RECIPROCATING COMPRESSORS FOR OXYGEN SERVICE

Code of Practice

AIGA 048/08

GLOBALLY HARMONISED DOCUMENT

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1 Introduction

As a part of a programme of harmonization of industry standards, European Industrial Gases Association (EIGA) and Japan Industrial Gases Association (JIGA) have prepared this code under their joint-lead and with the participation of a number of compressor suppliers. Asia Industrial Gases Association (AIGA) has adopted this code. This document is intended as an international harmonized standard for the worldwide use and application by all members of AIGA, CGA, EIGA and JIMGA (now JIMGA). The AIGA edition has the same technical contents as the EIGA/JIMGA edition, however, there are editorial changes primarily in formatting, units and spelling.

Oxygen compression represents a special risk in that the compressor can burn violently. This code defines design and operating parameters for reciprocating oxygen compressors. Compliance with this code 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 EIGA IGC Doc 27.

1.1 Scope

This code applies to conventional ringed and labyrinth compressors having a crosshead and distance piece. Most operating experience exists in compressors above 500 Nm3/hr at pressures up to 8.5 MPa gauge with oxygen purity of 90% or greater and with max 10 ppm water (volume basis). Additionally experience suggests that at a discharge pressure below 0.2 MPa gauge 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. The authors of this code believe the document can be applied to 10 MPa gauge without further special precaution.

1.2 Philosophy

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

1.2.1 Design of the compressor system (Sections 3 & 4)

- Robust and well proven compressor design
- Safe materials in critical areas
- Comprehensive instrumentation
- Safety shutdown system

1.2.2 Cleaning, Preservation and Inspection (Section 5)

- Correct and properly enforced procedures and well trained personnel.

1.2.3 Erection, Testing and Commissioning (Section 6)

- Skilled and well trained erection personnel
- Comprehensive testing programme to verify the design.

1.2.4 Operation (Section 7)

- Well trained and experienced personnel
- Correct procedures

1.2.5 Additional Guidance

Additional guidance on installation and operation can be found in CGA G-4.6, Ref [4].

1.2.6 Planned Maintenance (Section 8)

- Condition monitoring
- Planned preventive maintenance
- Well trained and experienced person
- Personnel Protection (Section 2)
- Identification of the hazard
- Safety barriers
- Location of the compressor
- Emergency procedures

1.2.7 Common Interest

The Code 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 feed back of operating experiences makes a powerful contribution to safe operation and design. The Code requires that all those who build and operate reciprocating oxygen compressors that have been specified to comply with the Code 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 (e.g. specified operating points, normal operating range, start-up and shut-down, etc).

1.2.8 Other Specifications

In case of conflict between this Code and the user's specification the information included in the order shall take precedence. The supply shall be in conformity with the rules of the country of the user and/or of the supplier.

1.2.9 Terminology

Although this code has no mandatory character, a clear distinction must be made between "should" and "shall".

"Shall" indicates a very strong concern or instruction.

"Should" indicates a recommendation.

1.2.10 Oxygen Compatibility

Non-metallic materials that have been tested and shown to be suitable by B.A.M., see Ref.[8], are acceptable. Additional information can also be found in ASTM Standards, see Ref. [9].
This does not preclude other methods of determining compatibility by other independent bodies, customers and suppliers.

1.3 Application of the Code

1.3.1 Oxygen Purity

This Code of Practice is based on experience in manufacturing and operating reciprocating oxygen compressors and it is applicable to those machines operating on dry gases containing 90% oxygen and above, and less than 10 ppm water (volume basis).

1.3.2 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 Code shall be considered for reciprocating compressors operating on oxygen enriched gases, and the degree of implementation shall be agreed between supplier and user.

1.3.3 Moisture

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

1.3.4 Discharge Pressure

The recommendations in this Code are based on the experience gained in the compression of oxygen up to 10 MPa gauge.

1.3.5 Suction Pressure

Traditional experience is with compressor suction pressure of less than 0.2 MPa gauge. 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.

1.3.6 Driver

The majority of experience has been with the use of constant speed electric motor drivers. The code has been written giving the best solution for this type of driver. However where another type of driver, e.g. variable speed electric motor requires a different solution, this has been clearly pointed out in the code (resonance, vibrations, and lubrication issues).

1.4 Definition of Terms

1.4.1 Normal Operating Range

The normal operating range is the range for which the compressor was specified and ordered.

1.4.2 Hundred-Percent Speed

The highest speed to meet all specified operating points.

1.4.3 Maximum Continuous Speed of the compressor

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

1.4.4 Maximum Operating Temperature

This is the highest temperature, which can be measured anywhere in the main gas stream, under the most severe operating conditions. See 4.7.3

2 Compressor Installation

2.1 Hazard Area

2.1.1 Description

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

The hazards that may result from a compressor fire are:

- Jets of molten metal
- Projectiles
- Flash
- Blast and overpressure
- 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.

2.1.2 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 then the code requires that 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 above 2 MPa gauge discharge pressure. However, in current practice, most users have adopted a 0.4 MPa gauge limit. National regulation may require a safety barrier for less than 0.4 MPa gauge.

2.1.3 Access to the Hazard Area

When the compressor is operating on oxygen, access to the hazard area is not permitted and warning notices to this effect shall be posted. Visual inspection can be done by using for example remote camera.

Before entering the hazard area, after the compressor has been shutdown or changed over to dry air or nitrogen, the atmosphere within the enclosure shall be analysed to ensure that it is safe to enter. It is recommended that the oxygen concentration should be between 19.5% and 23.5%.

2.1.4 Equipment Location

2.1.4.1 Equipment that shall be within the Hazard Area

- Compressor
- Compressor gas coolers and inter stage piping
- Throttling valves and downstream piping to the first elbow or tee – e.g. recycle valve
- The first elbow in each pipe to and from the compressor, cylinder, or pulsation bottles
- Piping components subject to sonic flow velocities or high velocity impingement

2.1.4.2 Equipment that shall be Outside the Hazard Area

- All operator controls
- All instrumentation readouts
- Alarms and shut-down indicators
- Emergency shut-down devices
- Separate lube oil reservoir
- All valves requiring manual adjustment while the unit is operating on oxygen service.

2.1.4.3 Equipment that may be either inside or outside the Hazard Area

2.1.4.3.1 Automatic Isolation Valves

The code requires that the 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.

2.1.4.3.2 Emergency vent valve(s), purge valve, relief valves

Refer to diagram and associated tables in 4.7. .

2.1.4.3.3 The Driver

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:

a) If the motor is fitted with hydrodynamic bearings then migration from the bearings should be prevented.

b) The safety barrier ventilation should be arranged in such a way 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.

2.1.5 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.

2.1.6 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. .

2.2 Safety Barrier

2.2.1 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 above by preventing flames, jets of molten metal or projectiles from penetrating or collapsing the barrier in the event of an oxygen fire, which has caused “burn through” of any of the oxygen containing equipment within the hazard area.

2.2.2 Responsibilities

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

2.2.3 The Nature of “Burn Through”

2.2.3.1 Likely Burn Through Positions

The majority of fires starts 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 seat of the fire where the gas pressure is high and the thermal mass small therefore the primary risk areas are:

a) The compressor cylinders and suction /discharge valves
b) The compressor distance piece.
c) The first elbow in the process pipe work immediately upstream and downstream of the compressor flanges.
d) The recycle valve and its associated outlet pipe and the first downstream bend.
e) The damping capacity and coolers.
f) Drain and vent connections
g) Piping around safety valves

2.2.3.2 The Results of “Burn Through”

2.2.3.2.1 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 barrier shall also be strong enough to withstand the impact of the jet.

2.2.3.2.2 A spray of molten metal

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

2.2.3.2.3 A blast and overpressure effect

This is caused by the release of high-pressure gas. This 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.

2.2.4 Strength & Burn Through Criteria

The barrier shall withstand the force resulting from the impact of a jet of molten metal issuing from a hole burnt in the compressor or pipe work, hitting the safety barrier, plus the overpressure due to the release of the stored inventory of the oxygen. The above 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 projected over the wall area. This value is based on the accumulated experience of members of the Working Group.

The barrier shall be designed to resist the effect of a jet of molten steel for 30 seconds without being breached. (See 2.2.5 - materials of construction).
Therefore, the design shall consider the following load types:

- Sustain temperature of molten metal
- Blast and overpressure
- Projectile impingement

2.2.5 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 2.2.4 - strength and burn through criteria). 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. Great 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 in such a way that it is prevented from being broken up by the force of the jet. Field trials by one of the working group members has 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 equal and shall meet the required strength criteria:

2.2.6 Layout of the Safety Barrier

The barrier shall meet the following criteria:

Vertical sides shall extend 1m above the height of any part of the compressor or piping that contains oxygen and no less than 2.5m above the walking area.

The barrier shall block any line of sight to permanently installed platforms or buildings within 30m 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, the wall shall provide a complete unbroken barrier with no weak spots. Access doors, which have latches, shall be provided with anti panic bars.

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 pressurizng the enclosure. The following ways of achieving the required open area are recommended:

a) A permanently open area with acoustic splitters.
b) Acoustic louvers, which are self-opening. These can be bought as proprietary items.
c) Acoustic doors, which are self-opening, hinged so as to have a small angular moment of inertia.
d) Concrete or steel caps, which are lifted by the gas pressure, provided that the caps are adequately restrained.

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

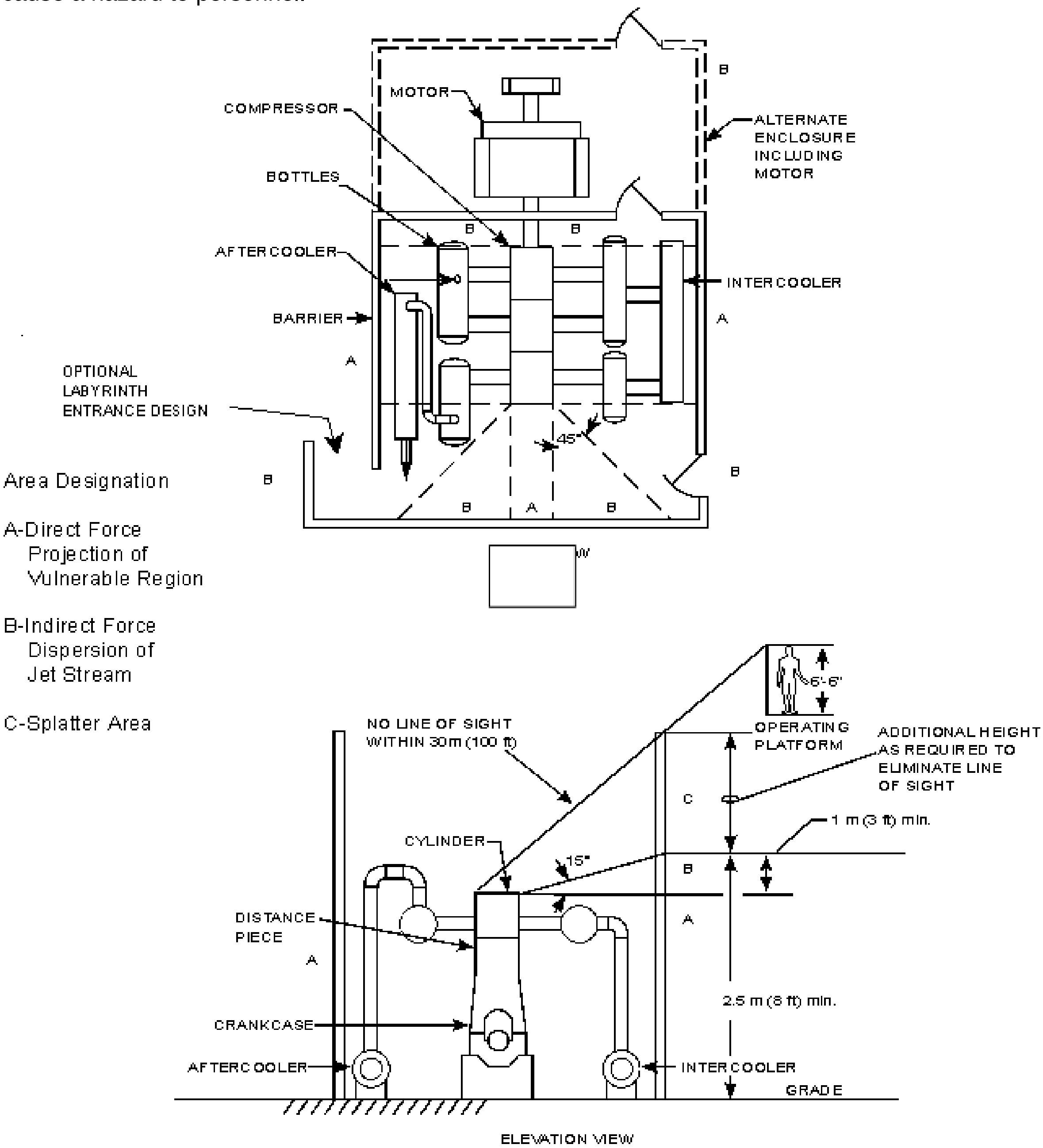


Figure 1

2.2.7 Safety Barrier Miscellaneous Design Features

2.2.7.1 Oxygen Accumulation

Since oxygen is denser than air it tends to accumulate in depressions or enclosed spaces. It is preferred 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.

2.2.7.2 Nitrogen Asphyxiation Hazard

If the compressor has the facility for test run on Nitrogen or Nitrogen is used for the purge gas then an asphyxiation hazard can exist. The barrier should be designed with at least two outward opening exit doors at each level and sufficient walkways to allow quick exit.

2.3 Location

2.3.1 Safety of Personnel and Plant

It is preferred 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.

2.3.2 Erection and Maintenance

The location shall be such that 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.

2.3.3 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.

2.4 Fire Protection and Precautions

2.4.1 Introduction

Fires in oxygen compressors, once started, 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 the above 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 fire fighting equipment.

2.4.2 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.

2.4.3 Protection of Personnel

Entry into an area of fire is to be discouraged and may only be justified where human life is at risk.

When a person has been in contact with an oxygen enriched atmosphere his clothes may have become saturated with oxygen and even when he has returned to a safe area he shall be careful not to approach any source of ignition (e.g. matches or an electric fire) until he has changed his clothes.

3 Compressor Design

3.1 Design Criteria

3.1.1 Possible Causes of an Oxygen Compressor Fire

It is normally very difficult to ascertain precisely 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 reciprocating oxygen compressor both active and passive safety measures must be taken to guard against any of the situations below leading to ignition:

- Mechanical rub, friction:
  Design, clearances, vibration, etc. operating pressure, assembly errors, bearing failure, alignment, improper inter-cooling, start-up/shut down instability (may include shock, adiabatic compression).

- Debris Impact:
  Screens - sizing or break-up, weld debris or slag, (friction/shock) maintenance debris, shot, sand.

- Oil:
  Faulty design of bearings/seals and/or faulty design of associated vents and drains.

- Resonance:
  Debris in dead areas.

- Cooling system: design the system to avoid concentrating ethylene glycol in the process arising from leakage.

3.2 Materials, General

3.2.1 Construction Materials

When selecting materials of construction for an oxygen compressor, it is desirable that 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; low heat of combustion.

3.2.2 Use of Aluminium

Because of its high heat of combustion the use of aluminium shall be limited for O_2 wetted or potential O_2 wetted parts. However, aluminium will not sustain combustion at certain pressures and purities.

One such condition agreed by Working Group Members for piston construction is up to 1.4 MPa gauge with O2 purity 97%. Anodized aluminium is acceptable within the constraints above.

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

3.3 Compressor parts: cylinders, cylinder liners, distance piece and crankcase

3.3.1 Cylinders and cylinder liners

3.3.1.1 Cylinder and cylinder liner Material

The following materials have proved satisfactory with regard to the criteria listed under section 3.3:

- Grey cast iron
- Nodular cast iron
- High alloy steel - cast or fabricated.
- Welding of cast-steel and fabricated steel casings is permitted if the execution and heat treatment are properly conducted.

3.3.1.2 Repairs

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

3.3.1.3 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 so as to prevent it from creeping and projecting into the inside of the machine. If required, threads shall also be sealed by materials that are compatible with oxygen.

3.3.1.4 Anti-galling Compound

If an anti-galling compound is to be applied to centering fits, bolts, studs, etc. only compounds compatible with oxygen service shall be used. Molybdenum disulphides in powder form have proved their value for oxygen service. Compounds shall be mutually agreed.

3.3.2 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.
The interior of each distance piece should be painted white to detect presence of oil or pollution. Piston rod slinger shall be provided to form a positive barrier against oil migration along the rod. Open distance piece is recommended to prevent oxygen enrichment. If distance piece covers are provided in case of hostile or polluted environment, 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 should be analysed continuously at the vent of the distance piece. Oil migration shall be checked on a regular basis.

3.3.3 Cylinder Valves

Compressor valves contain thin materials and represent a particular hazard. No firm rule exists for the design and construction of valves. Therefore only proven design shall be used. Actual experience of the members of the working group is listed here under but not limited.

3.3.3.1 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.

3.3.3.2 Materials 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
Nut: austenitic stainless steel.

3.3.4 Piston

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

3.3.5 Piston rod

Suitable materials for pressure above 4.5 MPa include K-Monel. Martensitic stainless steel can be used below 4.5 MPa gauge.
If a piston rod coating is used, it shall be of a proven technology that includes chrome plating or nitrited steel, or tungsten carbide coating.

3.3.6 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 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 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 150% equal to the diametral 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.

3.4 Drivers

3.4.1 Drivers in Hazard Area

It is permitted for the drivers to be in the hazard area (See hazard area equipment location). If they are then they shall be designed in such a way that oil or oil vapour is prevented from escaping there from.

3.5 Compressor Dynamic Analysis, Verification Tests and Data to be provided

3.5.1 Introduction

Note: This code basically follows internationally recognised standards and practices.

Due to their physical nature any responding vibrations or pulsations that occur can always be related either 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.

3.5.2 Pulsations limits

Pulsation level shall be not higher than API 618 Approach 1, within the limit of the OEM's scope

3.5.3 Vibration Limits

For stroke of 250 mm and less, vibration level shall be not higher than 12 mm/s RMS on compressor, and 20 mm/s RMS on piping system.
For stroke greater than 250 mm, vibration level shall be not higher 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.

3.6 Electrical Discharge

3.6.1 Earthing / Grounding

Great care shall be taken to earth 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 equipments shall be ensured with the appropriate devices.

4 Auxiliaries Design

4.1 Cooling

4.1.1 Scope of Supply

It is recommended that the coolers be supplied by the compressor supplier as it is his ultimate responsibility to ensure that the whole of the machine be 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 correct materials to be selected.

4.1.2 Types of Cooler

Any type of cooler can be accepted, provided that materials are oxygen compatible and that cleaning can be achieved (See also 5.3)

4.1.2.1 Design features - Specific to Coolers with gas in the Shell

As this type of cooler has “cooler heads”, containing the water return channels, in the oxygen side of the cooler, due care shall be taken with the jointing to minimise the risk of leaks between the oxygen and watersides.

4.1.2.2 Design features - Specific to Coolers with gas in the Tubes

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

4.1.2.3 Design features common to both types of Cooler

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

They shall have removable tube bundles.

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

When the tubes are expanded into the tube plates the lubricant used shall be oxygen compatible.

4.1.2.4 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 alloy or stainless steel.

Provided that the cooling water is of a suitable quality the most commonly used materials are Muntz metal for the tube plates and admiralty brass for the tubes. The fins are normally made of copper.

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.

4.1.2.5 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:

a) It requires special equipment to clean it after assembly or reclean it if it becomes contaminated.
b) 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.

4.1.2.6 Establishment and Maintenance of Oxygen Cleanliness - Gas in plain 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.

4.1.3 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.

4.1.4 Closed circuit cooling system

Closed circuit cooling water systems are often filled with water containing up to 50% ethylene glycol. Ethylene glycol is flammable and will concentrate if it leaks into an oxygen system and the water evaporates. Members have good experience with closed circuit systems having 50% ethylene glycol but such systems shall have all low points checked for leakage.

4.2 Pulsation and damping

Because of the dangers resulting from the fractures of pipes or other components, both mechanical vibration and gas pulsation must be limited. Pulsation can be limited by either pipe work 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 must be suitable for use with oxygen at the pressure and velocities concerned. It is recommended to define admissible pulsation limits in accordance with API 618, last edition.

Special care to ensure cleanliness must be taken 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.

4.3 Process Pipe work

AIGA 021/05 /EIGA IGC 13/02 “Oxygen pipeline Systems” harmonized Code Ref [2] states that it does not apply to oxygen compressor units. However compressor process piping specification, fabrication, cleaning and inspection shall follow the criteria shown in Sections 5 to 7 of reference code.

4.3.1 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 will include 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.

4.3.2 Vents to Atmosphere

Vent outlets shall be directed away from personnel and shall be located in such a way 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 pipe work shall preclude the accumulation of water.

4.3.3 Special Piping

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

a) They operate infrequently and for a short duration.
b) They 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 pipe work downstream of the device is sufficiently low to permit the pipe work 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 be not less than twice the diameter of the suction piping.

4.3.4 Bellows

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

4.3.5 Acoustic and Thermal Insulation

Pipe external acoustic and thermal insulation material 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 the material used. Pipe internal insulation is not permitted by the Code.

4.3.6 Silencers

Silencers are forbidden in the recycle or inter-stage pipe work. 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 fitted, 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.

4.4 Valves

4.4.1 Isolation system

Isolation system (manual valves, automatic valves, and check valves) shall be according to diagram in 4.7.8

4.4.2 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 recommendations in 4.3.3 shall apply.

4.5 Main Suction Filter

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

4.5.1 Rating

The filter rating should be 150 micron maximum.

4.5.2 Materials

The filter media should be preferably manufactured from Cu-alloy or Ni-alloy. Stainless steel shall not be used above 0.2 MPa gauge. If non-metallic materials are used then they shall be oxygen compatible. In both cases the materials used shall be approved by both supplier and user.

4.5.3 Design

In designing the filter, due regard shall be given to providing adequate strength so as to avoid failure of the filter element by the following causes:

- Differential pressure through partial or total blockage.
- Pressure pulsations
- Abrasion by supporting elements

Where particle separators are used the design should take into account the possibility that separated material may lift due to a sudden pressure drop.

4.5.4 Flow Direction

The filter unit shall be designed so that all attachments are upstream of the filter elements so as to be contained within the elements should failure occur.

4.5.5 Precaution against Installation Errors

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

4.5.6 Inspection

The filter element shall be easy to remove for inspection and cleaning. During removal it should fully retain all foreign particles.

4.6 Lubricating Oil System

4.6.1 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 pipe work 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 so as to avoid the possibility of lubricating oil dripping onto pipe work or other equipment.

4.6.2 Pumps

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

4.6.3 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. 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.

4.6.4 Crankcase Vents

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

4.7 Controls and Instrumentation

The capacity control shall be designed, manufactured and operated with special 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.

4.7.1 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 tabulated in 4.7.6. All measurements taken inside the hazard areas whilst the machine is on oxygen service shall be remotely read in a safe environment.

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.

If a fluid is used in a pressure transducer that is in contact with oxygen, then it 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 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.

4.7.2 Recycle System

Cooling will be required if recycle oxygen can cause excessive temperature in the machine.

4.7.3 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 preset levels. The tripping temperatures will be related to and in excess of the maximum normal operating discharge temperature experienced. However, maximum normal values are recommended: 170°C for ringed compressors, 200°C for labyrinth compressors

4.7.4 Vibration

Compressors shall be provided with a vibration shut down system. .

4.7.5 Compressor Isolation and venting

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

4.7.5.1 Non-Automatic Isolation and Vent Valves

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

4.7.5.2 Non Return Valve

A non-return valve shall be installed in the discharge pipe work of each compressor. This valve should be down stream of any recycle branch. A plate type check valve is recommended. Any type of swing type check valve shall not be used.

Non-return valves shall be marked with an arrow to indicate correct direction of flow. The non-return valve may be of the same design and materials as the compressor stage valves.

4.7.5.3 Automatic Isolation Valves

In addition to the suction and discharge isolation valves (4.7.7 & 4.7.8), an automatically actuated fast-acting isolation valve shall be installed in the suction pipe work when the normal suction pressure is greater than 0.1 MPa gauge and in the discharge pipe work. These valves shall be arranged to close on every routine shutdown or trip, and on instrument air failure or electrical failure.

4.7.5.4 Automatic Vent Valves

To limit the duration and extent of any fire, which 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 and discharge the bulk of gas contained in the compression system quickly to atmosphere. Experience with such 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 gauge 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 gauge 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.

4.7.6 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	Suction filter diff. pressure	Σ	**(Hi)**	**-**	
1.4	Compressor suction temperature	Σ	**(Lo)**	**-**	
1.5	Temperature of main gas stream at each process stage outlet (See 4.7.3).	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	Filter diff. 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])**	
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 after the oil cooler is recommended for unattended plant**

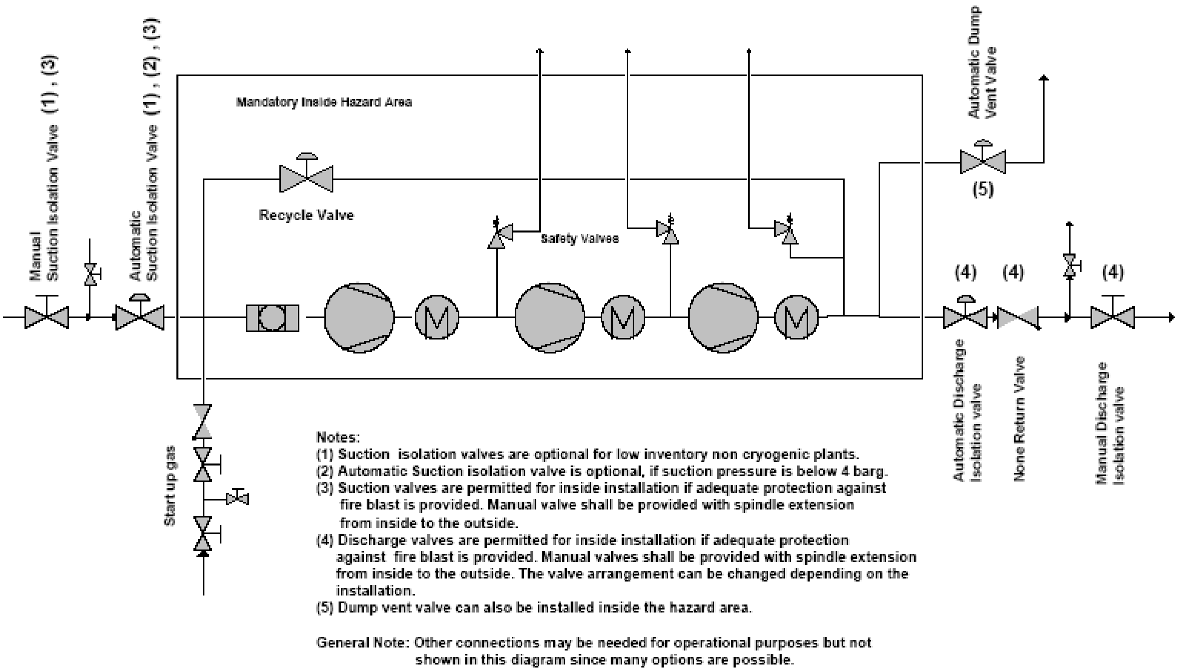
4.7.7 Failure Modes and Operating Speeds of System Valves

VALVE DUTY	On Compressor Shutdown	On Loss of Electrical Signal	On Loss of Motive Power	SPEED OF ACTION
Automatic Suction isolation valve	Shut	Shut	Shut	10 secs max
Automatic Discharge isolation valve	Shut	Shut	Shut	10 secs max
Dump Vent	Open	Open	Open	2 secs. max. auto reclose after depressurization

a) 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 to open.

b) The failure mode and operating speed of the recycle valve is not related to safety

4.7.8 Reciprocating Oxygen Compressor System flow diagram



5 Inspection and Shipping

5.1 Introduction – Code

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. This latter implies pipe work to be site fabricated.

Any combination between the two above extremes is also possible.

5.2 Responsibility

Whatever the extent of prefabrication there shall be a "designated" person responsible for ensuring that the compressor is correctly built. On request, supplier shall provide from his staff an experienced oxygen compressor erector, who will be in charge of the unit till 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 extend back to the supplier's and major sub supplier's works.

5.3 Inspection and Cleanliness Standards

Cleaning methods and acceptance criteria to be followed shall be those shown in AIGA 012/04 "Cleaning of equipment for oxygen service" Ref.[3]. Given hereunder are:

a) Some comments on topics that are specific to reciprocating oxygen compressors.
b) A summary for the convenience of code users.

5.3.1 Extent

The criteria "clean for oxygen service" shall apply to:

a) All parts that come in contact with oxygen;
b) Systems that supply gas to the oxygen compressor (e.g. start up gas) shall comply to the extent that the gas supplied is free of particles and hydrocarbons.

5.4 Preservation of Oxygen Cleanliness during Shipping and Storage

5.4.1 Equipment

All equipment sent to site "clean 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. The only methods of preservation, which are acceptable to the code, are as follows.

5.4.2 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.

5.4.3 Sub-assemblies, which can be made Pressure Tight

5.4.3.1 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.

Example: Gas in shell cooler with a zinc coated shell.

5.4.3.2 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:

a) 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.
b) 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.
   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.

5.4.4 Arrival on Site

When oxygen clean 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 “clean for oxygen service”.

6 Erection and Commissioning

Note: With the increased emphasis on packaged compressors it is probable that some of the work described in this section will be done in the supplier’s works.

6.1 Erection

6.1.1 Responsibility

(See 5.2 - inspection and shipping).

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 under 5.3 - inspection and cleanliness standards 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 “clean for oxygen service”. It should also record the inspection method used, e.g. ultra violet light, solvent analysis, etc.

6.1.2 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.

6.1.3 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.
- An 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.

6.2 Testing and Commissioning

6.2.1 Introduction

In some instances 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 must be adapted to the circumstances presented by the specific installation while meeting the objectives stipulated below.

6.2.2 General

Any instrumentation required for testing the machine, e.g. pressure gauges, 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, gas and oil pipe work shall be subjected to a pressure test, unless specified elsewhere in the code. The type of test and test pressure shall be agreed between supplier and user.

6.2.3 Testing Objectives

It is not permitted to put the compressor into oxygen service unless the testing has achieved the following objectives:

a) Demonstration of the mechanical integrity of the complete compressor system over the predicted operating range.
b) Verification of the predicted operating temperatures.
c) Functional demonstration of the instruments and controls.

6.2.4 Tests to be carried out

6.2.4.1 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 compressor:

a) Cylinders and rods shall be checked for scoring, scuffing or other types of damage
b) Distance pieces and piston rods shall be inspected for contamination or oil carryover.
c) 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.
d) Piston to cylinder clearances shall be checked and logged again.

6.2.4.2 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:

a) Alarm and trips
b) Shutdowns
c) All interlocks
d) Recirculation and vent valves
e) Isolation valves

6.2.5 Commissioning on Oxygen

6.2.5.1 Preparation for the initial run on oxygen

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

a) All the test objectives have been met.
b) The entire compressor system has been certified “clean for oxygen service”.

c) That run in with inert gas or dry air has been successfully performed and no leaks and/or abnormal running conditions have been detected.
d) 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.
e) The hazard area is clean and tidy and free from all combustible materials and fully functional

6.2.5.2 Initial Run on Oxygen

Before running the compressor on oxygen, the hazard area shall be cleared of all personal. 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 indicated should be logged at short intervals (about every 15 minutes). After about four hours of operation readings may be taken and logged at hourly intervals.

7 Operation

7.1 General

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

7.1.1 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.

7.1.2 Machine Rubs

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

7.1.3 Machine Vibrations

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

7.1.4 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 un-pressurized condition. The resulting scale can serve to promote ignition in the compressor.

7.1.5 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 indicate 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 run in can cause asphyxiation.

7.1.6 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 and therefore their performance shall be routinely monitored so that a potentially hazardous condition can be avoided.

7.2 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.

7.3 Hazard Area

If it is considered necessary to enter the hazard area for the analysis of defects when the machine is operating it must first be changed over to dry clean air or inert gas. It should be noted that, in the vicinity of the hazard area, both an oxygen enrichment and an 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%.

7.4 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.

7.5 Monitoring Critical Operating Parameters

Critical operating parameters should be monitored at least once per shift. 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. No readings are to be taken within the barrier unless it can be done through an inspection port.

7.5.1 Trip Override

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

7.6 Interlock Systems

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

7.7 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 must be taken by the user.

7.7.1 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
- Star-up of a machine after a prolonged standstill
- 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
    - Replacement of piston, piston rings, packing, etc…

7.7.2 Additional Requirements

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

- Start-up as a normal procedure after a planned shutdown.
- Start-up of an operational stand-by machine previously on oxygen service.
- Start-up after trip or malfunction shown on investigation not to be dangerous.
- Start-up of a machine after maintenance, except the types of maintenance listed above in 7.7.1.

8 Maintenance

8.1 General

8.1.1 Method

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 shutdown 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:

- The supplier's recommendations;
- The number of hours runs;
- The number of starts, since the last overhaul;
- The 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 6 must be complied with.

Note: It has been noted 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.

8.1.2 Purging during Maintenance

Prior to conducting 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 an oxygen enrichment and an 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%.

8.1.3 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 correct operation, all the components shall be recalibrated and the system subjected to a full functional test every 3 years at least.

8.1.4 Cleanliness during Maintenance

During maintenance of the compressor the standards of cleanliness specified in 5.3 - inspection and cleanliness standards should be observed.

8.2 Compressor Checks

8.2.1 Compressor Checks after Shutdowns

Periodically when the compressor is stopped:

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

8.2.2 Compressor Planned Maintenance Shutdowns

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

a) Cylinder valves, lanterns and gaskets.
b) Oil scrapers and piston rod surface.
c) Clearances of bearings.
d) Piston clearances.
e) Tightness of connecting rod bolts.
f) Tightness of piston nuts.
g) Piston rings, rider rings and packing
h) Crankshaft deflection.

8.3 Spare Parts.

All components that come into contact with oxygen gas should be preserved as specified in 5.4 Preservation of Oxygen Cleanliness during Shipping and Storage.

9 Instruction Manual

9.1 General

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

9.2 List of Minimum Information

9.2.1 Instruction Manual

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

a) Compressor design data and performance characteristics.

b) 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

c) 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

d) Compressor operation, including start-up, shutdown and restarting procedures to safeguard the compressor.

e) Maintenance with disassembly and assembly procedures and overhaul check list.

f) Measures to protect the compressor during prolonged standstill.

g) List of materials of construction

h) Troubleshooting guide

i) List of special tools for maintenance.

j) Spare parts list and after sales service.

10 References

[1] AIGA 005/04 'Fire hazards of oxygen and oxygen enriched atmosphere'
[2] AIGA 021/05 'Code of Practice - Transportation and distribution of oxygen by pipeline'
[3] AIGA 012/04 'Cleaning of Equipment for Oxygen Service'
[4] CGA 4.6 Oxygen Compressor Installation and Operation Guide.
[5] CGA 4.1 Cleaning equipment for oxygen service
[6] ISO-10816-6 Mechanical vibrations for non-rotating parts
[7] API 618 Reciprocating Compressor for Petroleum Chemical and gas industry services
[8] Liste der Nichtmetallischen Materialien die von der BAM zum Einsatz in Anlagenteilen für Sauerstoff als geeignet befunden worden sind (zu Merkblatt M034 „Sauerstoff“ (BGI 617)
[9] ASTM G63 Standard Guide for Evaluating Non Metallic Materials for Oxygen Service