

CGA G-4.7—2019

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

FIFTH EDITION

PREFACE

As part of a program of harmonization of industry standards, the Compressed Gas Association (CGA) has published CGA G-4.7, *Stationary, Electric-Motor-Driven, Centrifugal Liquid Oxygen Pumps*, jointly produced by members of the International Harmonization Council.

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.

PLEASE NOTE:

The information contained in this document was obtained from sources believed to be reliable and is based on technical information and experience currently available from members of the Compressed Gas Association, Inc. and others. However, the Association or its members, jointly or severally, make no guarantee of the results and assume no liability or responsibility in connection with the information or suggestions herein contained. Moreover, it should not be assumed that every acceptable commodity grade, test or safety procedure or method, precaution, equipment or device is contained within, or that abnormal or unusual circumstances may not warrant or suggest further requirements or additional procedure.

This document is subject to periodic review, and users are cautioned to obtain the latest edition. The Association invites comments and suggestions for consideration. In connection with such review, any such comments or suggestions will be fully reviewed by the Association after giving the party, upon request, a reasonable opportunity to be heard. Proposed changes may be submitted via the Internet at our web site, www.cganet.com.

This document should not be confused with federal, state, provincial, or municipal specifications or regulations; insurance requirements; or national safety codes. While the Association recommends reference to or use of this document by government agencies and others, this document is purely voluntary and not binding unless adopted by reference in regulations.

A listing of all publications, audiovisual programs, safety and technical bulletins, and safety posters is available via the Internet at our website at www.cganet.com. For more information contact CGA at Phone: 703-788-2700, ext. 799. E-mail: customerservice@cganet.com.

Work Item 19-026
Atmospheric Gases and Equipment Committee

NOTE—Technical changes from the previous edition are underlined.

FIFTH EDITION: 2019
FOURTH EDITION: 2014
THIRD EDITION: 2005
SECOND EDITION: 2003

© 2019 The Compressed Gas Association, Inc. All rights reserved.

All materials contained in this work are protected by United States and international copyright laws. No part of this work may be reproduced or transmitted in any form or by any means, electronic or mechanical including photocopying, recording, or any information storage and retrieval system without permission in writing from The Compressed Gas Association, Inc. All requests for permission to reproduce material from this work should be directed to The Compressed Gas Association, Inc., 14501 George Carter Way, Suite 103, Chantilly VA 20151. You may not alter or remove any trademark, copyright or other notice from this work.

Contents	Page
1 Introduction.....	1
2 Scope and purpose	1
3 Definitions.....	2
4 Safety considerations	3
4.1 Properties of oxygen	3
4.2 Oxidation hazards.....	4
4.3 Cryogenic hazards.....	4
4.4 Vaporization and pressure hazards.....	5
4.5 Incidents	5
4.6 Reapplication of used equipment.....	6
4.7 Management of change.....	6
5 Pump design	7
5.1 Materials of construction.....	7
5.2 Cold-end components	8
5.3 Mechanical design.....	12
5.4 Shaft bearings	13
5.5 Pump motors	15
5.6 Slow roll	15
6 Installation	15
6.1 Primary installation safety method.....	15
6.2 Hazard areas.....	16
6.3 Barriers.....	18
6.4 Layout.....	19
6.5 Piping.....	19
6.6 Additional considerations	21
7 Controls and instrumentation	21
7.1 General.....	22
7.2 Controls	22
7.3 Pump trip management	24
7.4 Condition monitoring instrumentation	24
8 Operation and maintenance	25
8.1 Warning signs.....	25
8.2 Training.....	25
8.3 Commissioning.....	25
8.4 Startup and operation	26
8.5 Pump and condition assessment.....	27
8.6 Maintenance and repair.....	28
8.7 Filters/screens inspection and cleaning frequency.....	28
9 References	29
Figures	
Figure 1—Example of a single-stage horizontal centrifugal oxygen pump with a mechanical seal	9
Figure 2—Example of a multi-stage vertical centrifugal oxygen pump with a labyrinth seal.....	9
Table	
Table 1—Summary of acceptable materials of construction	10

This page is intentionally blank.

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 gearboxes 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 CGA G-4.1, *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 CGA G-4.1 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 CGA P-45, *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 EIGA Doc 51, *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.