wall area. This value is based on the accumulated experience of members of this working group.

The safety barrier shall be designed to resist the effect of a jet of molten metal for 30 seconds without being breached, see 11.5.7.

Therefore, the design shall consider the following load types:

- sustained temperature of molten metal;
- blast and overpressure; and
- projectile impingement.

11.5.7 Materials of construction

Concrete safety barriers are a very effective way of meeting the strength and burn through criteria and have been used successfully, see 11.5.6. Experience has shown that the concrete can be badly damaged but not breached by the direct impact of molten metal and flame.

Steel structures have been used successfully. Care is needed in the detail design to ensure that a homogenous structure is provided which has no weak points that can be breached by the

overpressure or the impact from jets of molten metal or projectiles. Structural steel members, carbon steel walls, doors and closure plates that are likely to be exposed to the impact of a jet of molten metal shall be protected by a fire-resistant heat shield.

The fire-resistant heat shield may be a plaster like material, which is trowelled on, or it can be in the form of panels. Calcium silicate or shale board has been found to be effective. Not only shall the material form an effective heat shield but it shall also be mechanically strong enough to resist the scouring effect of the jet of molten steel. It is for this reason that rock wool is not acceptable as a heat shield in this application. The fire-resistant heat shield shall be supported so that it is prevented from being broken up by the force of the jet. Field trials have shown that a layer of heat resistant material 20 mm thick will satisfy the required burn through criteria.

Inspection ports, if provided, shall be covered with reinforced glass or equivalent and meet the following required strength criteria.

11.5.8 Layout of the safety barrier

The barrier shall meet the following criteria:

- Vertical sides shall extend 15degrees and at least 0,6 m (2 ft) above the height of any part of the compressor or interstage piping that contains oxygen and no less than 2,4 m (8 ft) above the walking area (see elevation view of Figure 2 as a typical barrier arrangement for a vertical compressor);
- The barrier shall block any line of sight to permanently installed platforms or buildings within 30 m (100 ft) that have normal traffic or occupancy;
- There should be space inside the barrier to allow for normal maintenance;
- The design of the safety barrier shall be such that, when all the closure plates are in place and the doors shut and locked or latched, the wall shall provide a complete unbroken barrier with no weak spots. Considerations about emergency egress shall be included. Labyrinth entrance is also allowed as shown in plan view of Figure 2. Figure 2 shows a typical barrier arrangement for a vertical compressor; and
- If the barrier has a roof ventilation ports shall be located at high level pointing in a safe direction.

The safety barriers shall be designed to cope with the inventory of high-pressure gas that is released when burn through occurs. If the barrier has an open top or a partial roof this does not represent a problem. If the compressor is fully enclosed - normally for acoustic reasons-then sufficient open area shall be provided to avoid over pressuring the enclosure. The following ways of achieving the required open area are recommended:

- A permanently open area with acoustic splitters;
- Acoustic louvers that are self-opening;
- Acoustic doors that are self-opening, hinged so as to have a small angular moment of inertia; or
- Concrete or steel caps that are lifted by the gas pressure provided that the caps are adequately restrained.

The previous open area shall be sited away from the compressor where the hazard is least. The open area shall be sited in a position so the operation of the doors and the blast of hot gas shall not cause a hazard to personnel.

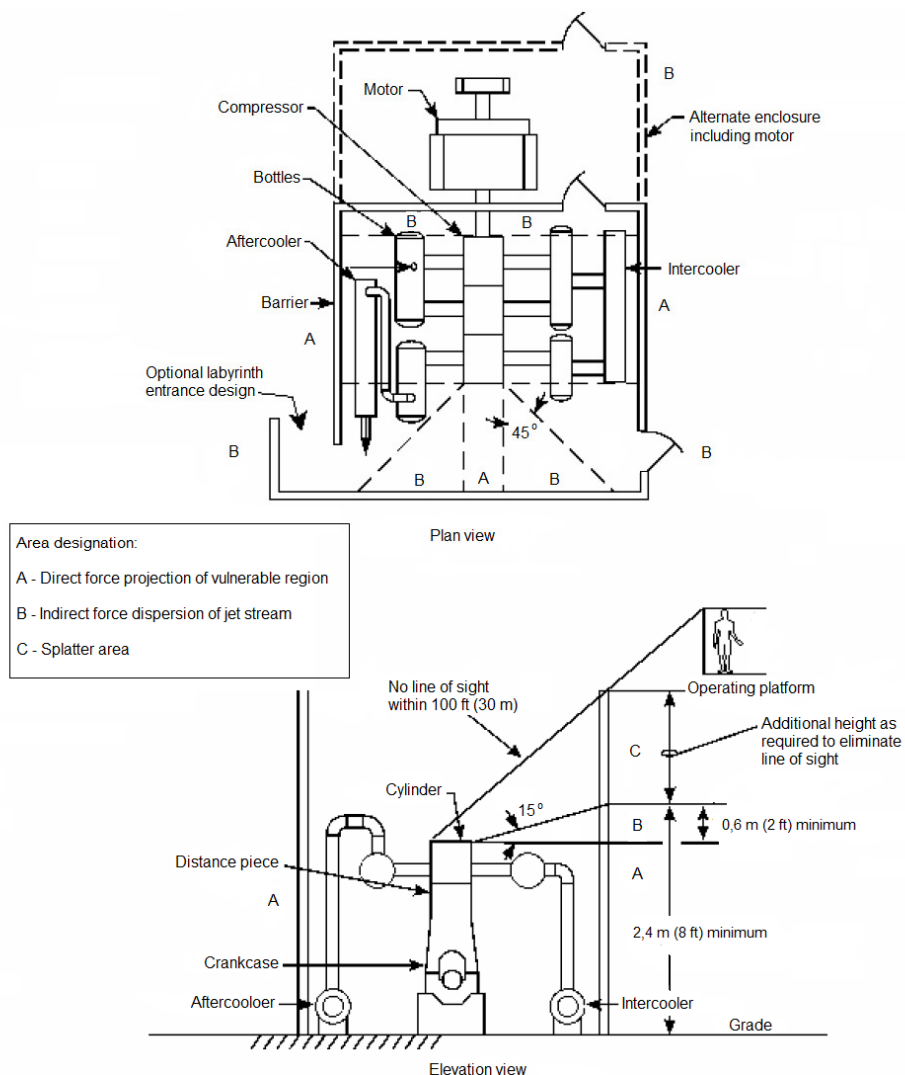


Figure 2—Typical layout of a safety barrier

11.6 Safety barrier miscellaneous design features

11.6.1 Oxygen accumulation

Since oxygen is denser than air, it tends to accumulate in depressions or enclosed spaces. It is recommended that trenches or pits are avoided. The safety barrier shall be provided with sufficient ventilation to prevent a build-up of oxygen around the compressor. If the barrier is open topped this is normally adequate; however, if it is enclosed then forced ventilation should be provided at the rate of not less than 6 air changes per hour.

11.6.2 Nitrogen asphyxiation hazard

If the compressor has the facility for being test run on inert gas (for example, nitrogen) or inert gas is being used for the purge gas or auxiliary equipment then an asphyxiation hazard can exist. The safety barrier should be designed with at least two outward opening exit doors or two openings (in case of labyrinth entrance design) at each level and sufficient walkways to allow quick exit.

11.7 Location

11.7.1 Safety of personnel and plant

It is recommended that oxygen compressors are located away from, main walkways, normally occupied areas - especially elevated ones, and other hazardous or critical equipment. It is important that there are good and clear evacuation routes from the vicinity of the oxygen compressor installation.

11.7.2 Erection and maintenance

The location shall be so the equipment can be kept clean and dry during installation and maintenance. During the design phase attention should be paid to the craneage and lay down areas that will be required for erection and maintenance. Different styles of compressor have different requirements.

11.7.3 Overhead cranes

Precautions shall be taken to prevent oil or grease from overhead or mobile cranes entering the oxygen clean areas or contaminating the hazard area during erection, maintenance, and operation. The layout should preclude the need for cranes to transit over operating oxygen compressors. If this is not possible, the cranes should be pendant operated and their movement and load strictly controlled. When not in use, the crane should be located away from the hazard area.

11.8 Fire protection and precautions

11.8.1 Introduction

Once started, fires in oxygen compressors are nearly impossible to extinguish until all the contained oxygen gas is consumed in the fire or vented to atmosphere. While it is true that once the oxygen supply is cut off and the inventory reduced the actual oxygen fire will be over quickly, extensive damage is likely and sometimes other combustible material, such as oil, is ignited and continues to burn after the actual oxygen promoted fire is out. For these reasons, it is imperative that oxygen compressor systems shall be designed to prevent the initiation of any fires and to vent the oxygen inventory as quickly as possible in case of a fire or potential ignition. These are the most effective ways of reducing the chance of personal injury and minimising equipment damage.

Fire protection should also include a strict housekeeping policy, developing an emergency plan with local fire officials, and supplying the proper firefighting equipment. The emergency plan should be reviewed periodically with local authorities.

11.8.2 Flammable material

The presence of flammable materials in the hazard area constitutes a hazard and should be avoided wherever possible. Where this cannot be avoided, for example, during maintenance operations, then any flammable materials introduced into the hazard area should be removed before oxygen is introduced to the compressor. In the event of an oil spill or leak, the oxygen compressor should be shut down at the earliest opportunity, the leak repaired, and the oil cleaned up.

11.9 Protection of personnel

Only trained personnel shall respond to a fire situation in an oxygen compressor or compressor system.

When a person has been in contact with an oxygen-enriched atmosphere, their clothes could have become saturated with oxygen. Even when they have returned to a safe area, they shall be careful not to approach any source of ignition (for example, matches or an electric fire) until they have changed their clothes.

12 Erection, testing, and commissioning

12.1 Erection

12.1.1 Responsibility

The increased emphasis on packaged compressors means that the responsibility for the correct erection and the maintenance of cleanliness of the compressor system may well extend back to the supplier's and major sub-suppliers works. The statement in 10.3 applies to the cleanliness standards throughout the erection of the compressor unit. On request, the designated person shall keep a chronological record showing who carried out the main assembly work and who took the "as built" measurements and carried out the testing. This applies even if the person concerned came from another firm. It is also recommended that he keeps an oxygen cleanliness log which records the time, the person, and the place that each part of the oxygen circuit, including the gas feeds to the compressor were approved as "cleaned for oxygen service". It should also record the inspection method used, for example ultra violet light and solvent analysis.

12.1.2 Tools

The tools, appliances, and measuring devices used during installation and assembly of the compressor and auxiliary equipment which come into contact with oxygen shall be cleaned with a suitable cleaning agent and maintained in a clean condition during their use for this purpose. Tools used for the lubricating oil system or other parts of the machine shall not be used for oxygen carrying components, unless they are properly cleaned first. Only lint-free cleaning cloth shall be used. When using lifting tackle, any contamination by oil from the ropes, gears, or other sources of lubrication shall be prevented.

12.1.3 Purging after assembly

If the compressor cannot be put into operation at the time erection is completed, appropriate measures shall be taken to protect it against possible damage:

- Cooling water spaces of compressor and coolers shall be drained, and drain valves left open; and
- Oil-free, dry, non-flammable gas purge shall be maintained in the compressor as necessary to ensure that a non-corrosive atmosphere is maintained in the machine.

12.2 Testing

12.2.1 Introduction

In some instances, the compressor is shipped from the supplier's works as a complete, fully tested, oxygen clean compressor system. However, in other instances the compressor system is site erected and fabricated. Therefore, the test plan employed shall be adapted to the circumstances presented by the specific installation while meeting the following objectives.

12.2.2 General

Any instrumentation required for testing the machine such as pressure gauges and flow meters should only be used for this duty. When they are used on site, they shall be specifically cleaned and marked "for oxygen use only". All parts that are normally under pressure including the instrumentation and gas and oil pipework shall be subjected to a pressure test, unless specified elsewhere in this publication. The type of test and test pressure shall be agreed between supplier and user.

12.2.3 Testing objectives

The compressor shall not be put into oxygen service unless the testing has achieved the following objectives:

- demonstration of the mechanical integrity of the complete compressor system over the predicted operating range;
- verification of the predicted operating temperatures; and
- functional demonstration of the instruments and controls.

12.2.4 Tests to be carried out

12.2.4.1 Functional demonstration of the instruments

Prior to running the compressor all the instruments shall be calibrated and loop checked. Functional checks shall be carried out of the following:

- alarm and trips;
- shutdowns;
- all interlocks;
- recirculation and vent valves; and
- isolation valves.

12.2.4.2 Compressor mechanical test

A leak test followed by a mechanical test (run test) shall be performed. During run test operating conditions, vibration amplitudes and frequencies, stages and valves temperatures, and bearings and oil temperatures shall be monitored and logged.

After run test:

- Cylinders and rods shall be checked for scoring, scuffing or other types of damage;
- Distance pieces and piston rods shall be inspected for contamination or oil carryover;
- Crosshead inspection covers shall be removed to inspect the crosshead slide for scoring or damage. Piston rod lock nuts shall be inspected for any looseness or movement; and
- Piston to cylinder clearances shall be checked and logged again.

12.3 Commissioning on oxygen

12.3.1 Preparation for the initial run on oxygen

Before any attempt to run the compressor on oxygen the designated person shall satisfy himself that:

- All the test objectives have been met;
- The entire compressor system has been certified “cleaned for oxygen service”;
- That run in with inert gas or dry air has been successfully performed and no leaks and/or abnormal running conditions have been detected; and
- There is satisfactory proof that the pipeline upstream of the compressor has been cleaned for oxygen service. In addition this can be demonstrated by blowing through with dry air upstream of the filter at a velocity not less than normal operating velocity for a period of

several hours. This blow through shall be vented upstream of the suction filter and as close to it as possible.

The hazard area is clean and free from all combustible materials and fully functional.

12.3.2 Initial run on oxygen

Before running the compressor on oxygen, the hazard area shall be cleared of all personnel. Oxygen should first be introduced to the running machine slowly blending it in until the unit is brought to design purity. During the start-up and until establishment of constant operation all indicating instruments should be constantly watched, with special attention devoted to the gas pressures and temperatures and the valves temperatures, and the vibration levels. The values taken should be logged at short intervals (about every fifteen minutes). After about four hours of operation readings may be taken and logged at hourly intervals.

13 Operation

13.1 General

Factors requiring specific attention in the operation of an oxygen compressor can be tabulated as follows:

13.2 Combustible matter

Dust, oil, grease, and other forms of combustible matter readily ignite in oxygen. Combustible materials shall not be stored in the vicinity of oxygen compressors.

13.3 Machine rubs

Rubs in a machine can cause ignition, due to localised high temperatures being generated.

13.4 Machine vibrations

Machine vibrations stemming from for example misalignment and mechanical defects. can cause bearing failures, subsequently leading to rubs.

13.5 Leaking cooler tubes

Leaking cooler tubes can result in rusting of the oxygen containing components due to water intrusion when the equipment is in an unpressurized condition. The resulting scale can serve to promote ignition in the compressor.

13.6 Gas leakage hazard

Although high efficiency packing and packing cases are used and leakage recovery piping provided, it is possible for oxygen leakage into the distance pieces to occur. Provisions shall be taken to avoid oxygen concentration build-up. Packing performance should be monitored for increases in leakage, which indicates excessive wear and the need for replacement.

Care shall be taken during compressor inspection, even with shutdown machinery. Leakage and accumulations of gases can occur without operators being aware of this. Any source of open flames or ignition can cause a conflagration in an operator's clothes that may be impregnated with oxygen. Oxygen deficiency from nitrogen leakage during compressor operation can cause asphyxiation.

13.7 Oil leakage hazard

It is a primary safety concern that the lubricating oil in the crankcases of reciprocating oxygen compressors shall not be allowed to migrate up the piston rods into the distance pieces. To prevent

this from happening, the frame oil heads are provided with high performance oil scrapers to clean any oil off the piston rods before they enter the distance pieces.

Because these scrapers are subject to wear their performance can deteriorate over time. Therefore, their performance shall be routinely monitored so that a potentially hazardous condition can be avoided.

13.8 Qualifications and training for operating personnel

The operating personnel should have special training in machine operation and should be fully aware of the special significance to be attached to variation in instrumentation readings.

Certain knowledge of the machine construction is necessary to fully understand the importance of oxygen safety.

13.9 Hazard area

If it is considered necessary to enter the hazard area for the analysis of defects when the machine is operating it shall first be changed over to dry clean air or inert gas. It should be noted that, in the vicinity of the hazard area, both oxygen enrichment and oxygen deficiency can occur due to, for example: leaking flanges or defective seal systems. For safe working the oxygen concentration should be between 19.5% and 23.5%.

13.10 Record of machine operation

A log of normal operating conditions shall be prepared, derived from commissioning and design data, and this shall form the basis of the log sheet for use by operating personnel.

Log sheets should be regularly compiled for the machine. Automatic logging may be used.

A record of the number of machine starts and hours run shall be kept.

13.11 Monitoring critical operating parameters

Critical operating parameters should be monitored at least once per day. In cases where plants are computer controlled, trend monitoring is easily accomplished. Where such equipment is lacking, data should be recorded on a regular basis. Data should be compared with previous readings to confirm that proper operation is continuing or if corrective action is required.

Critical operating parameters may include:

- vibration;
- temperature;
- stage pressure; and
- lube oil pressure.

No readings are to be taken within the safety barrier unless it can be carried out through an inspection port.

13.12 Trip override

The compressor shall not be run on oxygen with any trip by-passed. Where a machine is shut down by one of its protective trip functions, the machine shall not be restarted until the reasons have been investigated.

13.13 Interlock systems

Operators shall be conversant with the principles and operations of any interlock system that may be fitted.

13.14 Start-up procedures

Routine operation of an oxygen compressor may require shut-down and subsequent start-up as a normal procedure. The decision as to whether to start up directly on oxygen or on dry clean air or inert gas shall be taken by the user.

13.15 Advisory requirements

Start-up on dry clean air or inert gas is recommended on the following occasions:

- start-up of a new machine after erection;
- start-up of a machine after a prolonged standstill; and
- start-up of a machine after maintenance of the following type;
 - maintenance that has necessitated the purging of the machine with dry clean air or inert gas;
 - replacement of bearings; or
 - replacement of piston, piston rings packing, etc.

13.16 Additional requirements

Start-up on dry clean air, inert gas, or on oxygen is permissible for the following occasions:

- As a normal procedure after a planned shutdown;
- An operational stand-by machine previously on oxygen service;
- After trip or malfunction shown on investigation not to be dangerous; and
- A machine after maintenance, except the types of maintenance listed in 13.14.

14 Maintenance

14.1 General

The frequency and content of maintenance work should be based on the supplier's recommendation and the operator's experience. In the event of adverse trends being observed in machine operation the machine should be shut down for examination and remedial action taken. Regular and detailed analysis of the running data is of the utmost importance in ensuring the safe operation of the compressor. This data can be used as a guide in establishing the period between major overhauls.

It is not possible to state a precise period between major overhauls, which covers all circumstances. The period will depend upon the following:

- supplier's recommendations;
- number of hours runs;
- number of starts, since the last overhaul; and

- previous operating behaviour and history.

If the operator has insufficient capability, then it is recommended that the supplier be involved in major maintenance or repair work. The requirements and standards covered in Section 12 shall be complied with.

NOTE It has been observed that a number of fires have occurred immediately after overhauls. It is therefore recognised that internal inspections could also be the cause of an increased risk.

14.2 Purging during maintenance

Prior to performing any maintenance work on an oxygen compressor provisions shall be taken to ensure that the equipment is purged and positively isolated. It should be noted that both oxygen enrichment and oxygen deficiency can occur, due to, for example leaking flanges or defective seal systems. For safe working, the oxygen concentration around the compressor should be between 19.5% and 23.5%.

14.3 Functional test

The correct operation of the compressor trip system and the dump and isolation valves is an important contributor to the safe operation of oxygen compressors. In order to ensure operation, all the components should be recalibrated and the system subjected to a full functional test at least once every 3 years.

14.4 Cleanliness during maintenance

During maintenance of the compressor, the standards of cleanliness specified in 10.2 should be observed.

14.5 Compressor checks after shutdowns

Periodically when the compressor is stopped:

- Piston rods shall be checked for scoring, scuffing or other type of damage; and
- Distance pieces and piston rods shall be inspected for contamination or excessive oil carryover.

14.6 Compressor planned maintenance shutdowns

A maintenance schedule shall be defined for the compressor. This schedule shall define the maximum time between maintenance shutdowns and indicate the operations to be performed for overhaul, inspection, or checking of the following:

- cylinder valves, lanterns and gaskets;
- oil scrapers and piston rod surface;
- clearances of bearings;
- piston clearances;
- tightness of connecting rod bolts;
- tightness of piston nuts;
- piston rings, rider rings, and packing; and
- crankshaft deflection.

14.7 Spare parts

All components that come into contact with oxygen gas should be preserved as specified in 10.5.

14.8 Instruction manual

14.8.1 General

The instruction manual shall highlight the specific safety aspects in operating and maintaining oxygen compressors and the need for a high standard of cleanliness.

14.8.2 List of minimum information

The instruction manual should contain the following information as a minimum:

- compressor design data and performance characteristics
- description of the following systems, placing emphasis on the details which are special for oxygen service:
 - gas compression system
 - lube oil system
 - cooling system
 - control and instrumentation system
 - safety devices
- main components description:
 - piston and cylinder;
 - cylinder valves, lanterns and gaskets;
 - piston rod;
 - piston nut;
 - piston rings, rider rings, packing and stuffing box;
 - oil scrapers, piston rod and guide bearings.
- compressor operation, including start-up, shutdown and restarting procedures to safeguard the compressor
- maintenance with disassembly and assembly procedures and overhaul check list
- measures to protect the compressor during prolonged standstill
- list of materials of construction
- troubleshooting guide
- list of special tools for maintenance; and
- spare parts list and after sales service.

15 References

- [1] AIGA 071 *Centrifugal Compressors for Oxygen Service* www.asiaiga.org

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.

- [2] CGA 4.6 *Oxygen Compressor Installation and Operation Guide* www.cganet.com
- [3] Code of Practice M 034-1 *List of non-metallic material compatible with oxygen* by BAM Federal Institute for Materials Research and Testing Berufsgenossenschaft Rohstoffe und chemische Industrie www.bgrci.de
- [4] ASTM G63 Standard Guide for Evaluating Non Metallic Materials for Oxygen Service www.astm.org
- [5] API 618 Reciprocating Compressor for Petroleum Chemical and gas industry services www.api.org
- [6] AIGA 021 '*Oxygen pipeline and piping systems* www.asiaiga.org

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.

- [7] AIGA 012 *Cleaning of Equipment for Oxygen Service* www.asiaiga.org .