STATIONARY, ELECTRIC-MOTOR-DRIVEN, CENTRIFUGAL LIQUID OXYGEN PUMPS

AIGA 055/20

Revision of AIGA 055/14

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PREFACE

As part of a program of harmonisation of industry standards, the Asia Industrial Gases Association (AIGA) has published AIGA 055, "*Stationary, Electric-Motor-Driven, Centrifugal Liquid Oxygen Pumps"*, jointly produced by members of the International Harmonisation Council and originally published as CGA G-4.7 by Compressed Gas Association (CGA) as "*Stationary, Electric-Motor-Driven, Centrifugal Liquid Oxygen Pumps".*

This publication is intended as an international harmonized standard for the worldwide use and application of all members of the Asia Industrial Gases Association (AIGA), Compressed Gas Association (CGA), European Industrial Gases Association (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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NOTE—Technical changes from the previous edition are underlined.

1 Introduction

Like many current processes, pumping liquid oxygen is accompanied by some degree of hazard that needs to be recognized and addressed. The hazards include liquid under pressure, cryogenic temperatures, volume and pressure increases due to vaporization, and the ability of oxygen to aid ignition and accelerate combustion. An incident can result in: (1) burning through a pump casing or adjacent piping, releasing a powerful jet of liquid or gas with entrained molten metal, and metal oxides; or (2) the rupturing of motor housings, beltboxes, or gear-boxes with explosive force throwing metal fragments like shrapnel. Either can be fatal to unprotected personnel and can damage adjacent equipment. The consequences of these incidents can extend to 100 ft (30.5 m) or greater.

To address these hazards, this publication has been prepared by a group of experts in centrifugal liquid oxygen pumping systems, representing oxygen producers and oxygen equipment manufacturers, and is based on technical information and experience currently available. Current industrial experience involves pump installations where the liquid oxygen concentration is 95 mol % or greater at maximum operating pressures of approximately 1740 psi (120 bar) and 600 kW electric motor output.

To the extent that they exist, national laws supersede the suggested practices listed in this publication. It should not be assumed that every local standard, test, safety procedure, or method is contained in these recommendations or that abnormal or unusual circumstances may not warrant additional requirements or procedures.

2 Scope and purpose

This publication is written as a reference when specifying stationary, electric-motor-driven, centrifugal liquid oxygen pump designs and installations, and is a guide for the operation and maintenance of this equipment. This publication is based on experience in manufacturing and operating these pumps and it is applicable to those pumps operating on liquids containing greater than 95% oxygen.

It is not intended to cover other types of pumps such as reciprocating or vehicle mounted. While many parts of this publication can be used as the basis for those other types of pumps, it is not written considering all the special features of those designs. In addition, it does not attempt to include design and installation criteria for all cryogenic pumps but focuses on those specifically related to oxygen safety.

Unless a specific risk assessment allows deviations, the user shall follow the requirements of this publication when specifying pumping equipment for oxygen-enriched liquid mediums with oxygen concentrations between 23.5 mol % and 95 mol %.

Some of the practices presented represent conservative compromise and not all situations are covered. The user is cautioned that this publication is not a design handbook and does not eliminate the need for competent engineering judgment and interpretation. It does not purport to address all the safety problems or hazards associated with liquid oxygen pump use. It is the responsibility of the user of this publication to consult with qualified technical personnel, to establish appropriate safety and health practices, and to determine the applicability of regulatory limitations.

The purpose of this publication is to furnish qualified technical personnel with technical information to use in designing new liquid oxygen pump installations. It provides considerations that will enhance safe and reliable operation of liquid oxygen pumps.

The information contained in this publication may also benefit existing installations or those in the project phase. However, some of the requirements and recommendations in this publication may not always be practical or applicable with regards to the design and configuration of existing liquid oxygen pump systems. Requirements and recommendations related to operations and maintenance should be considered.

3 Definitions

For the purposes 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 the 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 Barrier

Device that provides physical protection to people or equipment from fire and shrapnel that could result from a cold-end or warm-end incident in a pump system.

NOTE—Also known as a shield.

3.2.2 Buffer gas

Ambient temperature dry (dew point of less than –40 °C [–40 °F]), oil-free, particle-free, and carbon dioxide-free (less than 3 ppm) nitrogen, oxygen, argon, or air.

NOTE—Also called seal gas.

3.2.3 Cold end

Pump assembly through which the cryogenic liquid passes and is elevated in pressure.

NOTE—When the pump is in service, it reaches the temperature of the fluid being pumped.

3.2.4 Pump insulation enclosure

Structure or device that is typically insulated and contains or encases the cold end such as a pit, pump box, duct, or pump coldbox.

3.2.5 Distance piece

Extended spacer or carrier frame between the cold end and the warm end.

NOTE—It is used to provide a thermal barrier and a physical separation between the process and the drive mechanism.

3.2.6 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.

3.2.7 Pump system

Pump, driver, and any related components from the suction valve to the discharge valve.

3.2.8 Purge gas
Ambient temperature, dry (dew point of –40 °F [–40 °C] or less), oil-free, particle-free and carbon dioxide-free (less than 3 ppm) air, nitrogen, or argon used to sweep away or prevent concentrated oxygen or moisture laden air.

3.2.9 Warm end
Electric motor, gearbox, beltbox, and bearing housing.

NOTE—The bearing housing may be separate or incorporated into one of the other warm-end components.

4 Safety considerations

4.1 Properties of oxygen

4.1.1 Hazards

Handling liquid oxygen involves hazards associated with its strong oxidizing properties, cryogenic temperature of the liquid and vapor, and pressure-producing potential of the vaporization and liquid expansion processes.

This publication incorporates lessons learned from incidents that occurred in the industry with liquid oxygen pump systems.

These incidents necessitate consideration of items for safe operation of liquid oxygen pumps such as:

- cooldown procedure, startup permissive;
- sufficient cooldown/degassing prior to startup and in normal operation;
- cold standby and slow roll;
- operation of manual and/or automatic isolation valves;
- operation in normal operating range as per design;
- cavitation detection and protection;
- buffer gas and purge gas systems;
- electric motor protection and lubrication;
- shutdown and trip conditions;
- possible backflow during transient conditions or shutdown;
- prevention of hydrocarbon accumulation;
- maintenance and repair;
- spare parts;
- oxygen cleaning and cleanliness preservation;
- access control for personnel;
- single or multiple liquid oxygen pump systems; and
- installation and commissioning.

4.1.2 Oxygen cleaning

Equipment including the pump, valves, piping, and other components that can come into contact with oxygen during normal or transient operations shall be cleaned for oxygen service in accordance with an approved cleaning procedure. The cleaning shall be done by individuals qualified to clean oxygen systems. Before use, all equipment that is normally in contact with oxygen shall be degreased and, if stored, shall be protected from contamination and corrosion and labeled to indicate it is suitable for oxygen service. Refer to AIGA 012, *Cleaning of Equipment for Oxygen Service* [1].[1]

4.1.3 Contamination

Personnel working on or handling parts or equipment shall follow the requirements of AIGA 012 to avoid contamination [1]. Precautions shall be taken to prevent contamination during installation, commissioning, or maintenance on site.

4.2 Oxidation hazards

4.2.1 Stability

Oxygen in gaseous or liquid form is stable, nonflammable, and classified as an oxidizer.

4.2.2 Flammability

Materials that burn in air burn much more vigorously and at a higher temperature in oxygen or in oxygen-enriched atmospheres. Refer to CGA G-4, *Oxygen* [2]. Some combustibles such as hydrocarbon-based lubricants, burn violently in oxygen-enriched atmospheres. Materials with greater resistance to ignition and lower rates of combustion shall be selected.

4.2.3 Ignition temperatures

Ignition temperatures are reduced in oxygen-enriched atmospheres. Some materials that do not burn in air burn readily and vigorously in an oxygen-enriched environment.

4.2.4 Clothing

Absorbent material such as clothing can become saturated with oxygen and readily ignite and burn rapidly. The hazard can continue for some time after exposure to the oxygen source. For more information, see AIGA 005, *Fire Hazards of Oxygen and Oxygen-Enriched Atmospheres* [3].

4.2.5 Ground surface

The ground surface in the vicinity of oxygen pump installations shall be inorganic material compatible with liquid oxygen. Asphalt and other hydrocarbon-based materials constitute a hazard and if saturated with liquid oxygen become explosive when ignited by a falling object or by any form of friction such as tire friction. Stepping on oxygen spill areas or rolling equipment across them can result in ignition.

4.2.6 Hydrocarbon-based lubricants

Hydrocarbon-based lubricants constitute a serious hazard in the presence of oxygen. If hydrocarbon-based lubricants are used in an oxygen pump installation, precautions such as a purge gas system shall be taken to ensure that the lubricants cannot come in contact with oxygen (see 4.5.5, 5.4.3, and 6.1.3.1).

4.2.7 Nonoxygen-compatible lubricants

There are lubricants other than hydrocarbons that are not compatible with oxygen.

4.3 Cryogenic hazards

4.3.1 Burns

Skin contact with spilled or spraying liquid oxygen, cold vapor, valves, couplings, piping, or other cold surfaces can cause severe frostbite or cryogenic burns. For more information, see CGA P-12, *Safe Handling of Cryogenic Liquids* [4].

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

4.3.2 Ice

Moisture condenses and freezes on exposed cold surfaces causing valves, couplings, and safety devices to freeze, preventing operation.

WARNING: *Ice buildup can block normal ventilation openings causing greater oxygen concentrations and diverting flow into unwanted spaces.*

4.4 Vaporization and pressure hazards

4.4.1 Trapped liquids

One volume of liquid oxygen expands to 856 volumes of gas at ambient conditions. Regardless of the pressure, liquid oxygen cannot exist as a liquid at temperatures above –181 °F (–119 °C).

When liquid or cold gas is trapped within a vessel or a section of piping, the rapid rise in pressure from heat leak into the contained space can cause the equipment to rupture. To prevent such failures, thermal relief valves shall be provided in each section of piping or equipment where cold oxygen could be trapped.

4.4.2 Housekeeping

Good housekeeping in and around the area of a liquid oxygen pump installation is an overall requirement. Thermal relief valves, vent valves, and drain valves that discharge liquid or gas to the atmosphere can result in increased concentrations of oxygen in the area. Combustible or flammable materials shall not be stored in the area.

4.4.3 Dispersion

Cold gaseous oxygen and liquid oxygen are considerably heavier than air and accumulate in pits, trenches, or other depressions in the ground surface.

4.5 Incidents

4.5.1 History

A review of known liquid oxygen pump system incidents revealed that the most common causes include:

- incorrect cold-end metallic materials of construction;
- incorrect internal seal design and material;
- electric-drive-motor bearing lubrication issues;
- shaft seal leakage resulting in oxygen enrichment of the warm parts including electric-drive-motor bearing;
- cavitation leading to mechanical issues and running with gaseous phase;
- backflow leading to possible ignition and fire; and
- contamination.

Some of these incidents were associated with pump main discharge isolation valves and recycle valves where primary ignition occurred. The valve technology and contamination has been identified as one of the main causes of the incidents.

The liquid oxygen pump size and discharge pressure have been identified as an aggravating factor in case of an incident.

4.5.2 Cold-end incidents

Pumps built before the 1980s were normally constructed of aluminum or aluminum bronze. Both materials can be readily ignited in an oxygen atmosphere and cause a violent uncontrolled energy release. Conversion of pump bodies and impellers to a tin bronze material significantly reduced the frequency of pump incidents related to materials of construction.

Material changes have not totally eliminated ignitions since elements can rub or foreign particles can be caught between moving parts. Cavitation has been identified as a contributing factor to major incidents with ignition and burn through. In addition, ignition has occurred due to the presence of gas as a result of insufficient degassing, insufficient cooldown, insufficient net positive suction head (NPSH), etc.

4.5.3 Warm-end incidents

Warm-end incidents have been largely attributed to prolonged or serious seal leaks and the presence of hydrocarbon lubricants in the warm end of the pump. Shaft seal leakage can result in high oxygen concentrations in the distance piece and then in the bearing housing leading to ignition and an energy release. The bearing housing could be the motor, gearbox, beltbox, or a separated bearing housing attached to the beltbox or installed in the distance piece depending on pump design.

4.5.4 Ice buildup

The accumulation of ice that occurs when moist air comes in contact with cold surfaces on the distance piece between the cold end and the warm end can cause bridging that can channel oxygen leakage to the warm end and increase oxygen concentrations in the bearing housing area. Seal leakage and ice buildup should be monitored and corrected to minimize the potential for pump incidents.

4.5.5 Lubricants

Oxygen-compatible lubricants are inferior to hydrocarbon-based lubricants with regard to lubrication properties and are often hygroscopic, causing corrosion and a decrease in bearing performance and reliability. Hydrocarbon-based greases are generally used in electric-drive-motor bearings for better reliability since the amount of lubricant is small. In that case, installation of an inert gas purge on the bearing housing or purged bearing protection chamber is a safe and effective method of preventing oxygen accumulation in the bearing housing.

4.6 Reapplication of used equipment

The user of liquid oxygen pumps is responsible for the safe installation of new and used equipment. Used pumps shall be investigated to verify age, operating condition, materials of construction, cleanliness, previous service, type of lubricants used, and suitability for the proposed application. Used equipment should be upgraded as necessary when reapplied to new installations or applications to conform to current design practice. The user should enlist the assistance of qualified technical personnel, if necessary, to confirm the used equipment is acceptable for oxygen service.

4.7 Management of change

A management of change (MOC) process shall be followed for any changes made, other than replacement in kind, to the oxygen pump system, including but not limited to:

- design;
- materials of construction;
- cold-end components;
- shaft bearings;
- hazard area;
- barriers;

- layout;
- pipework;
- controls and instrumentation; and
- drying, cooldown, standby, startup, operating, shutdown, emergency, maintenance and repair procedures.

See AIGA 010, *Management of Change* [5].

5 Pump design

This section only addresses pump and motor design.

This publication is not a design handbook and, therefore, is not a substitute for competent engineering judgment and interpretation. It is suggested that the user review any special problems or concerns with the pump manufacturer who should be more knowledgeable in these special practices.

For pumps not covered by this publication, appropriate engineering design and operation practices shall be used. Special applications, designs, or concerns shall be reviewed with the pump manufacturer and qualified technical personnel.

The pump is part of a system and appropriate safety criteria for the entire pump system design and operation shall be followed as detailed in other sections of this publication.

5.1 Materials of construction

5.1.1 General

In the past, many materials have been used in liquid oxygen pumps, but the use of materials that have relatively high heats of combustion and low ignition temperatures such as aluminum and aluminum bronze are not acceptable (see 5.2.3.2).

The use of pump components primarily made of tin bronze, (impeller, backplate, diffuser, and pump body) has nearly eliminated incidents of ignition and sustained combustion from severe internal rubs. Although the use of tin bronze pump components minimizes the potential for ignition and sustained combustion, they can still occur. Therefore, a prudent choice of materials of construction for each part is required. A sound technical knowledge of materials, design practices, test methods, and operational techniques shall be applied.

5.1.2 Sources of ignition

The following conditions can promote ignition in liquid oxygen pumps:

- insufficient internal clearances due to insufficient cooldown resulting in internal rubbing;
- dry operation for extended periods of time due to cavitation, loss of prime, insufficient cooldown, or insufficient degassing resulting in rubbing;
- bearing, shaft, or impeller failure resulting in severe internal rubbing;
- foreign material in the liquid oxygen flow stream;
- mechanical friction due to excessive vibration, shaft seal failure, particles trapped in running clearances, improper assembly, or excessive piping loads on pump flanges; and
- failure of metallic and/or nonmetallic static seal system exposed to high pressure differential inside the cold end.

5.1.3 Compatibility data

Acceptable materials of construction are based in part on American Society for Testing and Materials (ASTM) standards, ASTM Standard Technical Publications, and information compiled by the ASTM G-4 Committee.[2]

While not specifically for centrifugal liquid oxygen pumps, ASTM and other published sources can be used as a guide in the selection of materials. Tests show that ignition is more likely with increasing oxygen pressures and temperatures. In a pump, ignition is generally less likely due to the cryogenic cooling and the relatively high required ignition temperatures. However, this is not true at potential rubbing surfaces. Special material combinations shall be used at these surfaces due to the potential for high friction-induced temperatures.

The acceptability of some materials may be based on actual operating experience in oxygen equipment.

5.1.4 Material properties

The selection of materials requires the following two steps:

a) Verify the mechanical and chemical properties (other than oxygen compatibility) of selected materials based on design and operating conditions (including transient conditions); and

b) Verify the ignition resistance and burn resistance of the material in gaseous and liquid oxygen at the operating conditions. For nonmetallic materials, this can include an auto-ignition temperature (AIT), a mechanical impact test in liquid oxygen, and energy released when burning (heat of combustion). See 5.2.8.

Material properties that minimize the potential of ignition and inhibit sustained combustion include:

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

In addition to oxygen compatibility, the materials and construction shall be suitable for:

- cryogenic operation;
- intended function of the part;
- containment of pressurized liquid and gaseous oxygen;
- rapid depressurization from high pressures at cryogenic temperature; and
- mechanical strength.

5.2 Cold-end components

5.2.1 Typical pump

A cross-sectional drawing of a single-stage horizontal centrifugal oxygen pump with a mechanical seal is shown in Figure 1. A cross-sectional drawing of a multi-stage vertical centrifugal oxygen pump with a labyrinth seal is shown in Figure 2.

5.2.2 Materials of construction

A summary of the acceptable materials of construction is given in Table 1. Other materials may be used in centrifugal liquid oxygen pumps. However, specific knowledge and expertise are required for the use of other materials. Details regarding materials of construction are outlined in the following sections.

[2] More information on ASTM International publications is available at www.astm.org

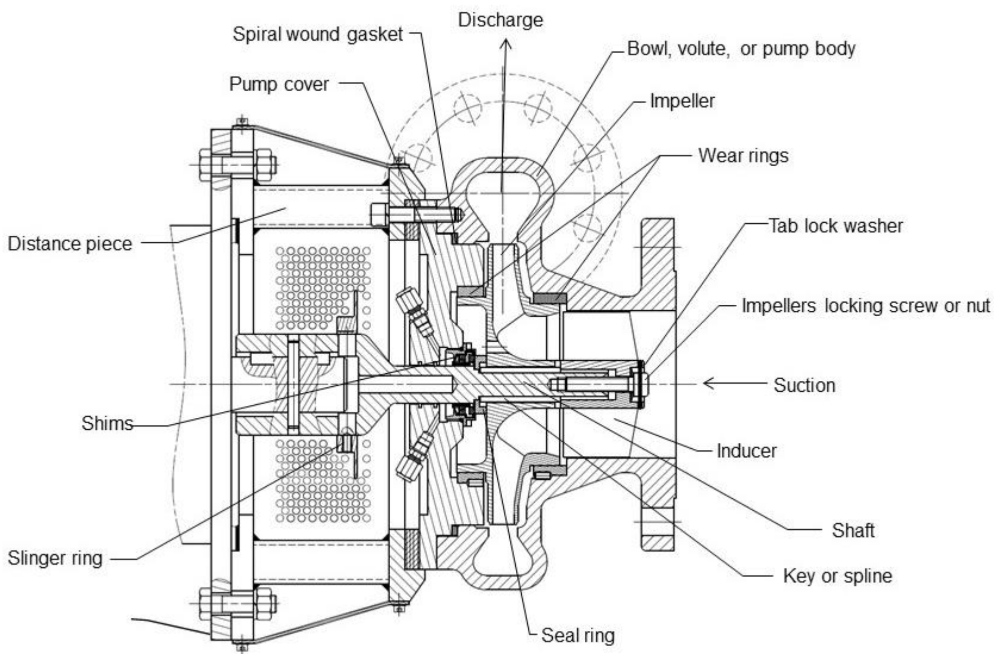

Figure 1—Example of a single-stage horizontal centrifugal oxygen pump with a mechanical seal

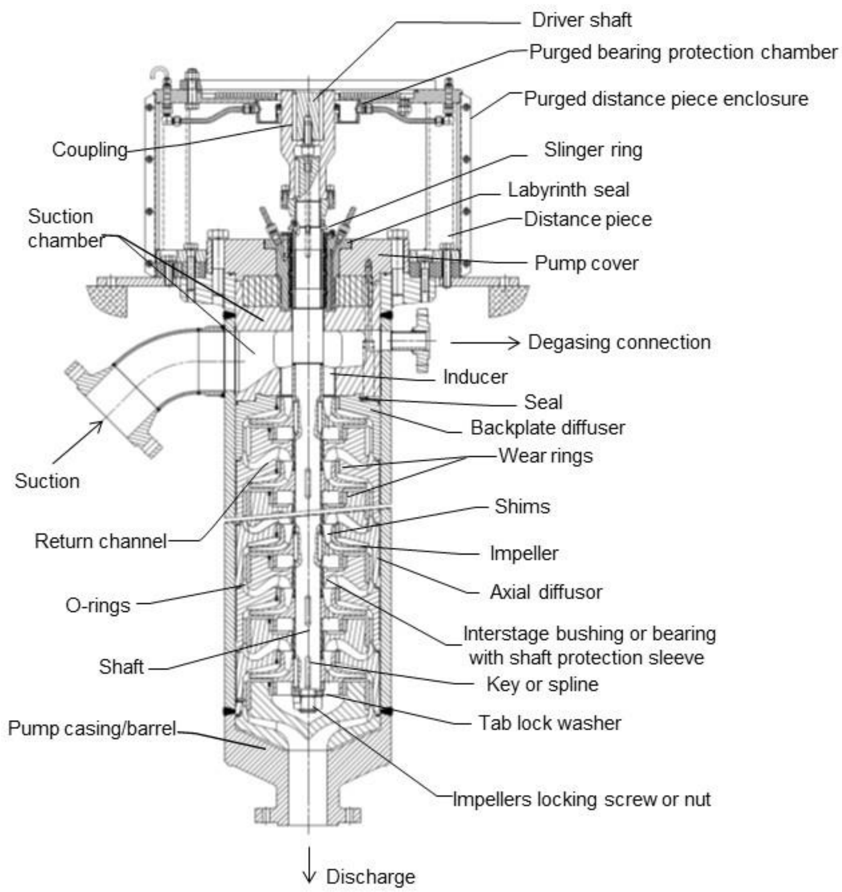

Figure 2—Example of a multi-stage vertical centrifugal oxygen pump with a labyrinth seal

Table 1—Summary of acceptable materials of construction

Part	Materials
Backplates Impellers Inducers Diffusers (axial, backplate) Wear rings	Copper alloy [1)], copper-nickel alloy, or nickel-copper alloy [2)]
Bowl, volute, or pump body and pump cover (see Figure 1) [3)]	Copper alloy [1)], copper-nickel alloy, or nickel-copper alloy [2)]
Pump casing/barrel and pump cover (see Figure 2)	Austenitic stainless steel
Protective sleeves Interstage bushings or bearings	Polytetrafluoroethylene [PTFE], copper alloy, copper-nickel alloy, nickel-copper alloy, or PTFE impregnated bronze alloy
Impeller locking screw or nut Fasteners	Austenitic stainless steel, copper alloy, copper-nickel alloy, or nickel-copper alloy
Tab lock washers Shims Lock wire	Copper alloy, copper-nickel alloy, or nickel-copper alloy Zinc copper alloy (brass)
Mechanical seal bellows	Austenitic stainless steel or nickel alloys
Seal ring (see Figure 1)	Stainless steel, tungsten carbide, or ceramic
Shafts Key or spline	Stainless steel, nickel-copper alloy
Slinger ring	Stainless steel, copper alloy
Seal	Copper-nickel alloy with PTFE
Gaskets	Filled PTFE, spiral wound stainless steel with graphite fillers
O-rings	PTFE, Viton®
Labyrinth seal (see Figure 2)	Silver, copper alloy, PTFE or Babbitt against nickel-copper alloy
Filter/strainer [4)]	Nickel-copper alloy mesh screen preferred or stainless steel [5)], nickel-copper alloy or stainless steel support
Suction chamber (see Figure 2)	Stainless steel, copper alloy
Distance piece	Stainless steel, copper alloy

NOTE—Refer to Figure 1 and Figure 2 for pump nomenclature.

1) Tin-bronze is an example of a copper alloy.

2) Monel® is an example of a nickel-copper alloy.

3) Any sealant used to impregnate cast parts to make them pressure-tight shall be oxygen compatible at the operating temperature range and at the maximum service pressure.

4) Not shown in Figure 1 or Figure 2.

5) See 6.5.6.

5.2.3 Copper alloys

The most suitable materials for wetted components (i.e., pump bodies, impellers, inducers, wear rings, diffusers, shims, and backplates) are copper alloys with a minimum of 80% copper and a maximum of only a trace amount of aluminum (0.1% maximum). Typical materials are tin and leaded bronzes.

5.2.3.1 Bronze cast alloys

Originally, the term bronze was used for copper alloys whose principal or only alloying element was tin. Broadly speaking, bronzes are copper alloys in which the major alloying element is not zinc or nickel. Today, to be technically correct, the term should be used with a modifying adjective. There are four main bronze cast alloys: tin bronzes, leaded and high-leaded tin bronzes, nickel-tin bronzes, and aluminum bronzes.

5.2.3.2 Aluminum bronzes

Aluminum bronze shall not be used.

Aluminum bronzes were used at one time in centrifugal liquid oxygen pumps because of their exceptionally high tensile strength. Cast aluminum bronzes typically range from 6.0% to 11.5% aluminum and from 0.8% to 5.0% iron. These elements have relatively high heats of combustion. Aluminum bronze can be ignited in an oxygen-rich atmosphere including liquid oxygen and is capable of propagating combustion. Once ignited, it is practically impossible to extinguish.

5.2.4 Copper-nickel alloys

Copper-nickel alloys exhibit outstanding resistance to promoted ignition/combustion and excellent castability, corrosion resistance, and mechanical properties over a range of temperatures, making them suitable for pump bodies and impellers. Copper-nickel alloys typically contain 10% to 45% nickel, with the balance predominantly copper.

5.2.5 Nickel-copper alloys

Nickel-copper alloys exhibit excellent oxygen compatibility and high strength, making them suitable for protective sleeves, bushings, and bolts. Nickel-copper alloys typically contain a minimum nickel content of 60%, with the balance predominantly copper.

5.2.6 Stainless steels

Stainless steels suitable for cryogenic applications are acceptable for components where there is no potential for stainless steel-to-stainless steel rubbing because of its high heat of combustion. If a potential for rubbing exists, the mating material shall be in accordance with 5.2.8. Shafts, fasteners, washers, locking devices, drive keys, and seal rings are typically made of stainless steel. See Table 1 for acceptable uses for other components.

5.2.7 Thin internal parts

Thin internal parts should be avoided because susceptibility to ignition increases as thickness is reduced.

Shims shall be made of copper alloy, nickel-copper alloys, or nickel-based alloys (see Table 1). Stainless steels and aluminum alloys shall not be used for shims as these materials are more likely to ignite and burn.

Stainless steel shall not be used for spring energized seals used in static sealing applications.

Locking wire and other components thinner than 0.032 in (0.8 mm) are not recommended for internal components. If they are used, the material shall be copper alloy, nickel-copper alloy, or nickel-based alloy (see Table 1).

5.2.8 Nonmetallic materials

Nonmetallic materials may be used for internal seals of the cold end.

Many nonmetallic materials are flammable in cold gaseous oxygen or in liquid oxygen even at low temperature and low pressure at oxygen concentrations greater than 23.5%. The main factors affecting their ignition and fire propagation are pressure, temperature, and oxygen concentration.

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

The suitability and mechanical properties of any nonmetallic material shall be evaluated for the full design temperature and pressure ranges, especially for elastomers used at cryogenic temperatures. Some elastomers used in O-rings can disintegrate and potentially ignite if rapidly depressurized from high pressure at cryogenic temperatures.

A minimum AIT of 572 °F (300 °C) should be considered.

Precautions shall be taken to avoid contamination during the manufacturing process of nonmetallic materials. Contamination can be introduced from high pressure hydraulic systems or other machining processes.

5.2.9 Potential rubbing surfaces

Silver, copper alloys, copper-nickel alloys, nickel-copper alloys, PTFE, Babbitt (also known as white metal), or oxygen-compatible antifriction material shall be used in one of the mating surfaces where metal-to-metal rubbing is likely to occur such as in a labyrinth-type shaft seal, interstage bushing, or interstage bearing.

5.3 Mechanical design

5.3.1 Clearances

When establishing clearances, the following items shall be considered:

- maximum particulate size;
- labyrinth shaft seal system;
- shaft axial and radial loads during cooldown, startup, operating conditions, and shutdown;
- pump performance;
- risk of rubbing between rotating and stationary parts;
- thermal effects;
- assembly; and
- vibration.

5.3.2 Fastening

All internal fasteners shall have a locking device. Impeller attachment fasteners shall use a positive-type locking device such as tab-lock washers or lock wire. Interference fits are not considered to be locking devices; however, interference fits may be used to install wear rings in the pump casing. The axial movement of the pump shaft shall be positively limited by its bearings.

Pumps and motors with assembled shafts or shaft extensions shall be assembled in such a manner where radial and axial movement is constrained and repeatable after reassembly.

5.3.3 Shaft seals

Industrial liquid oxygen pump experience has been with either a mechanical-type seal (contacting or noncontacting, dry gas) or a labyrinth-type seal. Mechanical seals in cryogenic pumps can fail unpredictably and leakage rates can change abruptly. Seal leakage creates a serious hazard that increases with the amount of leakage. The following requirements and recommendations may be used to reduce this hazard:

- A slinger or other deflection device shall be used to prevent direct impingement of shaft seal leakage on the driver bearing. This is to prevent the rapid freezing and failure of the bearing in the event of a shaft seal leak;
- The mechanical seal housing should have a purge port. Purging the external surface of the seal with dry gas can increase seal life by preventing moisture and ice from accumulating at the seal face, which can potentially cause damage. The manufacturer shall provide the port, but the user has the option of connecting a

purge gas to it. The user's experience with pump reliability in similar service should determine whether it is used;

- The mechanical seal housing shall also have a vent/drain port. Venting leakage out of and away from the housing reduces the hazard and measuring the vented flow can aid in detecting the onset of seal failure;
- For functional and strength reasons, mechanical seals use bellows that are typically made of relatively thin metal. A protective sleeve shall be used between the bellows and the shaft. Thin parts are more likely to ignite from rubbing or particle impact. The protective sleeve material shall be in accordance with Table 1;
- The mechanical seal design shall prevent metal-to-metal rubbing between the seal carrier and the rotating seal ring over the maximum possible axial movement of the bellows;
- Labyrinth shaft seals shall be treated as systems engineered for the particular application. The labyrinth shaft seal uses a small controlled leakage of a buffer gas to prevent liquid leakage. The buffer gas supply pressure should be slightly greater than the liquid oxygen pressure at the shaft seal. Typically, a differential pressure regulator is used to control the supply pressure. The buffer gas can leak into the liquid oxygen stream and to the atmosphere. To prevent particulate contamination and seal damage, a filter shall be used for the buffer gas supply of the seal gas system; and
- If contamination of the liquid oxygen (or oxygen-enriched liquid) being pumped is to be prevented when using a labyrinth seal, an oxygen buffer gas is used. If the small leakage of oxygen gas to the atmosphere is not acceptable, a dual gas labyrinth seal design or mechanical seal may be used. In the dual gas labyrinth design, the shaft seal has three axially spaced gas ports. At the pump end of the shaft, the oxygen buffer gas supply prevents liquid leakage. At the driver end of the shaft seal, an oxygen-compatible purge gas supply prevents oxygen leakage to the atmosphere. The middle port is the mixture outlet port, and it is used to vent the oxygen and purge the gas mixture to a safe area.

The shaft seal can be the limiting component for the pump suction pressure rating if less than pump body, suction flange, and suction piping pressure ratings. This publication does not address those shaft seals that have to seal against full discharge pressure as these are not commonly used in oxygen service.

5.3.4 Ice buildup

Consideration shall be given to preventing ice bridging to the driver or bearing housing. This bridging could allow oxygen from a shaft seal leak to be forced directly into the driver. Ice buildup and bridging is more likely to occur in continuous or extended duty pumps than in intermittent duty pumps. It can also occur when a pump is maintained in a cold standby condition.

An insulating shield or thermal barrier between the pump cold end and the driver can be effective for continuous duty applications. If the distance piece is enclosed, it shall be purged with a purge gas and shall be vented in a way that there is minimal pressure buildup from a seal leak.

5.4 Shaft bearings

5.4.1 Bearing types

The most common industrial experience is with rolling element bearings, which are external to the cold end. Internal bearings/bushings in contact with oxygen shall be designed and tested for oxygen and cryogenic compatibility before being put into liquid oxygen service.

5.4.2 Cold soak

Overcooling of bearings external to the cold end can be avoided by good design and suitable operating techniques. Consideration shall be given to the design of an intermediate thermal barrier between the cold end and the warm end (motor, gearbox, or beltbox). The pump shall not be kept in a cold, nonoperating, standby mode for a period longer than is specified in the manufacturer's manual and as agreed to by the user. If subjected to icy conditions when exposed to prolonged periods of operation or cold standby, the bearing closest to the cold end should have a heater to maintain a minimum temperature of the lubricant.

5.4.3 Lubrication

5.4.3.1 Minimum lubricant temperature

A suitable low temperature lubricant shall be used for the bearing closest to the pump cold end. As a minimum, the lubricant shall be suitable for operation at –40 °F (–40 °C). This is especially important for grease-lubricated bearings as they are more susceptible to lubricant freezing damage from excessive and prolonged pump cooldown. The temperature value is based on the availability of good low temperature greases.

5.4.3.2 Hydrocarbon lubricants

5.4.3.2.1 Hydrocarbon oil lubricants

Hydrocarbon oils shall not be used in an oxygen pump system. Because of low viscosity, these oils can flow along shafts, through tight clearances, and through seals. However, based on a risk assessment, nondrive-end motor bearings may be hydrocarbon oil lubricated.

5.4.3.2.2 Hydrocarbon grease lubricants

Hydrocarbon greases may be used if they do not come into contact with oxygen. See 6.1.3.1.

5.4.3.3 Oxygen-compatible lubricants

Consideration shall be given to ensure that potential oxygen leakage cannot come into contact with hydrocarbon lubricants. When this cannot be ensured, approved oxygen-compatible lubricants shall be used.

Oxygen-compatible lubricants provide poor corrosion protection as compared to hydrocarbon-based lubricants. They have poor wetting properties and do not provide a corrosion protective film. Many bearing failures have occurred due to corrosion caused by atmospheric moisture. Either a method of corrosion protection or a dry purge is recommended. Oxygen-compatible greases are inferior to hydrocarbon-based greases for pump bearings, because their high density makes them less suitable for the high-speed lubrication requirements of pump bearings (see 4.5.5).

Oxygen-compatible lubricants shall pass an internationally recognized standard test such as that of ASTM or BAM [6].

5.4.3.4 Regreasing bearings

Sealed for life greased bearings are normally preferred due to their limited maintenance requirements, especially eliminating the need for regreasing. Sealed for life greased bearing applications shall not have regreasing fittings.

Higher speed, higher loading applications, and larger bearing sizes can require regreaseable bearings for acceptable bearing life. Excessive or improper regreasing can result in large accumulations of grease in the bearing housing. For regreasing bearings, either the grease drain plug shall be removed when regreasing so that excess or old grease is removed through the drain rather than being forced into the main bearing housing or a grease chamber is available to catch spent grease.

Grease fittings should be removed and plugged to prevent unwarranted or unauthorized grease application. Regreasing should be performed only by personnel specifically trained in these requirements. If an oxygen-compatible grease is used, a separate dedicated manual greasing device shall be used to avoid mixing different types of greases. Greasing devices shall be protected from contamination (kept in clean area or bag/box when not used).

The use of automatic regreasers may also be considered.

The manufacturer’s maintenance procedures for regreasing shall be provided to the user. This includes the type and quantity of grease and number of operating hours between regreasings.

5.5 Pump motors

5.5.1 Motor type

Electric motors shall be of the totally enclosed fan cooled type or totally enclosed forced ventilation type, where an externally mounted fan provides cooling air over the outside of the motor. Totally enclosing the motor minimizes the potential for oxygen ingress. Open or weather protected type motors shall not be used except for large motors where a totally enclosed motor is not available and when a risk assessment has been conducted.

5.5.2 Direct coupled or rigid coupled

Motors directly coupled to the pump shall have a positive shaft axial location. The pump end bearing should be lubricated with a suitable low temperature lubricant as described in 5.4.3.1.

5.6 Slow roll

Slow roll is a specific operating condition at a lower operating speed that may be requested in the pump system design. Slow roll requires additional design considerations including bearing loading, seal design, variable speed drive, electric motor cooling, degassing, flow and cavitation control, etc., at the slow roll operating condition.

6 Installation

6.1 Primary installation safety method

Operating experience and incident history require that a liquid oxygen pump is considered as a complete system including the upstream and downstream piping and equipment such as valves, instrumentation, strainer, etc., to which personnel can be exposed.

6.1.1 Horizontal liquid oxygen pump system

Horizontal liquid oxygen pumps are used for liquid oxygen backup and transfer and truck loading as well as for process applications. These pumps usually have one or two impellers or stages and can be installed in a pump insulation enclosure or be noninsulated as necessary for continuous or noncontinuous (intermittent) service. The degassing piping of a horizontal liquid oxygen pump may be connected to the discharge side. Personnel may need to stand, at least temporarily, in close proximity for manual valve operation and to supervise the cooldown and startup.

The cooldown time and procedure of a horizontal liquid oxygen pump system shall consider the size and the mass of the cold end and the piping to cool down.

6.1.2 Vertical liquid oxygen pump system

Vertical liquid oxygen pumps are typically used for liquid oxygen process and/or back-up applications where high flow and pressure are required. These pumps have a more complicated process diagram and piping layout as compared to horizontal pumps. These pumps can have one or several impellers or stages. The cold end of these pumps may be installed in a stainless steel barrel usually in insulated casing or in a container installed at or below grade. The degassing piping of a vertical liquid oxygen pump system may be connected to the barrel and routed back to the gaseous phase of liquid oxygen.

The cooldown time and procedure of a vertical liquid oxygen pump system shall consider the size and the mass of the cold end and of the piping to cooldown. Cavitation can be more severe in multi-stage vertical liquid oxygen pump systems during startup or in normal operation, which can lead to ignition of internal seals of the cold end with possible escalation to combustion propagation up to burn through of the barrel and of the suction piping.

These liquid oxygen pump systems are usually in continuous operation at constant speed or variable speed (i.e., with/without variable speed drive) or in cold standby or in slow roll. The discharge pressure of vertical liquid oxygen pump systems can be 1450 psi (100 bar) at high flow rate. Vertical liquid oxygen pump systems can have large piping sizes with the corresponding valving and high-power electric motor (for example, 500 kW or higher).

6.1.3 Selection

In addition to only using the acceptable pump materials (see Table 1), one of the following two methods is the minimum required unless a risk assessment and hazard analysis dictate otherwise:

- primary safety instrumentation system (shaft seal leakage, cavitation protection, etc.); or
- hazard area.

Allowing the user a choice acknowledges the fact that different companies use different methods, and even individual companies use different methods in similar applications. At times, both methods may be used in a given installation. Other precautions may be added to the selected primary method as appropriate. The use of multiple methods should not result in the assumption that all equipment risk is gone.

6.1.3.1 Shaft seal leakage safeguards

A shaft seal leak detection system shall be provided. See 7.2.1.2.

For hydrocarbon-lubricated bearings and reservoirs (for example, gearbox) in close proximity to the pump, an engineered purge gas system shall be used. In direct coupled pumps, the drive-end motor bearing shall be purged. In beltbox pumps, the beltbox bearings shall be purged. The beltbox design shall be carefully examined since its bearings can be external to the box. In gearbox-driven pumps, the gearbox bearings as well as the gearbox housing and reservoir shall be purged.

If nonoxygen-compatible lubricants are used and the distance piece is enclosed, the distance piece shall be purged with a purge gas and shall be vented so there is minimal pressure buildup from a seal leak.

If oxygen-compatible lubricants are used, purging of the distance piece and motor bearing is not required. Oxygen-compatible lubricants can reduce the risk of a fire. However, these lubricants have mechanical deficiencies as described in 4.5.5.

When using a labyrinth seal, a buffer gas shall be used to prevent liquid oxygen leaking from the seal. See 5.3.3 and 7.2.1.2.

6.2 Hazard areas

Since the change to acceptable cold-end materials, cold-end incidents have mostly been eliminated. However, a few incidents have occurred in the cold end of vertical pumps resulting in breaches of the insulated carbon steel pump enclosure. These incidents resulted in damage to surrounding equipment and piping in the area.

A few incidents have also occurred in the warm-end components such as motors (gearboxes, beltboxes) of pumps. These incidents resulted in potential danger to equipment or personnel in an area behind or to the side of the motor.

6.2.1 Management of hazard areas

Personnel may need to stand, at least temporarily, in close proximity to the pump for manual valve operation, buffer and/or purge gas manual adjustment, greasing, data gathering (for example, vibration), and to supervise the cooldown and startup. Personnel can be exposed to potential hazards such as oxygen enrichment in the pump area due to a pump shaft seal leak.

Multiple oxygen pumps can be installed in the same area. In such cases, one pump could be operated while another one is in cold standby (i.e., ready to start) or during maintenance with personnel in close proximity.

The following parameters shall be considered for the determination of a hazard area:

- single or multiple oxygen pumps in the same area;
- maximum operating parameters: pressure, flow, electric motor power;
- continuous or noncontinuous service;

- local, automatic, or remote operation and monitoring (manned or unmanned plant) including startup and shutdown;
- maintenance procedures;
- history for equipment of similar design and operating conditions;
- proximity of pump installation to personnel walkways, work areas, and other equipment; and
- extent of monitoring and shutdown devices that provide early detection of problems before equipment failure.

The potential hazards shall be mitigated for personnel protection. One or more of the following means may be used:

- Mark the hazard area (for example, signs, ground marks, handrails, etc.);
- Limit access to the hazard area;
- Install shields or barriers considering the oxygen pump duty and discharge pressure; or
- Use visual and/or audible signals to alert personnel of automatic startup of an oxygen pump.

The distances to which this hazard area extends from the pump shall be established by qualified technical personnel designing the system. A set distance cannot be easily defined and differs between companies and installations. Some companies have used 15 ft (4.6 m) while some other companies use risk assessment techniques to establish the extent of the hazard area. Even if a hazard area does not apply, it should be assumed that risk can exist, and design and operation methods should be followed to minimize the time necessary for personnel to be near an operating pump. If a barrier is used, the hazard area is considered to end at the barrier (see 6.3).

Pumps that have the cold end enclosed within a pump enclosure may be considered to be within a barrier. The enclosure shall also be addressed in accordance with 6.3. The pump warm end shall also be addressed in accordance with 6.1.3.1.

If the emergency shutoff valve (ESV) is installed close enough to the pump so the valve could be rendered inoperative by fire or flying shrapnel as a result of either a cold-end of warm-end incident, it shall be shielded by a barrier.

Based on a risk assessment, protection shall be considered for other valves such as discharge and recirculation. Examples of protection include a barrier, distance, piping layout, redundancies, etc.

Items to consider for this risk assessment include if the valve(s):

- is installed in the hazard area;
- is the only means to prevent reverse flow;
- is connected to large volumes of oxygen; or
- could be rendered inoperative by fire or flying shrapnel as a result of either a cold-end or warm-end incident.

6.2.1.1 Barriers

Use barriers or shields to protect personnel and equipment in the event of an incident (see 6.3).

6.2.2 Entry into a barrier area

Access into an enclosed barrier is not permitted without approved written procedures and warning notices to this effect shall be posted.

6.2.3 First or one of a kind situations

The defined uses of a primary installation safety method are based on current common practice when all other specifics meet good safe practices such as those in this publication. Good engineering judgment shall be used to evaluate each installation to determine if certain situations exist that warrant additional safety precautions. Some, but not all, of the possible situations where additional precautions may be taken are:

- New unproven pump designs, applications, or installations;
- Flows, pressures, or speeds that are outside the pump manufacturer or user's experience;
- Use of any different components or materials;
- Pumps with reservoirs of nonoxygen-compatible lubricants in close proximity to the pump's oxygen-wetted area that do not use proven buffering or separating systems. For example, this can include gearbox-driven pumps with built-in reservoirs;
- Pumps in continuous cooldown or continuous operation, or which could be in continuous service at some time in their life unless proven by operating experience;
- Areas where maintenance or other activities require personnel to be in close proximity to the pump system piping/components/valves that can be in (or put into) service and that can pose additional risk during events such as a pump being started; and
- Any practice not in accordance with the requirements of this publication that provides an equivalent level of safety.

6.3 Barriers

6.3.1 General

If the results of a risk assessment determine that a hazard area exists around a pump, installation of a barrier or shield should be considered.

The main purpose of a barrier is to reduce the distance from the pump within which a person or equipment can operate safely in the event of an incident. It reduces the dimension of the hazard area and provides protection during startup and operation. On sides where barriers are not required to protect operating or maintenance personnel or equipment, a hazard area may exist.

6.3.2 Design

A barrier may be reinforced concrete or equivalent, low-carbon steel plate, or other suitable material. It shall be structurally designed to withstand the impact of projected parts or debris, a jet of liquid, and possible flame impingement. The design and materials selection need to consider details such as thickness of the barrier, proximity to the pump, and related valves, etc. The barrier shall be designed to protect personnel involved in the pump operation or in operating and maintaining adjacent equipment. The barrier shall not be installed too close to the pumps or in a fashion that restricts air circulation around the pump, or that concentrates leaking oxygen. Its design shall also allow nonoperating pump inspection including rotation check and maintenance. For pit-mounted or coldbox-mounted cold ends, the pump insulation enclosure can be considered the cold-end barrier; however, the warm end should be reviewed (see 6.1.3).

6.3.3 Accessory equipment

When barriers are installed, manual valves that have to be opened or closed while the pump is operating shall be located outside the barrier or positioned so the valve stem protrudes through the barrier, minimizing personnel exposure during pump operation. All devices requiring manipulation or observation while the pump is running shall be automated or shall be located so the operator is protected by the barrier while performing these duties. This includes but is not limited to the cooldown valve, start/stop buttons (see 6.4.2), pressure devices and discharge valve.

6.4 Layout

6.4.1 Pump environment

The area around a pump shall be carefully designed to promote oxygen safety. Accessibility is required for removal or maintenance of cryogenic pumps.

Good ventilation is required in the immediate vicinity to dilute the concentration of oxygen and prevent accumulation in low points or poorly ventilated areas near the pump if there is a leak. Where a cold end is installed in a pump insulation enclosure (i.e., coldbox- or pit-mounted), and has flanged and or screwed connections within the enclosure, the user should consider monitoring for the presence of leaking oxygen.

There should be no trenches, pits, or drains within 15 ft (4.6 m) of a pump with the exception of drains designed to divert spillage from the storage tank to safe areas. There should be no electrical cables within a 15 ft (4.6 m) radius (including the region above an oxygen pump) other than for the pump instrumentation or the pump motor.

Design and layout of other plant piping shall consider the possible impact on such piping if an incident occurs. Both fire and shrapnel shall be considered as possible consequences of an incident. The design shall prevent penetration or failure of piping associated with high pressure systems or systems with large volume storage (gas or liquid) resulting from a pump incident. This shall be done by keeping such piping (pump inlet and discharge piping excepted) a safe distance from the pump when not prevented by good hydraulic design or otherwise protecting the piping with barriers or shields. Piping in close proximity also shall be protected from the effects of cryogenic liquid contact by using suitable materials for low temperature service or by adequate shielding.

The ground surface where oxygen can spill shall be of inorganic material compatible with liquid oxygen. Asphalt and tar-based substances can become explosive when saturated with oxygen. Where concrete is used as a base for any cryogenic pump installation, care should be taken to avoid spillage or impingement of cold liquids or gases since this will break up concrete. Oxygen-compatible expansion joint material and caulking should be used in this area.

The designer should give consideration in design and layout the pump containment (supporting structures) so that the structural integrity is not compromised if cryogenic liquid leaks from the pump or pump system components.

6.4.2 Location of the local start/stop button

If provided, the local start/stop button should be outside the hazard area or at least 15 ft (4.6 m) from the pump. If this cannot be done, a barrier or shield should be provided behind which personnel can stand when the start/stop button is used.

For emergency stop button(s), see 7.2.4.

6.4.3 Visual inspection

If visual inspection is used to assess the condition of the pump, the layout shall provide that such inspection can be conducted safely and that corrective measures can be taken without hazard to personnel.

6.5 Pipework

6.5.1 Piping

Suction piping should be as short and straight as possible with a minimum number of bends and should be designed to ensure that the required NPSH is maintained at low liquid levels and at high and low flows. Where practical, piping should be sloped to return vapor produced back to the source of liquid. High points where gas can be trapped in piping systems should be avoided. Piping to cryogenic waste disposal systems should have a slope to avoid vapor lock.

Dead end boiling and hydrocarbon accumulation shall be avoided.

Suction and discharge piping should be attached to the pump so that the pump manufacturer's recommended flange loads are not exceeded when at ambient, cryogenic operating, or stand-still conditions. Flexible hose or bellows may be used to manage piping contractions and elongations due to temperature swings. Nevertheless, when flexible hoses or bellows are used, they should be installed so that the hose is not stretched, compressed, or twisted under operating conditions or to accommodate misalignment.

Because the consequences of a flexible hose or bellows failure at high pressures can be severe, consideration should be given to other means to manage flexibility requirements due to temperature swings and mechanical loading.

Oxygen-compatible components and lubricants shall be used in valves and instrumentation that come into contact with oxygen during normal or transient operations. For additional information on valves in liquid oxygen service, see AIGA 094, *Design, Manufacture, Installation, Operation, and Maintenance of Valves Used in Liquid Oxygen and Cold Gaseous Oxygen Systems* [7].

6.5.2 Relief valves

Relief valves shall be installed so that they do not become encased in ice, which can prevent proper operation of the relief valve.

Discharge from a relief valve shall be disposed of in a safe manner.

6.5.2.1 Pressure relief valve

A pressure relief valve(s) shall be installed if the pump system can develop a discharge and/or suction pressure greater than the system's maximum allowable working pressure (MAWP).

6.5.2.2 Thermal relief valve

Any part of the system in which liquid can be trapped (for example, by valves, check valves, spectacle blinds) shall be provided with a suitable thermal relief valve.

6.5.3 Vents and drains

Pipework shall be designed so that any liquid or gas vented or drained during cooldown or from relief valves or seal vents is diverted safely away from the operating area. It should be diverted so that the gas or liquid does not impinge on personnel or other equipment or cause high oxygen concentrations.

Liquid drain lines shall have a high point to create a vapor lock to avoid local hydrocarbon accumulation.

6.5.4 Emergency shutoff valve

For pumps connected to bulk liquid storage systems, the requirements of AIGA 031, *Bulk Liquid Oxygen, Nitrogen, and Argon Storage Systems at Production Sites* shall be met [8]. For all other applications, ESVs should be installed in the suction piping as a primary form of protection in the event of a pump failure. It shall be capable of remote activation from a safe location and shall be fail close. The valve shall close automatically on a pump trip or when activated by the operator. A single actuated ESV may be installed in the common header feeding multiple pumps.

The ESV shall be located between the oxygen volume and both the suction filter and the elbow closest to the pump inlet. If the valve is installed close enough to the pump so the valve could be rendered inoperative by fire or flying shrapnel as a result of either a cold-end or warm-end incident, it shall be shielded.

6.5.5 Isolation valve

At least one suction isolation valve shall be installed to isolate the pump from the upstream system.

Manual isolation valves such as suction, discharge, and recirculation valves should be used where necessary to isolate a pump and related automatic valves for maintenance.

6.5.6 Inlet filter

A removable strainer/filter shall be used to minimize particles from entering the pump. It should only permit the passage of a particle smaller than the smallest design gap between major rotating and stationary parts of the pump. Labyrinth shaft seals, internal bearings, impeller-to-body/diffuser sealing clearances, and inducer-to-body/suction chamber sealing clearances may be excluded from this requirement due to the small size of their clearances in some pump designs. However, selected mesh size shall balance pressure drop and filtration considerations. Commonly used filter sizes vary from 30 mesh to 100 mesh (opening between 0.0234 in and 0.0059 in [0.595 mm and 0.15 mm]). The filter shall be robustly constructed having the fine mesh filtration material supported by backing plates typically made of stainless steel or nickel-copper alloy. The filter mesh shall be manufactured from suitable materials such as nickel or nickel-copper alloy. The use of stainless steel for the filter mesh is not recommended.

6.5.7 Pipe insulation

Piping insulation should be used to minimize heat leak into the liquid oxygen and the hazard of potential ice buildup (for example, blocking valve operation, etc.). Piping thermal insulation shall be compatible for oxygen service. For use of vacuum-jacketed piping, see AIGA 106, *Vacuum-Jacketed Piping in Liquid Oxygen Service* [9].

6.5.8 Discharge check valve

A check valve shall be installed in the oxygen pump discharge header downstream of the first elbow. The installation should ensure that the check valve cannot be rendered inoperative by a fire or flying shrapnel as a result of either a cold-end or warm-end incident.

The risk of backflow across a single check valve shall be considered based on operating conditions such as discharge pressure. If required, mitigation measures include installation of either a:

- second check valve; or
- fail-safe, automatic discharge isolation valve.

6.5.9 Discharge isolation valve

A valve shall be installed to positively isolate the pump and associated piping from a downstream system that is continuously under pressure. See 6.5.8.

6.6 Additional considerations

6.6.1 Liquid storage

Liquid storage safety requirements shall be in accordance with AIGA 031 and AIGA 085, *Liquid Oxygen, Nitrogen, and Argon Cryogenic Tanker Loading Systems* [8, 10].

6.6.2 Vehicle access and parking

The passage of vehicles and parking within the hazard area shall be prohibited except for trailers being filled.

If no hazard area has been defined, vehicle passage and parking within 15 ft (4.6 m) of operating oxygen pumps shall be prohibited except for trailers being filled, unless a risk assessment is conducted.

7 Controls and instrumentation

Purge gas systems shall either be completely independent of the seal system or shall use the purge/buffer gas header with measures (for example, pressure reducers, check valves, etc.) to prevent any possibility of oxygen being routed to the bearing.

The pump shall not be operated without purge gas that shall be ensured by using appropriate flow or pressure measurements and interlocks or operational procedures.

7.1 General

Liquid oxygen pump operating controls should be provided consistent with good design practices, which apply for all cryogenic, centrifugal pumps. Detailed liquid oxygen pump controls vary since the system can be attended or unattended, the pump start sequence can be manual or automatic, and the pump can be operated in continuous or intermittent duty, prolonged cooldown, or slow roll conditions. All pump controls including a start/stop device should be located so that personnel are not required to enter or stand in any hazard area to operate the pump. Control devices that cannot be located outside of a hazard area and provide critical control functions shall be shielded from a pump cold-end or warm-end energy release or shall fail to a safe condition. Each liquid oxygen pump control system shall include a means of shutting down the pump and, when required, isolating the system.

7.2 Controls

7.2.1 Controls, hardware, and operator action

In addition to normal controls, the following controls, hardware, or operator actions should be provided for safety to shut down the pump to minimize damage and hazardous conditions.

For example, operating a pump outside of its designed performance range can result in gas formation, cavitation, and ultimately, loss of prime.

7.2.1.1 Pump discharge pressure detection and control

Discharge pressure detection shall be provided.

A method of limiting the discharge pressure developed by the pump shall be provided if the pump system can develop a discharge pressure greater than the system's MAWP. This method shall be installed in addition to any pressure safety valve (see 6.5.2.1). Examples include a high pressure shutdown, speed control, or a controlling bypass valve.

7.2.1.2 Pump shaft seal leak detection

An instrumented system shall be provided to detect a shaft seal leak, activate an alarm, and/or shut the pump down unless a risk assessment is conducted and determines that visual inspection is an acceptable alternative. See 6.1.3.1. A number of methods for instrumented systems are available including temperature detection or equivalent device.

If a shaft seal leak detection system requires a flowing purge gas to detect a shaft seal leak, loss of flow shall activate an alarm and/or shut down the pump.

If a labyrinth shaft seal is used, a means of detecting a loss of flow or pressure to the buffer seal gas system shall be provided. This detection system shall activate an alarm and/or shut down the pump.

7.2.1.3 Loss of prime detection

Operating a pump in a loss of prime condition can result in premature seal failures and even catastrophic incidents. A means of detecting and shutting down the pump on a loss of pump prime condition shall be provided. For attended pumps, this could be the operator. Loss of prime protection needs to include operating conditions and slow roll conditions. This system protects the pump from abnormal pump operations such as cavitation, loss of prime, operating the pump without liquid, or downstream piping breaks and ensures the pump is operated within the specified equipment limits. Suction pressure taps should be installed downstream of any valve or strainer and upstream of the pump. Pump discharge pressure taps shall be installed downstream of the discharge and prior to any isolation valves or check valves.

Commonly used methods for loss of prime detection include measurement of:

- pump suction and/or discharge pressure;
- differential pressure across the pump;

- total pump flow; or
- motor current.

An automated control method should be developed to temporarily bypass the loss of prime detection system for pump starting. The setting for pressure, flow, or motor low-amp is the responsibility of the system designer and shall be based on the pump's performance curve characteristics.

Guidance on the safe range of pump operation should be provided by the pump manufacturer. Variable speed pump operation shall be considered when designing loss of prime detection systems. The pump configuration (for example, horizontal, vertical, single stage, multi-stage) shall be considered when selecting a method for loss of prime detection.

7.2.1.4 Excess flow detection

A means of detecting excess pump flow may be incorporated into the system design. Pumps can be damaged due to forces not accounted for in the equipment design when operating at flow rates exceeding the intended design. The NPSH required by a centrifugal pump increases with flow. At excess flow, NPSH available may not be sufficient to prevent severe cavitation. It may also be necessary, depending on the system's hydraulic design, to install a pump flow limiting device such as a control valve or an orifice plate. The control devices outlined in 7.2.1.3 may be incorporated into a system design that can provide this protection.

7.2.1.5 Pump cooldown detection

The pump shall be properly cooled down and degassed. Proper cooldown ensures that the pump is filled with liquid and all parts are at the required temperatures so that the fits and clearances are per design. A startup permissive should be provided to prevent premature startup.

Commonly used methods to determine that the pump is properly cooled down include:

- Measuring a temperature at a high point in the pump, in the discharge piping immediately adjacent to the pump, and/or in the liquid section of the degassing line, which verifies that the minimum temperature is reached and is stable; or
- Use of a timer to ensure a minimum cooldown period before energizing the pump.

Multiple factors including the system configuration, piping, pump type and size, and elapsed time since last operation, etc., affect the settings for cooldown time or required temperature to ensure the pump is properly cooled down.

7.2.1.6 Bearing condition monitoring

Bearing failures in pump motors can lead to hard rubs in both pumps and motors that can result in excessive seal leakage and fires.

Typically, the drive-end bearing experiences higher axial loads and has an increased potential for failure.

7.2.1.6.1 Vibration

Vibration monitoring can provide early detection of a bearing failure so that the problem can be addressed before there is a significant failure. Permanent vibration monitoring should be provided for critical process and backup pumps that operate at higher pressures, power, and flows or in continuous duty.

7.2.1.6.2 Temperature

Motor bearing issues can also cause high bearing temperatures that show up before or after a change in vibration. Issues have occurred in both the drive-end and nondrive-end bearings. Temperature monitoring, alarm, and shutdown should be provided. These are more critical for process and backup pumps that operate at higher pressures, power, and flows or in continuous duty.

7.2.1.6.3 Drive-end bearing heater

Pumps employed in continuous cold standby starting conditions shall maintain the bearing lubricant above –40 °F (–40 °C) (see 5.4.3.1). The control system shall prohibit the pump from starting if the minimum lubricant temperature is not reached. To maintain the bearing lubricant temperature, the bearing closest to the cold end should have a heater (see 5.4.2).

Bearing heater designs vary but may include self-contained thermostatic control, self-regulating heaters, or heaters controlled through an external device or programmable logic controller (PLC)/distributed control system (DCS).

7.2.2 Spill detection

For pump systems downstream of bulk liquid storage tanks, consideration may be given to installing a spill detection system that can automatically activate the ESV in case of a large spill.

7.2.3 Variable speed drives

Good design practices shall be followed by the user/system designer on pumps equipped with variable speed drives, so the pump and associated system components are protected from potential failure modes of variable speed drives including overspeed. Overspeed results in increased pressures and flows. Overpressure control shall be provided as described in 7.2.1.1 and a properly sized pressure relief valve, if required (see 6.5.2.1).

The pump manufacturer shall provide the speed operating ranges for the specific pump to the user/system designer. The user/system designer shall use the flow and pressure developed at maximum operating speed to design the piping system for the pump.

The control system shall limit the pump operation to the specified operating speed ranges and the maximum and minimum operating speeds as agreed upon by the pump manufacturer and user/system designer.

7.2.4 Emergency stop button(s)

An emergency stop button station(s) shall be mounted at a location(s) that operating and maintenance personnel would normally pass through when exiting the pump installation during an emergency. The emergency stop button station(s) shall be clearly labeled and identified for the system it operates. The emergency stop button shall shut down the electric motor of the pump and close any automatic isolation valves.

7.3 Pump trip management

The control system may allow trips to be bypassed during startup sequences. Permanent trip overrides shall not be used. Temporary overrides may be used when approved through a MOC process.

There shall be no startup of a pump after a trip without a pre-established procedure. Where a pump is shut down by one of its protective trip functions, it shall not to be restarted until the reasons have been evaluated and addressed.

7.4 Condition monitoring instrumentation

Instrumentation may be used to detect the need for maintenance and/or analyze pump performance. Commonly used instrumentation includes:

- pump suction pressure;
- pump discharge pressure;
- pump differential pressure;
- pump suction strainer pressure drop;
- pump discharge flow;
- pump hour meter for elapsed running time;

- motor current;
- bearing temperature;
- buffer/purge gas flow;
- seal leak temperature; and
- vibration devices.

8 Operation and maintenance

8.1 Warning signs

8.1.1 Hazard area sign

If a hazard area is identified (see Section 6), warning signs shall be placed in clearly visible locations advising all personnel that access to the designated hazard area is restricted while the oxygen pump is in operation.

8.1.2 Oxygen pump sign

A sign should be located close to a pump to alert all personnel that the pump is an OXYGEN PUMP.

8.1.3 Additional warning signs

Additional warning signs to alert operators of potential excessive seal leakage, oxygen-enriched/-deficient atmospheres, ice ball formation, and other potential hazards (see Section 4) may be considered.

8.2 Training

All pump operators and maintenance personnel shall receive appropriate training such as:

- pump fundamentals (hydraulic and mechanical);
- specific cooldown, standby, startup, operation, shutdown, and maintenance procedures;
- anomaly detection (seal leakage, cavitation, unusual bearing/drive noises);
- trouble shooting;
- upset conditions and emergency procedures;
- oxygen cleaning and handling (see AIGA 012) [1]; and
- MOC procedures;
- use of appropriate lubricants;
- safe work permit procedures; and
- safety requirements for handling cryogenic liquid oxygen.

8.3 Commissioning

Written instructions that address commissioning should be developed for each pump system. These instructions may include items such as:

- leak check;
- cleanliness;
- system dryness;

- alignment of the piping to the pump nozzles;
- gaskets and bolt torque;
- installation as compared and verified against the piping and instrumentation diagram (P&ID);
- post warning signs;
- correct installation of strainer;
- pipe supports and pump mounting;
- satisfactory operation and adjustment of instrumentation, valves, safety devices, alarms, and trips, etc.;
- shaft freedom of rotation in warm and cold conditions;
- satisfactory operation of buffer and purge gas systems;
- verification of pump direction of rotation; and
- variable speed drive such as operating and maximum speed settings.

8.4 Startup and operation

8.4.1 Written procedures

Written instructions that define drying, standby, cooldown, startup, operating, shutdown, and emergency procedures shall be developed for each liquid oxygen pump and shall be kept in the plant files. A copy of these instructions shall be reviewed with and made available to the pump operators. Instructions should be periodically reviewed and updated as required, and changes shall be reviewed with the appropriate operators. Instructions shall include, but not be limited to, details pertaining to the following items:

- Methods needed to determine that cooldown is achieved without freezing the pump/motor bearing lubricant and considering the recommendations of the pump manufacturer. The cooldown procedure shall consider the pump and all piping components upstream of the pump and shall be included in the startup permissive associated with the cooldown achievement;
- Precautions to be followed to provide adequate liquid subcooling at the pump inlet to prevent cavitation such as minimum tank liquid level/pressure;
- Appropriate position of all piping system valves for each mode of operation (cooldown, startup, operation, shutdown, etc.);
- Method used to check the pump shaft for freedom of rotation (warm and cold condition) and the frequency of these checks. The shaft freedom of rotation should be checked during commissioning and after pump maintenance. All freedom of rotation checks shall be performed only after the pump motor has been electrically isolated, locked out, and tagged. Typical methods used to check for freedom of rotation are turning the pump shaft by hand, removing the end bell of the motor and turning the pump motor fan or shaft, using a wrench on the pump shaft flats, and opening the beltbox and carefully using force on the belts. For a pump with a gearbox, this check may be done by rotating the pump shaft in the distance piece area or by turning the motor fan at the top of the motor;
- Permissible process operating limits to preclude pump damage. For example, permissible flow or discharge pressure ranges to prevent cavitation and maximum allowable speed ranges for the pump;
- Pump normal operating conditions such as pump flow rate, purge and/or buffer gas flow rate, discharge pressure, and motor load (amps);
- Methods to determine if the pump loses prime during startup and normal operation and procedures to stop the pump before pump damage can occur;
- Precautions to be followed to stop the pump if abnormal conditions are detected such as seal leakage or abnormal noises;

- Requirements for personnel access to the hazard area; and
- Procedure in case of a shutdown or abnormal or upset operating conditions of the pump.

8.4.2 Cold standby

The following apply for pumps on cold standby:

- A means of preventing the warm-end bearing lubricant from freezing shall be used. Pump design considerations to prevent the bearing lubricant from freezing are discussed in 5.4.2 and 7.2.1.6.3; and
- Pumping systems have the potential to accumulate hazardous dissolved hydrocarbons at low points in the system. A pump shall be periodically flushed or a routine sampling/analysis program shall be instituted to detect any hydrocarbons at the system low points. Hydrocarbon concentrations greater than allowable limits require that the pump system be drained (see AIGA 035, *Safe Operation of Reboilers/Condensers in Air Separation Units*) [11].

8.4.3 Slow roll

Pump operation at slow roll speed shall be reviewed. Pump design, system controls, and set points to be reviewed at slow roll speed include, but are not limited to:

- axial bearing loading;
- seal system including dry face seal (if any);
- variable speed drive;
- electric motor cooling;
- degassing; and
- flow and cavitation control, etc.

8.4.4 Ice bridging

If the pump develops a significant ice buildup, steps shall be taken to reduce the size of the ice ball. Examples include stopping and defrosting the pump using dry, warm air or hot gas to melt the ice or physically removing the ice. When removing the ice, care shall be taken to prevent overpressure or damage to the pump. See 5.3.4.

8.5 Pump and condition assessment

Pump performance and mechanical condition shall be periodically reviewed. Observations or at least details of abnormalities should be recorded for further action or reference. These checks should include:

- analysis of operating data;
- unusual noise or vibration;
- oil level/lubrication replenishment as appropriate; and
- seal leakage.

Internal seal leaks can occur especially where high pressure differential is present in a vertical liquid oxygen pump, which can lead to loss of hydraulic performance.

The frequency of these reviews depends upon extent of use, manufacturer's recommendations, and actual operating experience.

8.6 Maintenance and repair

Attention shall be paid during maintenance to preserve oxygen cleanliness in accordance with AIGA 012 such as [1]:

- Ensure that the deriming and warming-up process of the entire pump system prevents moisture entrapment on cold surfaces; and
- Protection of the openings during maintenance to prevent contaminants from entering into the system.

After a prolonged shutdown or after maintenance, system modification, or repair is performed on a pump system, recommissioning may be required. See 8.3 for items to be considered.

Verify direction of pump rotation before any unit that could have had motor wiring phase changes. Wiring phase changes are possible after any motor/pump maintenance requiring lead disconnection at the motor or motor control center.

For multi-stage vertical liquid oxygen pumps, the pump manufacturer shall also specify the axial preload to be applied on the cold end as per assembly procedures.

8.6.1 Maintenance program

A maintenance program shall be developed based on the pump manufacturer's recommendations and/or users experience.

8.6.2 Repair procedures

Written repair procedures produced by the manufacturer, the user, or both shall be followed for any pump repair.

For maintenance of the cold end of a vertical liquid oxygen pump, certain pumps may be designed to keep the barrel in place inside the liquid oxygen pump insulation enclosure. This can prevent further potential safety issues and leaks at upstream/downstream connections, and avoid prolonged shutdown of the liquid oxygen pump system. The liquid oxygen pump manufacturer shall provide clear instructions for safe cold-end handling and to prevent any damage on accessible components during maintenance as well as for reassembly of the cold end.

A safe work permit procedure shall be applied when maintenance or repair is performed on an operating or installed pump or for any other work in the hazard area.

Additional and specific precautions shall be adopted for pumps installed in confined spaces such as for those in the coldbox enclosure.

8.6.3 Parts

Only original spare parts should be used. If not, the suitability of the spare part shall be approved by a competent person through a MOC process. Parts approved for use in oxygen service shall be properly inspected, cleaned, handled, and stored. Refer to AIGA 012 [1].

8.6.4 Personnel qualifications

All maintenance shall be performed by individuals trained for the specific tasks being performed.

8.6.5 Records

A chronological record of pump maintenance and repairs shall be kept. These records are necessary in identifying and diagnosing chronic problems.

8.7 Filters/screens inspection and cleaning frequency

Pump inlet filters/screens shall be periodically inspected and cleaned, if necessary.

Cleaning frequency is dependent upon the level of inlet contamination and is especially critical following either system modifications or repairs. The following should be considered to determine cleaning frequency:

- After pump system commissioning or if a system modification or repair is done on the suction of the pump, the filter/screen should be inspected and, if necessary, cleaned within approximately 100 hours of operation;
- If the pump is unable to be cooled down, if there is a rise in the differential pressure across the filter/screen, if there is loss of prime, or if the pump is losing performance, the pump filter/screen should be inspected and, if necessary, cleaned;
- At each pump replacement or removal, inspection of filters/screens should be considered; and
- If excessive contamination or debris is found, the filter/screen should be periodically reinspected.

When removed, filters/screens shall be inspected for mechanical integrity of the mesh and support plate.

9 References

Unless otherwise specified, the latest edition shall apply.

[1] AIGA 012, *Cleaning of Equipment for Oxygen Service*, Asia Industrial Gases Association. www.asiaiga.org

NOTE—This publication is part of an international 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 G-4, *Oxygen*, Compressed Gas Association, Inc. www.cganet.com

[3] AIGA 005, *Fire Hazards of Oxygen and Oxygen-Enriched Atmospheres*, Asia Industrial Gases Association. www.asiaiga.org

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[4] CGA P-12, *Safe Handling of Cryogenic Liquids,* Compressed Gas Association, Inc. www.cganet.com

[5] AIGA 010, *Management of Change,* Asia Industrial Gases Association. www.asiaiga.org

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

[7] AIGA 094, *Design, Manufacture, Installation, Operation, and Maintenance of Valves Used in Liquid Oxygen and Cold Gaseous Oxygen Systems,* Asia Industrial Gases Association. www.asiaiga.org

NOTE—This publication is part of an international 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.

[8] AIGA 031, *Bulk Liquid Oxygen, Nitrogen, and Argon Storage Systems at Production Sites*, Asia Industrial Gases Association. www.asiaiga.org

NOTE—This publication is part of an international 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.

[9] AIGA 106, *Vacuum-Jacketed Piping in Liquid Oxygen Service,* Asia Industrial Gases Association. www.asiaiga.org

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[10] AIGA 085, *Liquid Oxygen, Nitrogen, and Argon Cryogenic Tanker Loading Systems,* Asia Industrial Gases Association. www.asiaiga.org

[11] AIGA 035, *Safe Operation of Reboilers/Condensers in Air Separation Units*, Asia Industrial Gases Association. www.asiaiga.org

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