

LARGE HIGH PRESSURE CENTRIFUGAL COMPRESSORS FOR OXYGEN SERVICE

by

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ABSTRACT

Centrifugal compressors have been used to compress oxygen for at least 25 years. Until ten years ago, the flows were relatively small and discharge pressures were relatively low. In the mid 1960's the size of single train oxygen plants increased dramatically, and this allowed discharge pressures from the centrifugal machine in the 28 to 41 bar range.

Change in the design and installation of centrifugal oxygen compressors evolved in the late 1960's as a result of the increase in both size and discharge pressure. It also made consideration of 69 bar discharges possible after experience was gained with the 41 bar discharge level.

The rapid change in the state of the art of application of centrifugal compressors to oxygen service in conjunction with the known hazards of the gas has prompted this discourse. Consideration will be given to the application including safety features, materials of construction, cleanliness required, desirable installation and maintenance features and the present and projected design limits for these centrifugal compressors.

INTRODUCTION

Oxygen as a component of the atmosphere in which we live is vital to our existence and relatively safe and easy to deal with. In its pure form, however, it can be extremely dangerous if not handled properly. Since the very early days of the air separation industry, oxygen has been compressed to high pressures, (69 to 138 bar).

However, at that time, the volumes of gas were relatively small and compression was accomplished by the means of either reciprocating compressors or liquid pumps. The increase in air separation plant sizes in the past ten years has made the use of centrifugal compressors for oxygen service more attractive. In the early 1960's applications of centrifugal compressors for oxygen service involved a single casing compressor with discharge pressures of between 17 and 21 bar,

dependent upon the inlet pressure. These single casing units were applied to plants with a capacity of 300 to 400 short tons of oxygen per day. Plants in the range of 600 short tons per day of oxygen allowed adequate flow in the last impeller to justify pressures between 28 and 34 bar. This necessitated a two-casing compressor, and as plant sizes increased eventually allowed for the utilization of the second casing to the nominal 41 bar discharge pressure.

Many of these 28 and 41 bar pipeline pressures were used to serve the steel industry. The steel industry requirements were lower, normally in the 17 to 21 bar level; however, the higher pressures were used to provide gaseous storage. In 1970 two centrifugal compressors discharging oxygen at 65 bar were furnished for a partial oxidation process at a plant in Germany. A limited number of high pressure compressors are now on order, however successful operation of the initial units built five years ago has prompted the same customer to order another unit in the past year. Figure 1 shows such a unit.

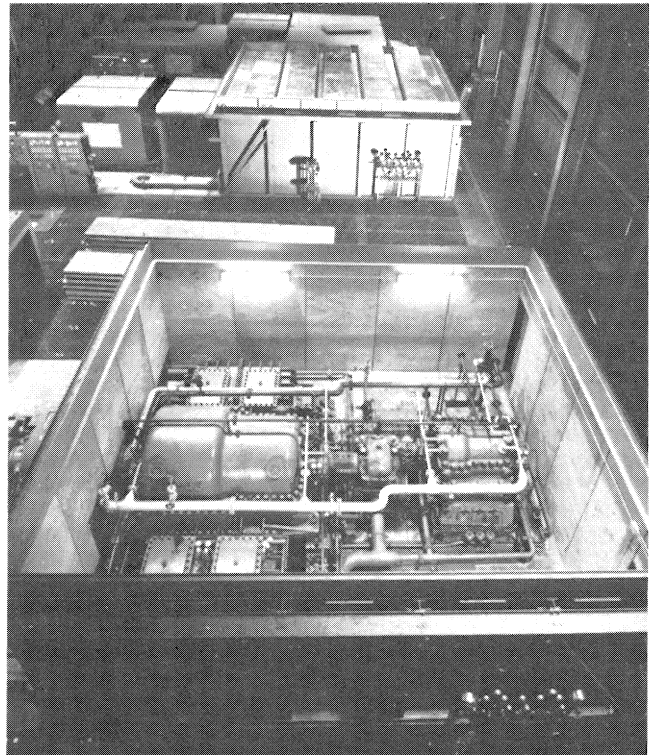


Figure 1. Oxygen Compressors. Two-casing Centrifugal Oxygen Compressors installed in an air separation plant in Germany.

Flow = 47088 m³/h, inlet pressure = 1.03 kp/cm², discharge pressure = 67 kp/cm², Power = 11000 kW, Speed = 7840/12450 RPM

The compressor casings are surrounded by fire walls, and covered on the top with sound absorption parts.

From the foregoing you can see that the application of centrifugal oxygen compressors has evolved over the past quarter of a century with plateaus ten years ago when the industry went to two-casing units and then within the last five years when 69 bar oxygen compressors were built.

Currently the U.S. production of gaseous oxygen is over 25 billion cubic feet per month averaged quarterly, and with an expected growth rate of approximately 5% per year. A trend to larger plants to more economically satisfy these needs will give preference to the application of centrifugal compressors.

With this background, I will now discuss the four (4) areas which affect the application and operation of the centrifugal compressors for this service. The areas to be covered include: machine design; installation considerations; operation of the compressor; and maintenance of the compressor.

DESIGN

The design of the centrifugal compressor is the responsibility of the manufacturer who in addition to good machine design practices, must rely heavily upon his experience in applying centrifugal compressors for oxygen service. Particular attention must be given to the following:

- A. Rotor stability to preclude component rub within the compressor is extremely important. The current state of the art of rotor dynamics calculation, which is described in an advisory issued by the Compressed Air and Gas Institute, is a very significant tool. In order to check the rotor dynamics calculations, some users will conduct a full capacity field test on the compressor utilizing a mixture of 75% nitrogen and 25% carbon dioxide to simulate the characteristics of oxygen without the risk of the hazards of oxygen.
- B. Because of the nature of the gas its temperature must be limited, and this limit is defined by the Code of Practice established by the European Working Panel at 200°C. To accomplish this, multi-stage centrifugal compressors must be intercooled.
- C. The materials of construction must be considered with regard to their compatibility with oxygen as well as their physical and thermal properties for both normal and abnormal operation. Silver for instance is considered as a material for labyrinth seals, so that in case of a component rub its softness and low melting temperature (900°C) allows it to relieve itself without ignition, which is estimated to be above 1500°C in an atmosphere of oxygen at 1 bar pressure. The high conductivity properties of silver also contribute favorably in that it allows the heat to be carried away from the local area. For casing and casing parts, cast or nodular iron is normally preferred to cast steel in that the oxide of iron is normally in a fine powdered form, which has a reasonable chance of passing through the machine without incident, whereas steel under heavy corrosion will have a tendency to flake. The casing material, of course, is a preference since there is a point at higher pressures where steel must be used because of its strength characteristic.

The seal bodies for inserts are generally made of non ferrous materials, so that if a massive rub should occur, which would wipe out the silver labyrinth tips, the contact between two ferrous materials would be avoided as seen in Figure 2.
- D. The design of the machine must provide for a positive separation of the gas and hydrocarbons (oil). Specifi-

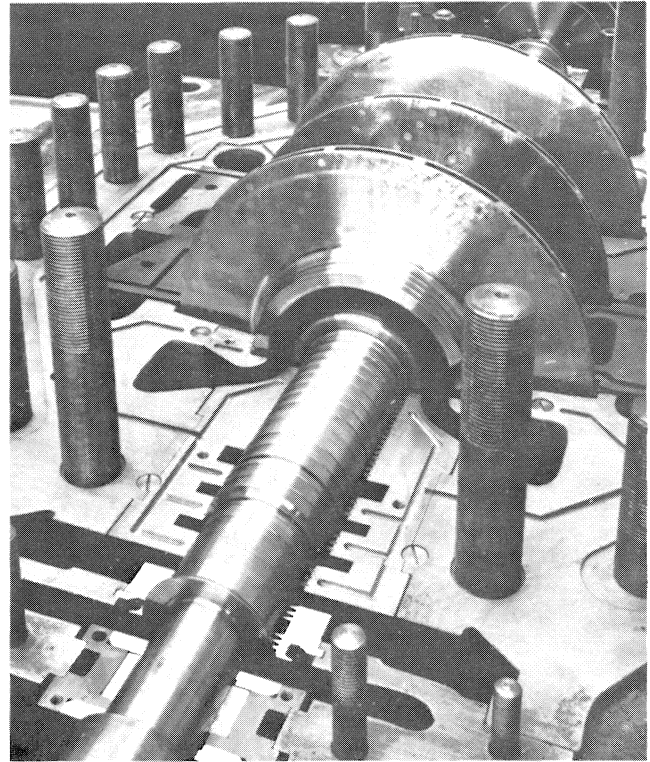


Figure 2. Bronze Inserts with Silver Tips for multi-chamber labyrinth sealing system in the high pressure part of a two-casing centrifugal oxygen compressor. Flow = 1375 m³/h, inlet pressure = 18.28 kp/cm², discharge pressure = 41.82 kp/cm², speed = 11,025 RPM. For this application (high pressure) the impellers are also of bronze.

cally the bearing housings must be separate from the casing to provide atmospheric space between the labyrinth seal and the bearing housing. Most recent designs carry this further by adding a purge to the bearing housing seals to further assure this separation. Shafts are designed with either a step or a slinger between bearing and the oxygen immersed portion of the shaft.

The machine must also be designed so that it can be easily cleaned for oxygen service. Cleanliness is extremely important, and a machine that can be easily cleaned for oxygen service probably will be cleaned better. Dead air spaces and blind areas, which must be cleaned and flushed because they are in contact with the oxygen gas, should be avoided. These design features should be developed in conjunction with shop and service personnel to avoid pitfalls. Figure 3 shows a view of such a facility.

Because of the complexity of the design function and the fact that this paper is directed toward the application of centrifugal compressors for oxygen service, the items listed represent only the major considerations that must be taken into account for the design of these compressors.

INSTALLATION

The installation of a centrifugal oxygen compressor requires the same good engineering design practices that we use for other turbo-machinery installations. In addition, there are

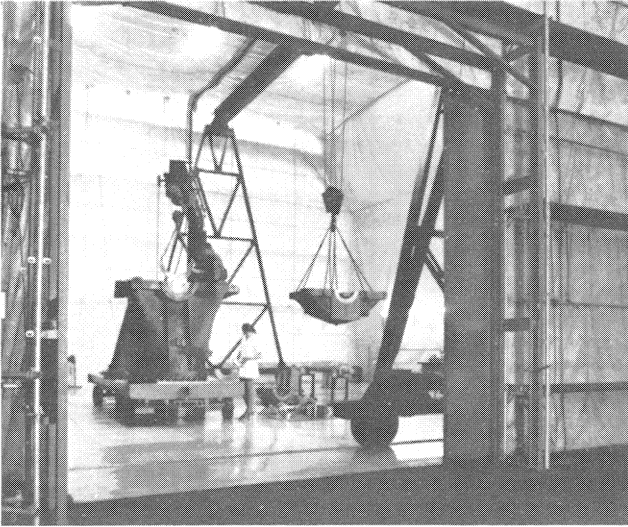


Figure 3. "Clean-Room" in the large assembly hall of the Duisburg factory. It fulfills the cleanliness conditions necessary for the final assembly of turbo compressors for oxygen. All equipment can easily be kept clean; an overpressure inside the tent room prevents the entry of dust.

several features requiring special attention when considering an oxygen compressor application. These fall into two general categories, one being the accessory equipment, and the second the environment of the compressor.

First of all, let's consider the accessory equipment:

- A. The lube oil system in addition to providing adequate lubrication for the compressor and its accessories must also be designed to prevent the mixing of hydrocarbon vapors and oxygen. The removal of hydrocarbon vapors from the area of the compressor is provided for by the proper design of lube oil drain piping utilizing partially full drain lines to allow carry-over of vapor and a purge system backed up by an eductor or vacuum blower on the lube oil tank. These vapors should be piped to the outside of the compressor house away from the oxygen producing equipment.

Another factor to be considered is the operation of the auxiliary lube oil pump. An auxiliary lube oil pump, designed to start on low oil pressure, can in the case of a compressor incident contribute to the proliferation of a fire. This can be avoided by an automatic shut-down of the auxiliary oil pump should the compressor be taken off the line by the fire protection system.

- B. A filter or strainer should be installed at the inlet to the compressor. This filter according to the European Code of Practice should remove all particles larger than 150 microns in diameter. It must be made of material compatible with the oxygen, and it must be adequately designed and braced to be able to withstand the maximum differential pressure and/or turbulence that it may be subjected to. In his paper delivered at the CGA Symposium on oxygen compressors, bibliography reference four page 26, Mr. Connally of AIRCO Industrial Gases offered a suggested design for an inlet filter.
- C. Careful attention must also be given to the antisurge and by-pass control system. Surge should be carefully avoided in an oxygen compressor since it is an unstable operating condition which can contribute to com-

ponent rubs within the compressor as well as being the vehicle for lifting dirt from corners or their settling places within the system. Surge also because of the turbulence it generates will raise the temperature of the gas within the system.

- D. The fire protection system is probably the most unique to an oxygen compressor system. The nature of oxygen compression is such that should an incident occur, the duration of the fire will probably be less than 1 minute however, the potential energy released within that short period of time can cause extensive damage. A fire detection system ideally should provide the back-up for a well-designed compressor system. Its function is to detect a temperature increase at the earliest possible time and react with sufficient dispatch to contain the conflagration within the compressor casing and minimize damage. The detection system in most common use today utilizes temperature sensing devices at each stage.

Several centrifugal oxygen compressors have been equipped with melting fuse sensing devices for faster action. Photo sensing devices are being developed and tested to provide even faster response. The signal from the sensing devices is used to automatically shut down the compressor, isolate the compressor from the system and vent the gas pressure. In many cases it also is used to actuate a deluge system to avoid the spread of the fire as seen in Figure 4.

The environment, in which the compressor will operate, is the result of the design of the air separation plant. Again as with the design of the compressor, good engineering practice should be utilized in planning and laying out the compressor building. There are, however, several unique requirements of an oxygen compressor installation, which must be considered.

- A. Since oxygen is heavier than air, it will tend to collect in low areas, pits, and trenches. Places where an oxy-

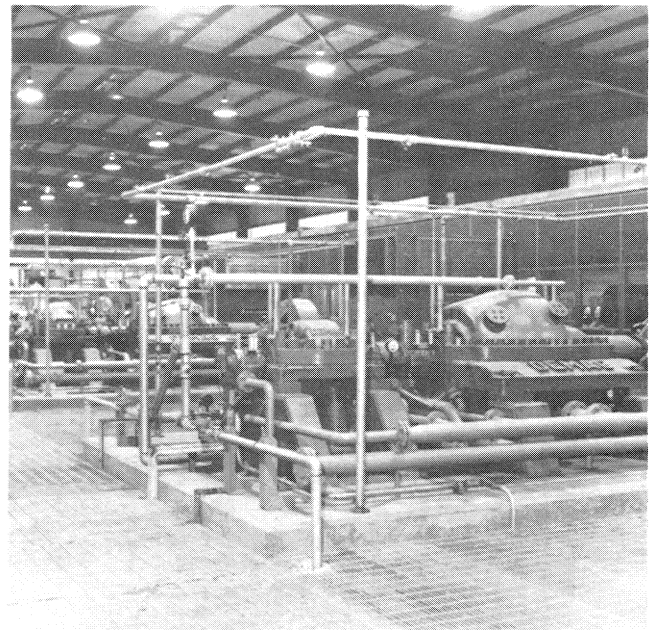


Figure 4. Oxygen compressors at an air separation plant built in 1966. This shows the open construction prevalent at the time without barriers but with a deluge system. Open grating is not recommended by the Code of Practice.

gen concentration can accumulate must be avoided in the vicinity of the oxygen compressor.

- B. Because of the need for cleanliness, an area should be provided around the machine which can be isolated during erection and maintenance of the oxygen compressors. This area must be adequately sized to allow for setting down oxygen cleaned parts of a disassembled compressor. The area must also be protected from overhead cranes that have a potential for dripping oil or grease into the area or on the compressor.
- C. As a matter of safety, should an incident occur, a clear level operating floor without obstructions and/or steps and doors that allow easy egress must be provided.
- D. On the subject of enclosures, current practice among air separation plant builders ranges from minimal barriers to a total enclosure as seen in picture of the high pressure oxygen compressor installation. Although the frequency of incidents involving oxygen compressors is relatively low for the number of compressor hours operated, and because the units are usually unattended, the frequency of personal injury is relatively low. However, because of the potential energy release in case of an incident, many users now utilize barriers or enclosures to protect other equipment and personnel. The materials of construction for these barriers include flame resistant insulating panels, sandwiched metal and insulation panels and cinder block. In the case of an incident, the molten slag or burning mate-

rial will be propelled by the pressure of the gas. At points where this burning material has the potential for burning through the casing piping elbows, or other vulnerable areas, sufficient space must be allotted between that part and the enclosure to prevent a burn-through of the enclosure with the appropriate consideration given to the material of the enclosure and pressure of the gas in the part. Appropriately protected inspection ports should be provided and instrumentation should provide readout on the outside of the enclosure.

As with the compressor itself, the oxygen piping system should be designed for ease of cleaning and to minimize dirt buildup within the system. The use of welding backup rings should be avoided where possible, and likewise bellows type expansion joints should be provided with appropriate liners in order to avoid places for dirt and foreign matter to build up. Gas velocities within the piping system should be kept relatively low in order to avoid carrying dirt and foreign material with the possibility that it would impinge on containing surfaces where the direction of the gas is changed. While the allowable maximum velocity is a function of the oxygen pressure within the pipe, there are no firm agreed upon limits because of the number of variables involved. Although the European Code of Practice recommends a relatively high limit, most oxygen plant builders will limit the velocities to something in the range of 6 to 8 meters per second. Figure 5 shows an air separation plant in Antwerp.

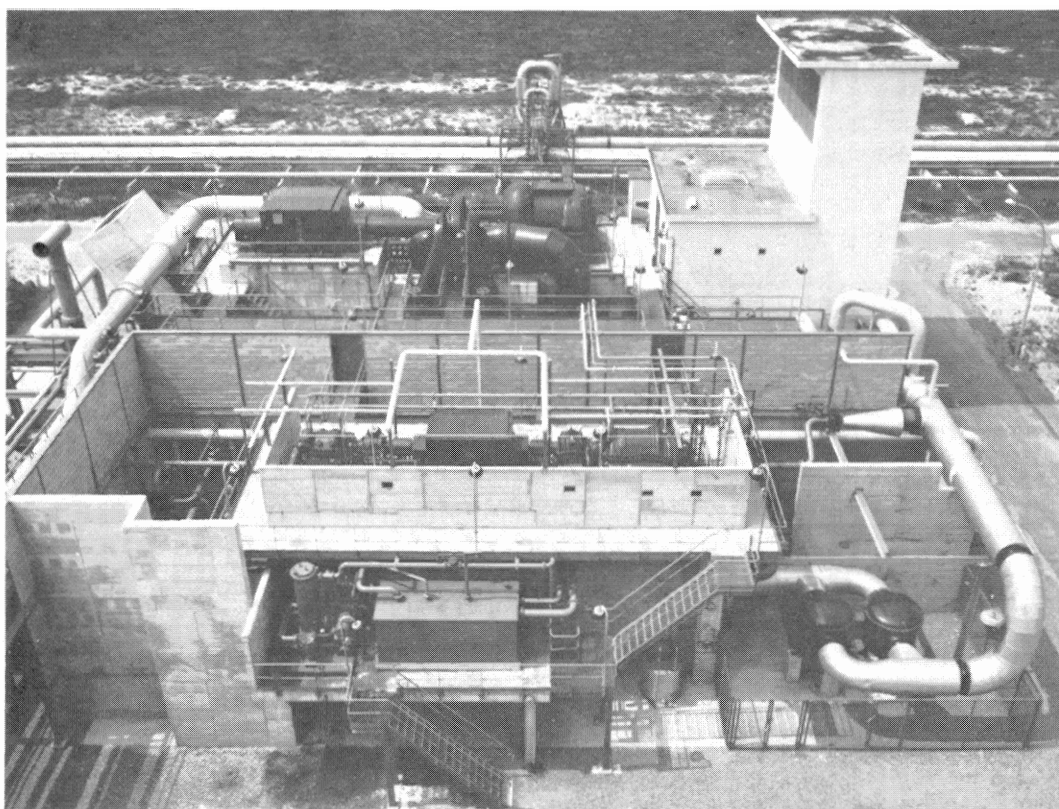


Figure 5. Air Separation Plant in Antwerp for 1540 tons per day oxygen with 1 turbo compressor for air and a two-casing turbo compressor for oxygen.

Oxygen Compressor: (in foreground)

Two-casing turbo compressor

Flow = 36,150 m³/h, inlet pressure = 1.105 kp/cm², discharge pressure 41.5 kp/cm²,

Power = 7900 kW (electric motor), speed = 7600/12,100 RPM

OPERATION

Safe operation of the centrifugal oxygen compressor involves limiting the operation to the flows and pressures for which it was designed. This means that a close and clear communication between the user and the manufacturer of the compressor is imperative to properly define all normal and potential abnormal operating conditions. In the case where the abnormal operating condition might result in unstable operation of the compressor, then the appropriate controls must be designed and provided to limit the compressor's operation.

During startup and shut-down of any turbo compressor, the machine experiences unstable operation. Because of this, almost all users now start and shut down oxygen compressors using an inert gas such as nitrogen. During normal schedule shutdowns, safety devices should be checked for proper operation. Recording devices are desirable to allow the engineers to evaluate the performance of the machine should trouble occur.

MAINTENANCE

Maintenance and the original installation of the compressor have one important common requirement and that is cleanliness. A suitable work area must be provided with a set of tools appropriately cleaned and with a work crew trained to "think clean." As with operation of the machine, maintenance records must be kept regarding the condition of parts within the machine with particular emphasis on clearances.

CONCLUSION

Oxygen has been successfully compressed to discharge pressures in the range of 70 bar provided that certain design features and operating procedures are incorporated into the installation. As plant sizes and discharge pressures increase, the importance of these special design features and operating procedures becomes more important; however, the economics of centrifugal compression for large air separation plants, which are being built and projected for future needs, makes these special considerations worthwhile.

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