



RECIPROCATING CRYOGENIC PUMPS AND PUMP INSTALLATIONS

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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 will operate both safely and reliably it is important that pumps are correctly designed, installed, operated and maintained as required for the 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 vaporization and the ability of oxygen to accelerate combustion.

This document gives guidance to manage these hazards.

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2 Scope

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

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

NOTE Information regarding carbon dioxide pumps is in CGA G-6.3, Carbon Dioxide Cylinder Filling and Handling Procedures [1].

NOTE Centrifugal liquid oxygen pumps are covered by AIGA 055, *Installation Guide for Stationary, Electric-Motor-Driven, Centrifugal Liquid Oxygen Pumps* [2].

3 Definitions

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 and Need Not

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 Cavitation

This phenomenon occurs when the pressure in a liquid drops below the vapour pressure of the liquid at a certain temperature. At this point liquid vaporizes, thereby creating vapour bubbles. 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 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, oil free 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 below its boiling point.

NOTE Subcooling: can be achieved by increasing the liquid pressure above 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 drive box

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 vaporizer, interconnecting and delivery pipework. A general arrangement of cryogenic pump equipment is shown in Figure 1; not all required control and safety elements are shown. 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. The tank is usually filled from a road tanker, but may be filled directly from a production plant. 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. The thermosiphon tank is a more recent development and 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 vaporizer to convert it from liquid to the gaseous phase. Vaporizers can be ambient, that is relying on no additional heat input to vaporize the product, or there may be an external heat source such as hot water, steam or hot air.

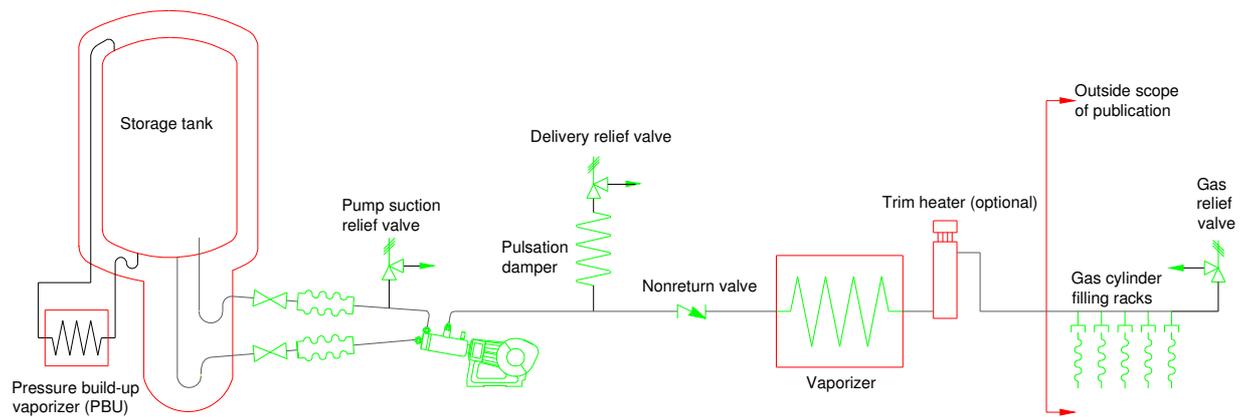


Figure 1 General arrangement of cryogenic pump equipment

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

A simplified thermosiphon tank piping arrangement is shown in Figure 2; not all required control and safety elements are shown. 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. This 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 it 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 cryogen and therefore icing when a pump is isolated.

Heat gained in the external pump pipework reduces the cryogenic liquid density sufficiently to generate a thermo siphon 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 and keep the depth of internal gas traps to a minimum.

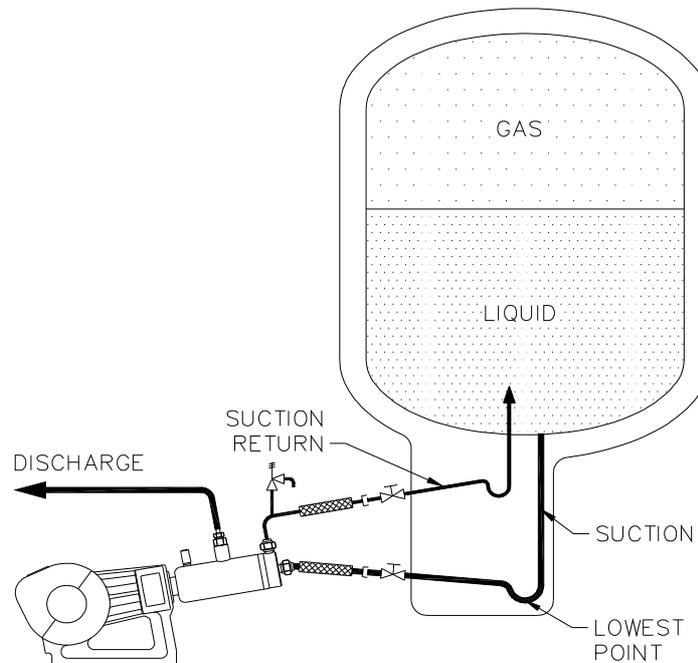


Figure 2 Simplified thermosiphon tank arrangement

5.1.2 Standard conventional use tanks piped for pumps

Standard tanks, as shown in Figure 3, 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; not all required control and safety elements are shown. Pumps are used in different applications that require different controls and safety elements. Cryogenic pumping systems should be designed by qualified personnel 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.

The disadvantage of this liquid feed-vapour return arrangement is that once the tank level falls below a certain level, the feed to the pump becomes effectively a long single pipe containing at least one gas trap. Should the pump be shutdown 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 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.

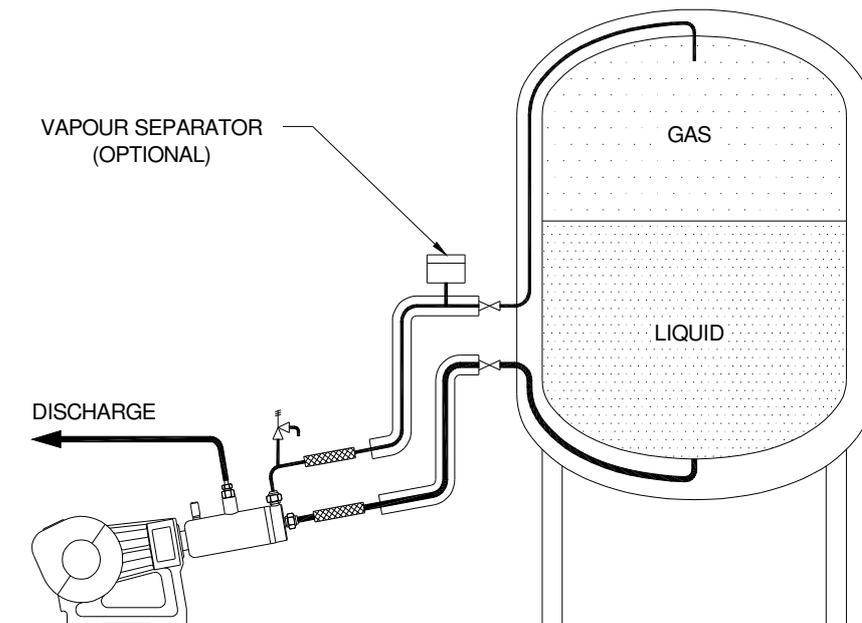


Figure 3 Simplified standard tank arrangement

5.1.3 Pressure build up and tank pressure

Standard and thermosiphon tanks may incorporate a pressure build up vaporizer (PBU). If the system experiences pumping problems the PBU can be used to increase the NPSH or subcooling.

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 have in common, provision for vapour escape, ideally 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.

The pump components are shown in Figure 4. Recommended materials are covered in Section 6.

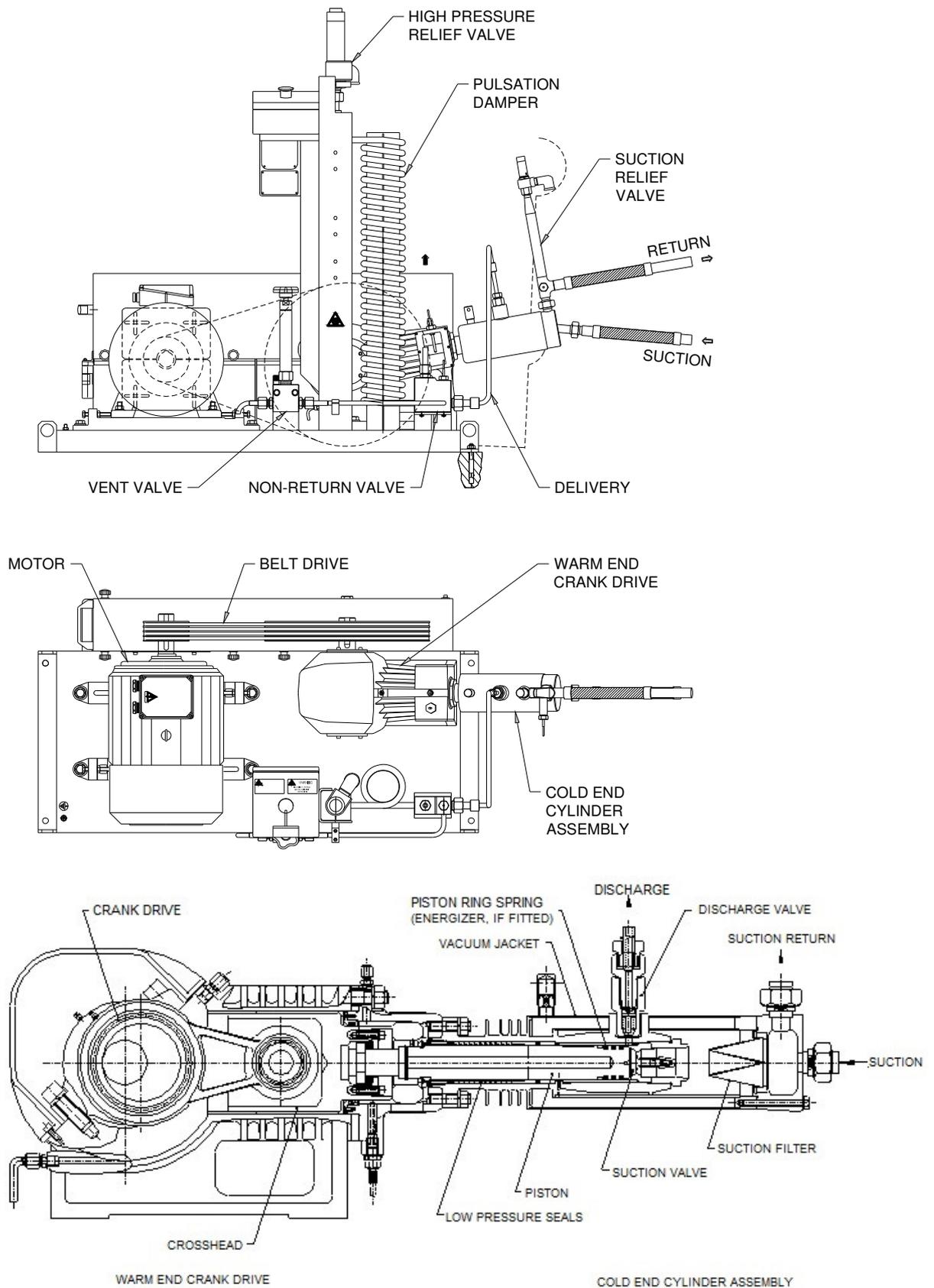


Figure 4 Example of reciprocating pump components

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 liquid to the atmosphere from the piston assembly is prevented by 'low pressure' 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 liquid 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, and may be accomplished by use of a thermal shutdown device such as a thermocouple. An electrical seal heater or clamp on heater can 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 inert gas purge around the exposed piston rod can be used to extend the seal life.

NOTE 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 pre-packed grease lubricated main rolling element bearings. Higher duty crank drives are usually oil lubricated.

NOTE For pumps in oxygen service the design and selection of lubricants, materials, and purge gases is 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 can 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.

For oxygen pumps, the electric motor should be positioned so leaking or venting oxygen cannot drip onto or enter the motor, which 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 Vaporizers

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

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

Where there is insufficient space for an ambient vaporizer, or where the vapour generated during operation may be unacceptable, vaporizers that require an external heat source can be used. These include fan assisted ambient vaporizers, steam heated or others using a direct fired boiler. An ambient vaporizer 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 vaporizers in cold climates, 'trim heaters' (typically electrically heated) are sometimes installed downstream of the ambient vaporizer.

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.

In some cases safety systems are needed to prevent low temperature fluid from being delivered downstream of the vaporizer(s) in the event of vaporizer overload or failure. AIGA 027, *Cryogenic Vaporization Systems—Prevention of Brittle Fracture of Equipment and Piping* gives guidance on where this is appropriate [3].

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, low points and long horizontal runs should be avoided. The bore of this pipework should be selected according to the pump flow rate requirements. Fluid 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/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 3mm per metre during cool down.

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. 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.

NOTE Some designs of ball valves in cryogenic service require the ball to be drilled on its upstream side to ensure that any liquid that may be trapped can escape.

NOTE For oxygen service, ball valves are not typically 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) as the primary form of protection in the event of a pump failure should be considered for oxygen and inert gas service. This actuated valve should be capable of remote activation from a safe location. When remote actuated valves are used, they shall be fail closed, i.e., they shall close in the event of loss of pneumatic or electrical supply.

Automatic systems can utilise these valves for process isolation.

Actuated valves can be fitted with limit switches to confirm whether the valve is open or closed.

In addition or alternatively, a low pressure switch can 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 higher than the design pressure of the system.

The relief valve shall vent to a safe area.

A pressure relief valve shall be installed at any point where liquid can become trapped for example between two valves, between a check 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* [4]

6 Material selection

Materials for components need to have adequate properties e.g. mechanical, low temperature, lubricating, material compatibility, for the system operating temperature, pressure and process gas.

NOTE Pumps, equipment, and components for oxygen service shall have all wetted components cleaned for oxygen service in accordance with AIGA 012, *Cleaning of Equipment for Oxygen Service* and CGA-4.1, *Cleaning Equipment for Oxygen Service* [5, 6]. In addition, qualified personnel shall verify that all components are suitable for oxygen service.

For guidance see ISO 21028, *Cryogenic vessels—Toughness requirements for materials at cryogenic temperature*, Parts 1 and 2, and ISO 21010, *Cryogenic vessels—Gas/materials compatibility* [7, 8, 9].

Additionally for installations that will be supplying medical and breathing gas, the potential release of toxic gas by some materials should be considered.

Some halogenated materials such as PTFE may give off toxic gases from decomposition or burning: see AIGA 059 *Design considerations to mitigate the potential risks of toxicity when using non-metallic materials in high pressure oxygen breathing gas systems* [10].

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 (e.g. medical and breathing gas), etc.

The use of such materials should be eliminated where an ignition cannot immediately be detected, e.g., 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 [9]. It should be noted, however, that such oxygen compatible lubricants are less able to protect the bearing against corrosion (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 therefore possible ignition more likely.

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

The following two tables give a non-exhaustive list of commonly used materials for the construction of oxygen pumps and pump installations.

Table 1 Typical materials of construction for reciprocating pumps

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 LP section	
Piston Ring	PTFE with 60% bronze filling, PTFE with carbon filling	For medical installations, see Section 6 and AIGA 059 [9]
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	For medical installations, see Section 6 and AIGA 059 [9]
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)	PCTFE, PTFE with 15% glass fill, High nickel/copper alloys (such as Monel® or Inconel®)	For medical installations, see Section 6 and AIGA 059 [9]
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.

Table 2 Typical materials of construction for oxygen pump installations (piping, valves, vaporizer, etc)

Item	Materials
External fittings, connections	High nickel/copper alloys (such as Monel® or Inconel®), stainless steel, tin bronze, phosphor bronze
Piping	High nickel/copper alloys (such as Monel® or Inconel®), stainless steel, tin bronze, phosphor bronze
Valves (isolation, non-return)	High nickel/copper alloys (such as Monel® or Inconel®), tin bronze, phosphor bronze, stainless steel
Pulsation damper	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 Table 2 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 will depend upon the operational requirements of the installation and fluid pumped. A typical pump system is shown in Figure 5; see Table 3 for the instrument schedule.

As a minimum all pumps 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.
- 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. This has to be overridden 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.
 - Another method of loss of prime/cavitation protection is a low current trip on single-speed pumps. Current detection is difficult to configure and is less reliable on variable speed pumps.
 - Differential pressure trips, while common on centrifugal pumps, are usually unsuitable for typical reciprocating pump installations as the discharge pressure will not normally fall on loss of prime.
 - 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.
- A high discharge pressure trip (PSHH)
 - This will shut the pump down before the discharge relief valve lifts.

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 cool down 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 might be expected in the storage tank (the higher the operating pressure of the tank, the warmer the potential liquid temperature).
- Gland leakage low and high temperature (TSLH)
 - This a temperature probe located between the cold and warm end. This will notify the system of piston gland seal leakage (TSL).
NOTE This should be fitted as standard on liquid oxygen pumps.
 - The same temperature probe may be used for high temperature detection to give warning of possible cold end/warm end mechanical issues (TSH).
- Vaporizer discharge low temperature (TSL)
 - This is a temperature probe located after the vaporizer 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 vaporizer 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 pumps discharge outlet (after the pulsation unit) for monitoring the discharge pressure of the pump.
- Inert gas (e.g., nitrogen, argon) purge to the internals of the warm end drive
 - 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 pressurization 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 startup
 - Typical methods include starting the pump unloaded or through the use of an unloader valve.
- Liquid vessel isolation
 - Typical method includes the use of a fail closed actuated cryogenic vented ball valve.

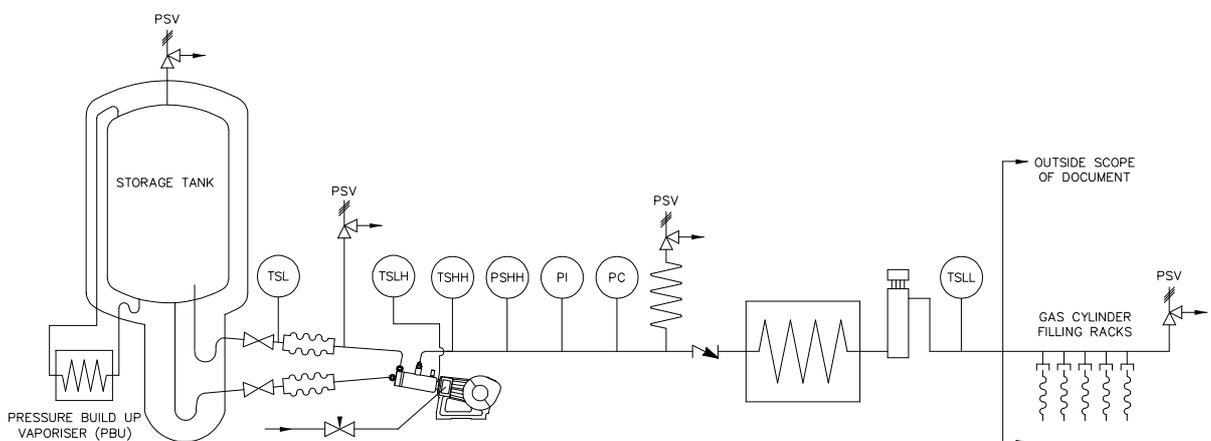


Figure 5 Example of a pump system

Table 3 Instrument schedule

TAG	Instrument	Typical values	Status
TSHH	loss of prime shutdown system	for air gases -120°C	Mandatory
PSHH	high discharge pressure switch	Less than relief valve	Mandatory
TSL	Suction return low temperature permissive start		Optional
TSLH	Gland leakage low and high temperature	-50°C+50°C.	Recommended for LOX pumps
TSLL	Vaporizer discharge low temperature	-20°C	Mandatory where bypass fitted
PC	Pressure switch or pressure transmitter (pressure set point low and high (PSL and PSH))		Optional
PI	Pressure gauge positioned at the pumps discharge		Optional
	Inert gas purge to the internals of the warm end drive		Optional. Recommended where oxygen compatible grease used

8 Insulation

The requirement for any insulation depends on the liquid conditions and pipework arrangement. When insulation is used, the type and material depends 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.

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. 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, nor shall it be run in proximity to liquid lines as the insulation materials of the wires can be subject to low temperature embrittlement and fail.

For oxygen installations additional hazards and mitigations should be considered.

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

Fully enclosed pumps are not desirable 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; the risk assessment should show that the barrier does not create additional hazards such as oxygen enrichment due to restricted air flow, obstructed visibility, limited emergency and maintenance access.

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

10 Operating pumps

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

In addition a list of common problems and solutions are detailed below.

- 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
- Noisy pump:
 - Check for damaged bearings
 - Check for partial loss of prime/cavitation.

11 Maintenance

Maintenance should be carried out on cryogenic pumps in accordance with the manufacturer's recommendations. In addition, routine maintenance, checks should be carried out during pump operation for signs of leakage and other items that may need rectification. This includes listening for abnormal noises, increased temperatures etc.

12 References

Unless otherwise specified, the latest edition shall apply.

[1] CGA G-6.3, *Carbon Dioxide Cylinder Filling and Handling Procedures*, Compressed Gas Association, Inc., 4221 Walney Rd., 5th Floor, Chantilly, VA 20151. www.cganet.com

[2] AIGA 055, *Installation Guide for Stationary, Electric-Motor-Driven, Centrifugal Liquid Oxygen Pumps*, www.asiaiga.org

[3] AIGA 027, *Cryogenic Vaporization Systems—Prevention of Brittle Fracture of Equipment and Piping*, www.asiaiga.org

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

[5] AIGA 012, *Cleaning of Equipment for Oxygen Service*, www.asiaiga.org

[6] CGA-4.1, *Cleaning Equipment for Oxygen Service* Compressed Gas Association, Inc., 4221 Walney Rd., 5th Floor, Chantilly, VA 20151. www.cganet.com

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

[8] 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

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

[10] AIGA 059, *Design Considerations to Mitigate the Potential Risks of Toxicity When Using Nonmetallic Materials in High Pressure Oxygen Breathing Gas Systems*, www.asiaiga.org