RECIPROCATING CRYOGENIC PUMPS AND PUMP INSTALLATIONS FOR OXYGEN, ARGON, AND NITROGEN

Doc 159/21

Revision of Doc 159/14

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RECIPROCATING CRYOGENIC PUMPS AND PUMP INSTALLATIONS FOR OXYGEN, ARGON, AND NITROGEN

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As part of a programme of harmonisation of industry standards, the European Industrial Gases Association (EIGA) has published EIGA Doc 159, *Reciprocating Cryogenic Pump and Pump Installations for Oxygen, Argon and Nitrogen*. This publication was jointly produced by members of the International Harmonisation Council.

This publication is intended as an international harmonised publication for the worldwide use and application by all members of the International Harmonisation Council whose members include the Asia Industrial Gases Association (AIGA), Compressed Gas Association (CGA), European Industrial Gases Association (EIGA), and Japan Industrial and Medical Gases Association (JIMGA). Regional editions have the same technical content as the EIGA edition, however, there are editorial changes primarily in formatting, units used and spelling. Regional regulatory requirements are those that apply to Europe.

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	Editorial to align with IHC associations
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5	Minor updates to provide guidance of best operating practice
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5.5	Recommendation of using plastic tubing for valve actuation
6	Additional information on selection of materials reference to EIGA Doc 200 and EIGA Doc 73

7	Clarification of mandatory requirements for oxygen and optional requirements for inerts
8, 9, 10	Minor updates for best practice
11	New sub-sections on maintenance programmes

NOTE Technical changes from the previous edition are underlined

1 Introduction

Reciprocating cryogenic pumps have become key components within the industrial gas industry handling primarily, liquid oxygen, argon, and nitrogen. To ensure that pumps operate both safely and reliably, it is important that pumps are correctly designed, installed, operated, and maintained for the required duty.

Pumping cryogenic fluids is accompanied by some degree of hazard. The hazards include liquid under pressure, cryogenic temperatures, volume and pressure increases due to vaporisation, and the ability of oxygen to accelerate combustion.

This publication gives guidance to manage these hazards.

2 Scope

This publication is intended to cover cryogenic reciprocating pumps and installations for liquid oxygen, argon, and nitrogen.

The publication contains a summary of industrial practices and is based on the combined knowledge, experience, and practices of industrial gas and equipment suppliers.

Carbon dioxide pumps are not covered in this publication. For information regarding carbon dioxide pumps, see CGA G-6.3, *Carbon Dioxide Cylinder Filling and Handling Procedures* or EIGA Doc 83, *Recommendations for Safe Filling of CO2 Cylinders and Bundles* [1, 2]. [1]

Centrifugal liquid oxygen pumps are not covered in this publication. See EIGA Doc 148, Stationary Electric-Motor-Driven Centrifugal Liquid Oxygen Pumps [3].

The design and installation requirements and recommendations included in this publication apply only to installations begun after the publication date and not to existing installations. However, the information contained in this publication may benefit existing installations or those in the project phase. Furthermore, 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.

3 Definitions

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

3.1 Publication terminology

3.1.1 Shall

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

3.1.2 Should

Indicates that a procedure is recommended.

3.1.3 May

Indicates that the procedure is optional.

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

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 Cavitation

This phenomenon occurs when the pressure of a liquid drops to less than the vapour pressure of the liquid at a certain temperature. At this point, liquid vaporises, thereby creating vapour bubble. These bubbles can cause a pump to lose prime or suffer heavy vibration and damage.

3.2.2 Cold end

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

3.2.3 Cryogenic reciprocating pump

Consists of a motor (single, twin, or variable drive) belt drive, gear drive or direct couple assembly, warm end (crank drive), and the cold end.

3.2.4 Loss of prime

Loss of liquid flow to and/or through the pump.

3.2.5 Net positive suction head (NPSH)

Margin of difference (measured in height) between the actual pressure of a liquid flowing into a pump and the vapour pressure of the liquid.

3.2.6 Purge gas

Ambient temperature, dry (dew point of –40 °C [–40 °F] 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.

3.2.7 Subcooled liquid

Liquid at a temperature less than its boiling point.

NOTE Subcooling can be achieved by increasing the liquid pressure greater than its equilibrium pressure or bubble point.

3.2.8 Thermosiphon tank

Tanks with dedicated pump pipework with both feed and return pipework connected to the tank liquid phase. This arrangement improves pump priming by allowing circulation of liquid from tank, through the pump and back to the tank, even when the pump is not running.

3.2.9 Warm end

Crank case box that drives the cold end.

4 Description of a reciprocating cryogenic pump and pump installation and components

A general arrangement of a cryogenic pump installation consists of a vacuum insulated cryogenic tank, reciprocating pump, a vaporiser, and interconnecting and delivery pipework. An example of a general arrangement of cryogenic pump equipment is shown in Figure 1. Cryogenic pumping systems shall be designed to ensure that required controls and safety elements are used in accordance with the application of the system.

Typical applications include filling of compressed gas cylinders, but there are other applications where high pressure gas or cryogenic fluid is required.

In most cases, the pump will be supplied by liquid from a vacuum insulated cryogenic tank consisting of an inner vessel and an outer jacket. There are two main types of vacuum insulated cryogenic tanks used in cryogenic reciprocating pump installations. One type is a standard conventional use tank. The other is a thermosiphon tank. Both tanks are described in more detail in Section 5.

The reciprocating pump increases the pressure of the cryogenic fluid to the required pressure of operation, as described in Section 5.

If the product is required in the gaseous condition, then the product passes through a vaporiser to convert the cryogenic fluid to temperature gas. Vaporisers can be ambient, which relies on no additional heat input to vaporise the product, or there may be an external heat source such as hot water, steam, or hot air.

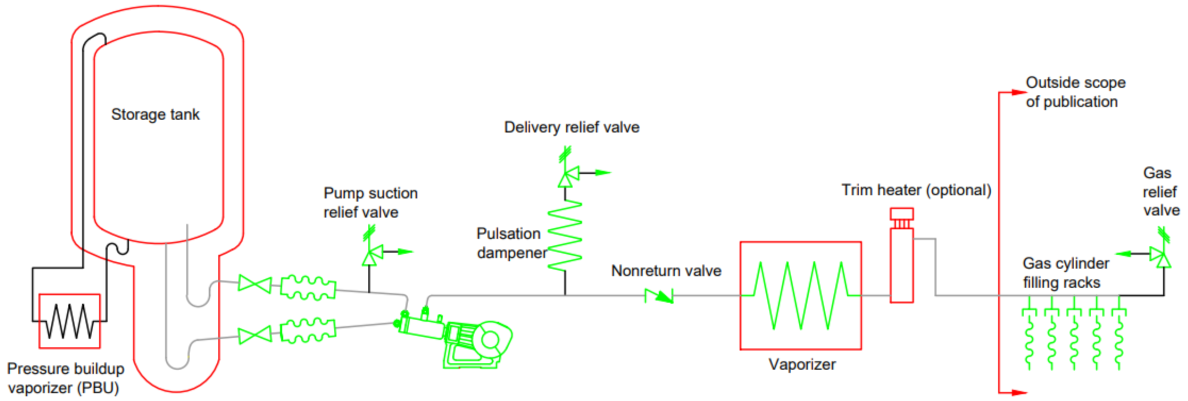

Figure 1 – Example of a general arrangement of cryogenic pump equipment

5 Description of individual components

5.1 Tanks

Installations may use a thermosiphon tank with dedicated pump feed and return piping, rather than a conventional tank. A simplified piping arrangement for a thermosiphon tank and a conventional tank are described in 5.1.1 and 5.1.2.

5.1.1 Thermosiphon tanks

An example of a simplified thermosiphon tank piping arrangement is shown in Figure 2. Tanks and related piping shall be designed to ensure that required controls and safety elements are used in accordance with the application of the system.

The pump feed and return pipework ensures good suction conditions to the pump when running and during standby. The rate of tank pressure rise and therefore vent losses are reduced.

The thermosiphon tank design incorporates both the suction and return pipes in a vacuum insulated leg that descends from below the tank to a point almost level with the ground.

The pump suction pipe descends from the centre of the inner vessel to a low point within the vacuum insulated jacket extension. The suction pump then rises and exits the vacuum jacket, continually rising towards the pump. A liquid return from the pump suction rises back towards the vacuum jacket extension. After penetrating the vacuum jacket, the return pipe is then connected through the inner vessel lower dished end. The return connection is usually made closer to the vessel outer diameter than the suction feed. The return pipe is usually extended internally up from the dished end to ensure that the warmer return liquid rises away from the lower pump suction feed nozzle.

Shallow gas traps are included on both feed and return pipes within the vacuum jacket extension to stop external pipes from retaining cryogenic liquid and therefore icing when a pump is isolated.

Heat gained in the external pump pipework reduces the cryogenic liquid density sufficiently to generate a thermosiphon circulation of liquid from suction to return pipework even when the pump is not running.

For effective operation, designers should ensure that a sufficient height difference exists between suction and return tank connections, ensure that the pipe slopes are preserved, and keep the depth of internal gas traps to a minimum.

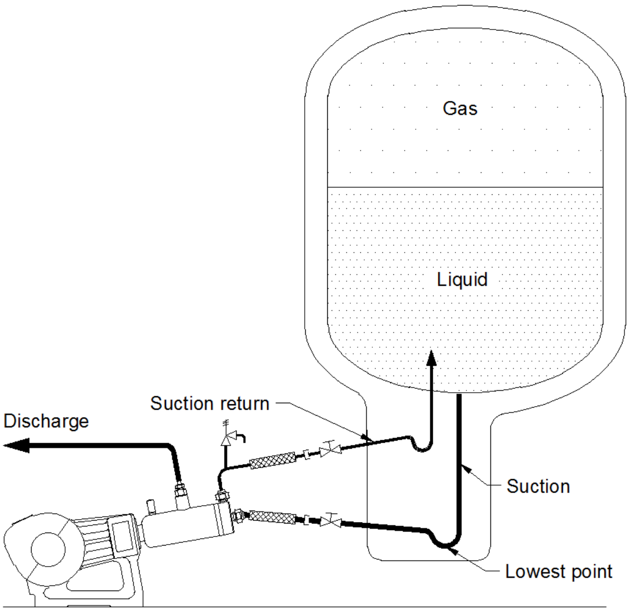

Figure 2 – Example of a simplified thermosiphon tank arrangement

5.1.2 Conventional tanks piped for pumps

Conventional tanks, are usually piped up with the pump suction feed from the bottom of the tank and a vapour return to the top of the tank. See Figure 3 for an example of a simplified conventional tank arrangement. Pumps are used in different applications that require different controls and safety elements. Cryogenic pumping systems shall be designed to ensure that required controls and safety elements are used in accordance with the application of the system.

The pump suction feed can be from a pipe dedicated for this purpose or one used for tanker filling or other process duties.

Depending on the actual pipe routing between the inner and outer vessel, the disadvantage of this liquid feed-vapour return arrangement can be that once the tank level falls to below a certain level, the feed to the pump becomes effectively a long single pipe containing at least one gas trap. If the pump shuts down for even a short period, the liquid in the suction pipework rapidly reaches its boiling point and the pipe becomes gas locked.

Pump priming can only be achieved by product venting or by the use of liquid vapour separators at a high point on the suction pipework. Such separators can vent the vapour but cannot re-establish subcooled liquid (with adequate net positive suction head [NPSH]). Separators also increase the risk of liquid spillage from the tank.

Vapour return lines from pump suction should not be piped into the tank main relief valve line because the relief valve pipe can become flooded and be unable to protect the tank from overpressure.

In addition, it can cause the relief valve (and bursting disk) to discharge the full tank content to the ground.

5.1.3 Pressure build up and tank pressure

Conventional and thermosiphon tanks may incorporate a pressure build up vaporiser (PBU). If the system experiences pumping problems, the PBU can be used to increase the NPSH.

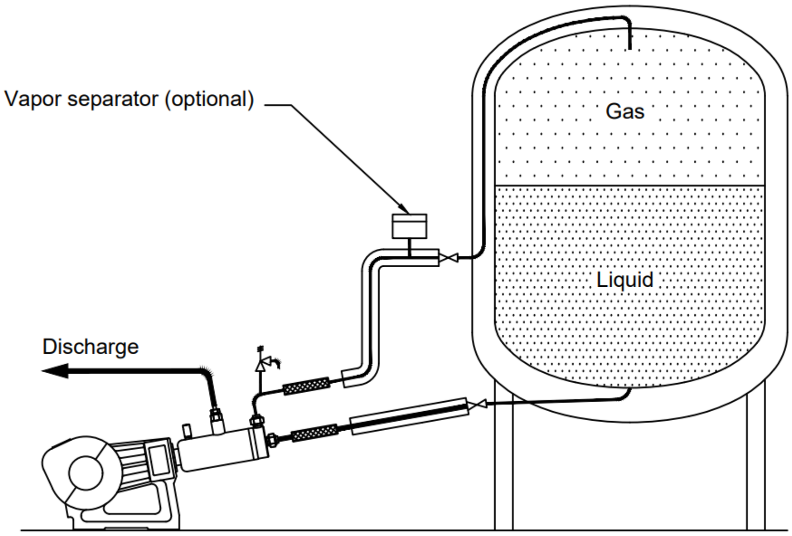

Figure 3 – Example of a simplified conventional tank arrangement

5.2 Pump

The reciprocating pump increases the pressure of the cryogenic fluid to the required pressure of operation.

Pump design has progressed and evolved over the years as filling to higher cylinder pressures has increased.

A variety of pump configurations are in use. All configurations have a means of degassing typically back to the storage tank.

Modern designs enclose the cold-end piston, barrel, suction, and discharge valve assemblies in a vacuum jacket.

The pump is usually driven by an electric motor.

Examples of reciprocating pump components are shown in Figure 4. Recommended materials are covered in Section 6.

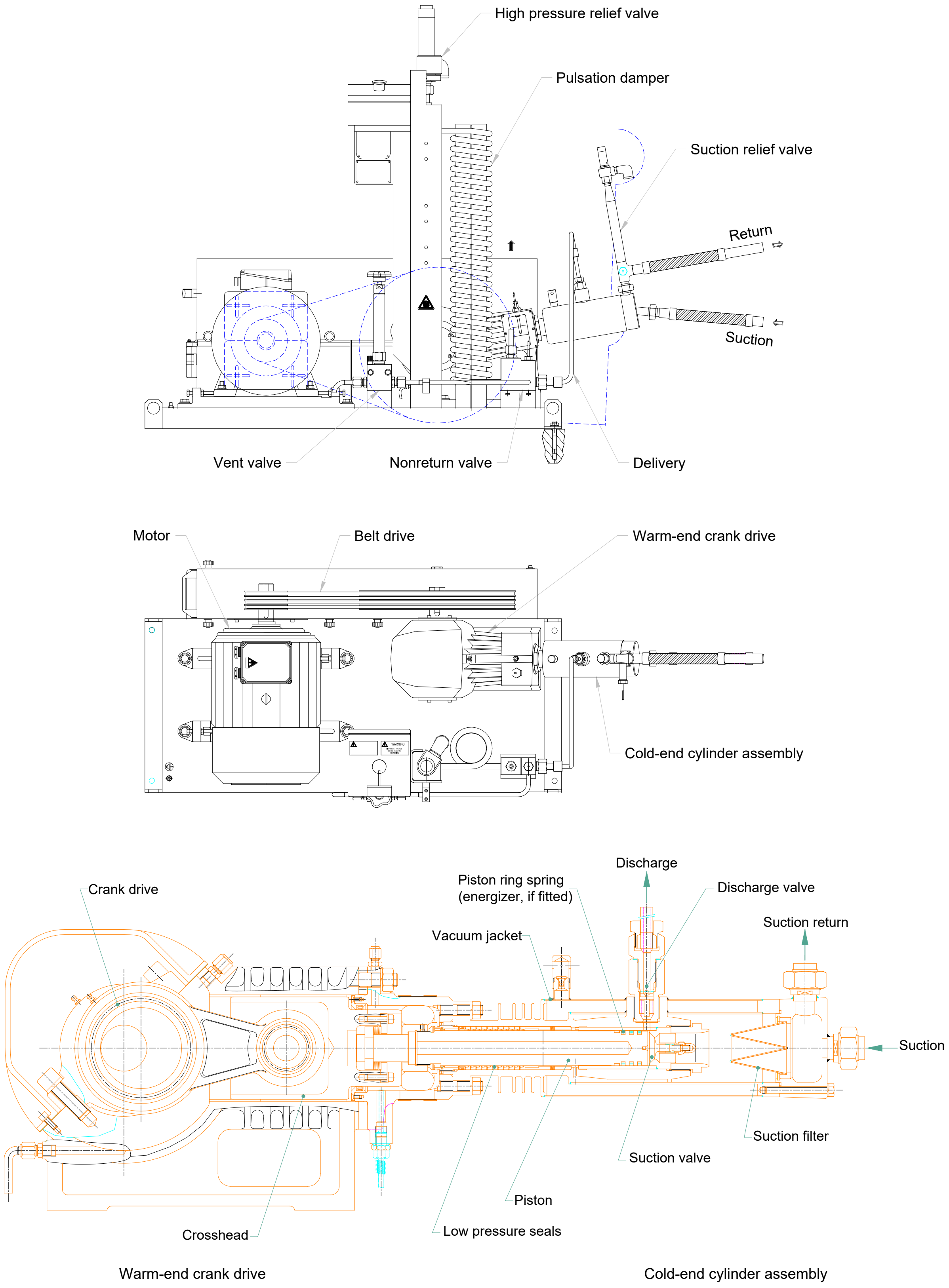

Figure 4 – Example showing reciprocating pump components

5.2.1 Suction filter

To prevent damage to pumps, a filter should be fitted to the suction side of the pump. Fine mesh filters (typically 150 microns or 100 mesh) are usually incorporated within the pump suction chamber. Filters should have a large surface area and be readily accessible for inspection or maintenance.

The design of the filter and selection of filter material for oxygen service is a critical issue, see Table 1.

5.2.2 Cylinder assembly

The main components are the piston, piston rings, cylinder, and suction and discharge valves.

Piston rings are often made from a compound including polytetrafluoroethylene (PTFE) or similar materials. Such plastics have a much larger coefficient of expansion than that of the surrounding metals. Therefore, it is important to ensure that pumps are adequately cooled before operating, to reduce piston ring wear and the risk of overheating.

5.2.3 Gland seals

Leakage of cryogenic fluid to the atmosphere from the piston assembly is prevented by gland seals around the piston rod. These can be damaged by frozen moisture on the piston rod or excess play in the piston rod due to wear in the warm-end drive.

Cryogenic fluid leakage through worn gland seals has resulted in brittle failures of warm-end drives and also oxygen related fires. Avoidance and detection of such leakage is important, in particular for oxygen, and may be accomplished by use of a thermal shutdown device such as a thermocouple. An electrical seal heater or clamp on heater may be used on inert gases. If an electrical seal heater or clamp is used for oxygen, the design shall limit the maximum heat that can be put into the system or heater to prevent ignition conditions. The application of a warm, dry purge gas around the exposed piston rod may be used to extend the seal life.

The electrical seal heater should be in use during cold standby only.

5.2.4 Warm-end drive

The piston is normally driven forwards and backwards by a crank drive and crosshead assembly. These are usually of standard design, rated for the pressure and flow rate expected for the cold end. Smaller, lower duty crank drives often have dry running crossheads and prepacked grease lubricated main rolling element bearings. Higher duty crank drives are usually oil lubricated.

NOTE For pumps in oxygen service, design and selection of lubricants, materials, and purge gases are extremely important to safety.

5.2.5 Cold- and warm-end connection

The warm and cold ends are often separated by a bolted assembly that ensures both correct alignment and transmission of forces and that any leakage of cryogenic liquid is kept away from the warm end.

Correctly tightened bolts are important to avoid fatigue related bolt failures. This is usually achieved by the use of a torque wrench and appropriate lubricant on the washers, stud, and nut threads.

5.2.6 Electric motors

Electric motors may be single, dual, or variable speed. The use of variable speed drives gives additional flexibility for controlling filling rates and temperatures, for example when filling small cylinders.

The electric motor should be positioned so leaking or venting cryogenic fluid cannot drip onto or enter into the motor. For oxygen pumps, this can result in a fire or explosion. The motor shall not be placed under the gland seals or other known leak points without protection such as leak detection and / or gland seal protective guards in place.

5.3 Vaporisers

High pressure ambient vaporisers used in inert service are typically constructed from stainless steel piping surrounded by aluminium fins.

High pressure ambient vaporisers used in oxygen service are typically constructed from stainless steel or high nickel / copper alloys piping (such as Monel® or Inconel®) surrounded by aluminium fins. Pressures, materials, velocities, and particle impact should be considered when designing systems for oxygen service. For commonly used materials of construction for oxygen pump installations, see Table 2.

Where there is insufficient space for an ambient vaporiser, or where the vapour generated during operation is may be unacceptable, vaporisers that require an external heat source can be used. These include fan assisted ambient vaporisers, steam heated, or others using a direct fired boiler. An ambient vaporiser should be sized for the product, flow, and expected ambient conditions using accurate and detailed weather data for the region of operation.

To supplement ambient vaporisers in cold climates, trim heaters (typically electrically heated) are sometimes installed downstream of the ambient vaporiser.

Direct electrical element contact with oxygen is not recommended. Only indirect heated units should be considered for trim heaters in oxygen service.

In hot climates, bypasses are sometimes installed to reduce the temperature of the outlet gas.

A review shall be conducted in accordance with EIGA Doc 133, *Cryogenic Vaporisation Systems - Prevention of Brittle Fracture of Equipment and Piping*, to determine if a safety system is required to prevent low temperature fluid from being delivered downstream of the vaporiser(s) in the event of vaporizer overload or failure [4]. EIGA Doc 133, gives guidance on where this is appropriate [4].

5.4 Piping and piping components

Piping shall be suitable for the pressure, temperature, and fluid being pumped.

The piping assembly should be designed and installed to take into account the stresses caused by temperature cycling and vibration from a low temperature reciprocating system.

Pipework between the tank and pump should be as short as possible and have continuous slopes, while low points and long horizontal runs should be avoided. The bore of this pipework should be selected according to the pump flow rate requirements. Liquid velocity is optimised when the loss of NPSH due to heat leak is equal to the loss of NPSH due to frictional pressure drop.

Fittings and adapters with sharp bends or changes of section should be avoided to keep pressure losses to a minimum.

Piping should be adequately supported and allow for contraction and expansion due to temperature cycles.

Lines to thermal relief valves should rise or include a gas lock to prevent icing of the valve.

Flexible hoses reinforced by external braiding are often used on the suction side of pumps to isolate the tank and suction valves from pump vibration. Where no other provision for suction pipework thermal contraction is made, these flexible hoses should be installed slightly compressed to anticipate the reduced pipe length of approximately 3 mm per metre during cooldown.

Consideration should be given to access for ease of pump removal and to the possible requirement for the system to be warmed or purged with a dry, warm gas before and after maintenance.

5.5 Valves

Ball valves are commonly used between the tank and pump for isolation of liquid for operation, maintenance, or emergency. Ball valves are used to reduce pressure drop. These valves should be designed for cryogenic service with extended spindles and the stem packing located away from the valve body and may be operated manually or automatically.

Ball valves in cryogenic service shall either be drilled on the upstream side or designed to ensure that any liquid that could be trapped inside the ball can escape to prevent pressure build up.

For oxygen service, ball valves should not be used on the high pressure side of the pumping system due to the risk of adiabatic compression, flow friction, and particle impingement.

Use of actuated valves fitted on at least the liquid feed valve(s) and gas return valves in the event of a pump failure shall be installed for oxygen and shall be considered for inert gas service to increase the protection level of the installation. These actuated valves should be capable of remote activation from a safe location. When remotely actuated valves are used, they shall be fail closed. The actuated valve should be located as close to the vessel as possible, downstream of vessel isolation valve. A system like a mechanical fuse or an equivalent method of self-closure should be implemented. For example, the last part of pneumatic tubing that feeds the actuator of the valve may be in plastic so that in case of fire it burns or melts relieving the pneumatic air from the actuator.

Automatic systems may use these valves for process isolation.

Actuated valves may be fitted with limit switches to confirm whether the valve is open or closed. The valves should be interlocked with the motor control to ensure pumps cannot run when the valves are not open.

In addition, or alternatively, a low pressure switch may be fitted on the pneumatic supply to the actuator to detect loss of pressure.

Where there is any possible method of isolation in the discharge pipe, a full flow relief valve shall be fitted. The relief valve shall be sized for full pump flow and set at no greater than the design pressure of the system.

The relief valve shall vent to a safe area and shall be installed to protect against reaction forces.

A pressure relief valve shall be installed at any point where liquid can become trapped, for example, between two valves, between a nonreturn valve and valve, or between pump discharge and a valve.

A non-return valve should be fitted in the downstream pipework to prevent backflow of high pressure gas in the event of a pipe break or fire.

Manual or automated valves are sometimes fitted between this non-return valve and the pump discharge valve to aid priming or reduce back extrusion of the pump discharge valve when sitting warm.

Valves shall be manufactured to a recognised standard such as ISO 21011, *Cryogenic vessels - Valves for cryogenic service* [5].

6 Material selection

Materials for components shall have adequate properties, for example, mechanical, low temperature, lubricating, material compatibility, for the system operating temperature, pressure, and process gas. For more information on material selection in oxygen service, see Section 6 of EIGA Doc 200, *Design, Manufacture, Installation, Operation, and Maintenance of Valves Used in Liquid Oxygen and Cold Gaseous Oxygen Systems* [6].

Pumps, equipment, and components for oxygen service shall have all wetted components cleaned for oxygen service in accordance with EIGA Doc 33, *Cleaning of Equipment for Oxygen Service* [7]. In addition, components shall be verified as suitable for oxygen service.

For guidance see ISO 21028-1, *Cryogenic vessels—Toughness requirements for materials at cryogenic temperature—Part 1: Temperatures below -80 degrees C*, ISO 21028-2, *Cryogenic vessels—Toughness requirements for materials at cryogenic temperature—Part 2: Temperatures between –80 degrees C and –20 degrees C*, and ISO 21010, *Cryogenic vessels—Gas/Material compatibility* [8, 9, 10].

Additionally, for installations that will be supplying breathing gas and gases for medical, food, or pharmaceutical purposes, the potential release of toxic products by some materials should be considered. See EIGA Doc 73, *Use of Non-Metallic Materials in High Pressure Oxygen Breathing Gas Applications* [11].

Some halogenated materials (for example PTFE) can give off toxic gases from decomposition or burning, see EIGA Doc 73 [11].

Combustion of such materials within cryogenic pumps is usually an obvious event and should be followed by quarantining of any downstream cylinders in critical applications.

The use of such materials should be eliminated where an ignition cannot immediately be detected, for example avoid using soft seal valves and keep their use to a minimum where their elimination is not practical.

Specific precautions including leak detection, lubrication, and material compatibility should be taken when using pumps in oxygen service. Liquid oxygen pumps shall be constructed so possible oxygen leakage cannot contact any hydrocarbon lubricant. Where this cannot be prevented with certainty, the use of oxygen compatible lubricants meeting the requirements of ISO 21010 shall be considered [10]. However, it should be noted that such oxygen compatible lubricants are less able to protect the bearing against corrosion as they have poor wetting properties and do not provide a corrosion protective film.

Oxygen compatible lubricants are also inferior to hydrocarbon based greases in their ability to withstand load and speed. Simple substitution of oxygen compatible lubrication without taking the overall design / duty into consideration can make a failure and possible ignition more likely.

Oxygen compatible lubricants can also have some adverse reaction with some materials such as aluminium.

Tables 1 and 2 give a non-exhaustive list of commonly used materials of construction for oxygen pumps and pump installations.

Table 1 – Typical materials of construction for reciprocating pumps in oxygen service

Item	Materials	Comment
Cold-end cylinder assembly	High nickel/copper alloys (such as Monel® or Inconel®), stainless steel	Aluminium alloys should not be used.
Sleeve (cylinder liner)	High nickel/copper alloys (such as Monel or Inconel), stainless steel	
Piston	High nickel/copper alloys (such as Monel or Inconel), silicon bronze, stainless steel, beryllium copper for low pressure section	
Piston ring	PTFE with 60% bronze filling, PTFE with carbon filling	For medical installations, see Section 6 and EIGA Doc 73 [11].
Piston ring spring energiser, if fitted	Beryllium copper, stainless steel	
Guide (rider) ring	PTFE with 60% bronze filling, PTFE	
Piston low pressure seal	PTFE with 15% glass fill, PTFE with carbon graphite	For medical installations, see Section 6 and EIGA Doc 73 [11].
Suction valve seat	High nickel/copper alloys (such as Monel or Inconel), stainless steel	

Suction valve	High nickel/copper alloys (such as Monel or Inconel), nickel coated stainless steel, stainless steel	
Discharge valve (poppet valve)	Polychlorotrifluoroethylene (PCTFE), PTFE with 15% glass fill, high nickel/copper alloys (such as Monel® or	For medical installations, see Section 6 and EIGA Doc 73 [11].
Discharge valve spring (if fitted)	Beryllium copper	
Discharge valve body	High nickel/copper alloys (such as Monel® or Inconel®), stainless steel	
Discharge valve gasket	Copper	
Suction filter/strainer	High nickel/copper alloy (such as Monel® or Inconel®), copper, bronze, stainless steel	Some pump styles may not have a suction filter/strainer.
NOTE The materials listed in this table may be used for inert gas service, when they meet the requirements of Section 6.		

Table 2 – Typical materials of construction for pump installations (piping, valves, vaporiser etc.) in oxygen service

Item	Materials
External fittings, connections	High nickel/copper alloys (such as Monel® or Inconel®), stainless steel, tin bronze, phosphor bronze, brass
Piping	High nickel/copper alloys (such as Monel® or Inconel®), stainless steel, copper
Valves (isolation, non-return)	High nickel/copper alloys (such as Monel® or Inconel®), tin bronze, phosphor bronze, stainless steel
Pulsation dampener	High nickel/copper alloys (such as Monel® or Inconel®), stainless steel
Vaporizer	High nickel/copper alloys (such as Monel® or Inconel®), stainless steel
NOTE The materials listed in this table may be used for inert gas service, when they meet the requirements of Section 6.	

7 Instrumentation

The instrumentation fitted to a cryogenic pump and pump installation depends upon the operational requirements of the installation and fluid pumped. An example of a typical pump system is shown in Figure 5. See Table 3 for the instrument list.

As a minimum all pumps and pump installations shall have:

- An emergency stop button. This hard wired emergency stop shall be included within the control circuit to stop the pump and return any actuated liquid or vapour valves to their fail safe position; and

- A high discharge pressure trip (PSHH). This will shut the pump down before the discharge relief valve lifts. There should be no valve between the pump discharge and the high pressure switch.

As a minimum, all oxygen pumps or pump installations shall have the following, which are optional for inert gases:

- A loss of prime / cavitation shutdown system to prevent overheating and damage and potential ignition in the case of pumps in oxygen service. This is normally a high temperature trip (TSHH) on the pump discharge line as close as practicable to the pump discharge. This requires an override for a short period on start-up to allow the pump to be primed. The start up timer override should be set for the shortest time possible that will allow the pump to reliably detect prime; and

- Gland leakage low temperature (TSLL) trip or any other appropriate method of gas leakage detection. This is a temperature probe located between the cold and warm end. This will notify the system of piston gland seal leakage (TSLL).

Other instrumentation may include:

- Suction return low temperature permissive start/trip (TSL). This is a temperature probe positioned to notify the system that the desired cooldown temperature has been reached and that the fluid condition remains acceptable during operation. The set point should be as low as possible consistent with the warmest liquid that can be expected in the storage tank (the greater the operating pressure of the tank, the warmer the potential liquid temperature);

- Gland high temperature (TSHH). The same temperature probe from gland seal low temperature may be used for high temperature detection to give warning of possible cold and warm end mechanical issues (TSHH);

- Vaporiser discharge low temperature (TSLL):

    - This is a temperature probe located after the vaporiser to ensure that the gas flowing downstream is not too cold, with the risk of embrittlement of the cylinders, etc.

    - The determination of appropriate Safety Integrity Level (SIL) for the loss of prime shutdown system may be required. The system should then be designed and installed to meet this level

    - Temperature elements may be resistance bulb (PT100) or thermocouple. Whichever is selected, the system shall shutdown in the event of element or detector going closed or open circuit

    - The temperature sensing element should be installed at an appropriate distance downstream of any vaporiser bypass line return to allow for mixing;

- Pressure control (PC):

    - Typical method of detection is the use of a pressure switch or pressure transmitter (pressure set point low and high [PSL and PSH]);

- Discharge pressure gauge (PI):

    - This gauge is positioned at the pump discharge outlet (after the pulsation unit) for monitoring the discharge pressure of the pump;

- Dry, oil-free gas purge to the internals of the warm-end drive and/or intermediate piece between cold end and warm end:

    - This purge is recommended for pumps in oxygen service

    - This purge is fitted to some pumps to prevent the ingress of moisture. A manually adjusted flowmeter is often fitted to indicate and regulate this flow

    - The potential for over pressurisation of the warm-end drive should be considered and if necessary a low pressure relief valve should be fitted

    - If the purge to the crank drive is shared with one to the pump gland area, a non-return valve should be considered to prevent any liquid gland leakage being directed to the warm end;

- Pump prime at start up:

    - Typical methods include starting the pump unloaded or through the use of an unloader valve; and

- Liquid vessel isolation:

    - Typical method includes the use of a fail closed actuated cryogenic vented ball valve.

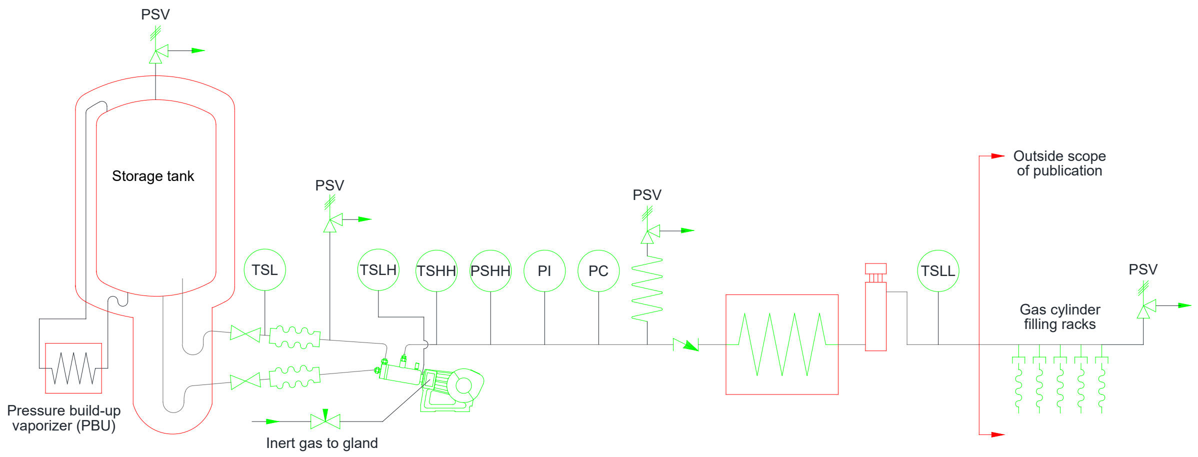

Figure 5 – Example of a pump system

Table 3 – Instrument list

TAG	Instrument	Typical values	Oxygen	Inert gases
TSHH	Loss of prime shutdown system	For air gases: –120 °C (–184 °F)	Mandatory	Optional
PSHH	High discharge pressure switch	Less than relief valve	Mandatory	Mandatory
TSL	Suction return low temperature permissive start		Optional	Optional
TSLL	Gland leakage low temperature	–50 °C (–58 °F)	Mandatory	Optional
TSHH	Gland leakage high temperature	+ 50 °C (+122 °F)	Optional	Optional
TSLL	Vaporiser discharge low temperature	–20 °C (–4 °F)	Mandatory where bypass fitted	Mandatory where bypass fitted
PC	Pressure switch or pressure transmitter (pressure set point low and high) (PSL and PSH)		Optional	Optional
PI	Pressure gauge positioned at the pump discharge		Optional	Optional

8 Insulation

The requirement for any insulation depends on the liquid conditions and pipework arrangement. When insulation is used, the type and material depend upon a number of items, including the product being pumped, and volume of product pumped through the piping. Insulation should be compatible with the product being pumped and condensed air where condensation can occur. Insulation of a suction line is recommended to minimise heat leak.

9 Installation

Equipment is usually securely bolted to a concrete foundation.

Consideration should be given for access for operation and maintenance. Piping and cable routes should be considered early in the design stage to minimise (and combine where possible) the number of runs. Suction pipework should be short and direct to reduce pressure drop. Delivery pipework and cabling may be long and run to keep the installation clear for operation and maintenance. Cabling and conduit shall not be located under cryogenic pumps or piping where leakage can occur and shall not be run in proximity to liquid lines as the insulation materials of the wires can be subject to low temperature embrittlement and can fail.

For oxygen installations, additional hazards and mitigations should be considered including avoidance of flammable surfaces (such as asphalt / tar) in close proximity to oxygen pump and pump installations.

Any risk assessment shall consider the duty of the pump (including pressure and flow), materials of construction, lubricant, safety devices / instrumentation, and installation location.

Fully enclosed pumps are not recommended as they can create more hazards that have the potential to go unnoticed until a fire or explosion occurs. If it is determined that a barrier is required to protect personnel from an oxygen fire or explosion, a risk assessment should show that the barrier does not create additional hazards such as oxygen enrichment due to restricted airflow, obstructed visibility, and limited emergency and maintenance access.

Oxygen pumps should not be enclosed by more than two walls as it greatly increases the likelihood that a hazardous accumulation of oxygen can occur, which could result in a fire or explosion.

10 Operating pumps

The cooling down time shall be sufficient to ensure that all parts of the cold end of the pump are cooled down. The cooldown should be monitored by a temperature probe on the suction return (degassing) line and should include an interlock to prevent the pump from starting if not adequately cooled down.

A number of problems can occur during the operation of a cryogenic reciprocating pump. Pump manufacturers should supply comprehensive operating and troubleshooting information.

The following is a list of common problems and solutions:

- Pump fails to produce expected flow or pressure:
  - Ensure that both the feed and return line valves are open
  - Check tank liquid levels and liquid condition
  - Check for blocked filters
  - Check for damaged, stuck or leaking suction or discharge valve(s)
  - Check for worn or loose drive belts;
- Piston gland seal leakage:
  - Check seals for wear and running hours
  - Check crank drive for worn crosshead guides (allowing excessive piston lateral movement)
  - Check that the gland purge or heater is not allowing ice formation on the rod; and
- Noisy pump:
  - Check for damaged bearings
  - Check for partial loss of prime / cavitation.

11 Maintenance and repair

11.1 Maintenance

A maintenance programme shall be developed based on the pump manufacturer's recommendations and / or user experience. Failure to follow the maintenance programme can result in fires in oxygen service. In addition, routine checks should be carried out during pump operation for signs of leakage, abnormal noises, increased temperatures, and other items that may need attention.

11.2 Repair procedures

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

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.

11.3 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 management of change (MOC) process. Parts approved for use in oxygen service shall be properly inspected, cleaned, handled, and stored. Refer to EIGA Doc 33 [7].

12 References

Unless otherwise specified, the latest edition shall apply.

[1] CGA G-6.3, *Carbon Dioxide Cylinder Filling and Handling Procedures*, www.cganet.com.

[2] EIGA Doc 83, *Recommendations for safe filling of CO2 cylinders and bundles*, www.eiga.eu.

[3] EIGA Doc 148, *Stationary Electric-Motor-Driven Centrifugal Liquid Oxygen Pumps*, www.eiga.eu.

NOTE This publication is part of an international harmonisation programme 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 harmonised regional references.

[4] EIGA Doc 133, *Cryogenic Vaporization Systems—Prevention of Brittle Fracture of Equipment and Piping*, www.eiga.eu.

NOTE This publication is part of an international harmonisation programme 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 harmonised regional references.

[5] ISO 21011, *Cryogenic vessels - Valves for cryogenic service*, www.iso.org.

[6] EIGA Doc 200, *Design, Manufacture, Installation, Operation, and Maintenance of Valves Used in Liquid Oxygen and Cold Gaseous Oxygen Systems*, www.eiga.eu.

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[7] EIGA Doc 33, *Cleaning of Equipment for Oxygen Service*, www.eiga.eu.

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[8] ISO 21028-1, *Cryogenic vessels—Toughness requirements for materials at cryogenic temperature—Part 1: Temperatures below -80 degrees C*, www.iso.org.

[9] ISO 21028-2, *Cryogenic vessels—Toughness requirements for materials at cryogenic temperature—Part 2: Temperatures between –80 degrees C and –20 degrees C*, www.iso.org.

[10] ISO 21010, *Cryogenic vessels—Gas/Material compatibility*, www.iso.org.

[11] EIGA Doc 73, *Use of Non-Metallic Materials in High Pressure Oxygen Breathing Gas Systems*, www.eiga.eu.

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