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| <b>AEROSPACE<br/>INFORMATION REPORT</b> | <b>AIR825™/5</b>  | <b>REV. A</b> |
|   | Issued 2002-03<br>Revised 2003-03<br>Reaffirmed 2023-08<br><br>Superseding AIR825/5 |               |
| Liquid Oxygen Systems                   |   |               |

RATIONALE

AIR825/5A has been reaffirmed to comply with the SAE Five-Year Review policy.

FOREWORD

This document is one of a set of related documents. These documents comprehensively address the "Introduction to Oxygen Equipment for Aircraft", and are referred to as slash (/) documents, rather than chapters. The documents may be obtained as a set or individually. As the field of oxygen systems for aircraft has evolved, it became cumbersome for one document to cover the full range of subject matter. The reader who is seeking overall familiarity with oxygen systems for aircraft should read all of these documents that combine to form a general reference to oxygen systems. The reader who is familiar with oxygen systems for aircraft may want to obtain only the slash documents that pertain to topics that are of specific interest.

The document set is written as an introductory level, suitable for anyone who would like to understand the basics of oxygen systems in aircraft, and specifically for the engineer who has just recently been assigned to aircraft oxygen systems. Many of these documents point the reader toward more detailed treatments located in other SAE documents.

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## 1. SCOPE:

This Aerospace Information Report provides general information to aircraft designers and engineers, regarding LOX, its properties, its storage and its conversion to gas. Much useful information is included herein for aircraft designers regarding important design considerations for a safe and effective installation to an aircraft. The associated ground support equipment needed to support operations of LOX equipped aircraft is also discussed. It is important to realize that LOX equipped aircraft cannot be supported unless this support infrastructure is also available. A significant part of this document will address the specific advantages, disadvantages and precautions relating to LOX systems. These are important issues that must be considered in deciding which oxygen system to install to the aircraft. Also, many commercial and military aircraft use aeromedical LOX equipment that is mostly portable equipment. Aeromedical LOX equipment is not addressed herein as it is beyond the scope of this document.

## 2. REFERENCES:

### 2.1 Applicable Documents:

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

#### 2.1.1 SAE Publications: Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

AS8010 Aviator's Breathing Oxygen Purity Standard

#### 2.1.2 U.S. Government Publications: Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-PRF-27210 Oxygen, Aviator's Breathing, Liquid and Gas

#### 2.1.3 NFPA Publications: Available from National Fire Protection Association, 11 Tracy Drive, Avon, MA 02322.

NFPA Standard No. 401 B

## 2.2 Related Publications:

The following publications are provided for information purposes only and are not a required part of this SAE Aerospace Technical Report.

|             |   |
|-------------|---|
| MIL-D-19326 | Design and Installation of Liquid Oxygen Systems in Aircraft, General Specification for |
| TR-56-260   | Air Force Handbook of LOX Systems, Volumes I & II                                       |
| STANAG 3056 | Marking of Airborne and Ground Gas and Cryogenic Fluid Containers                       |
| STANAG 3545 | Characteristics of Breathable Liquid Oxygen   |
| STANAG 3976 | Lubricants for Use in Oxygen Systems with Oxygen Rich Environments – AEP-15             |
| STANAG 3978 | Purging Liquid Oxygen Storage and transport Tanks and Aircraft                          |

## 2.3 Definitions:

LOX: An abbreviation for liquid oxygen

NATO: An abbreviation for North Atlantic Treaty Organization

STANAG: A NATO Standardization Agreement

## 3. LIQUID OXYGEN (LOX):

When choosing a source of oxygen supply for any type of aircraft, various types of systems are considered and trade studies conducted. Oxygen may be supplied from either gaseous, liquid, solid or chemical block sources, or concentrated from air by on-board oxygen concentrators for use in aircraft systems. However, the use of solid oxygen is considered impractical. It is almost impossible to provide in practice with a freezing point of  $-227.2\text{ }^{\circ}\text{C}$  ( $-377\text{ }^{\circ}\text{F}$ ) and its use offers no further advantage when compared to the liquid state. Gaseous oxygen has been commonly used in aircraft installations ever since flights were made at altitudes requiring supplemental oxygen for occupant survival. Gaseous oxygen is presently the most common source of supply used in commercial aircraft. A practical LOX system for aircraft use was developed in the 1950's for application to past military aircraft design programs. Size and weight penalties of gaseous oxygen equipment needed to support long military missions demanded the advanced technological development of practical aircraft LOX systems. Now LOX supply systems are installed in many military aircraft. New fighter and bomber aircraft designs are actively pursuing the on-board oxygen generating system (OBOGS) designs. OBOGS equipped aircraft concentrate oxygen from pressurized air sources. However, many military transport aircraft still need LOX systems because of the large number of crewmembers and passengers to support for extended time periods. OBOGS is limited to smaller aircraft because of its limitations of flow and ability to store oxygen for use when in nonuse conditions. Consideration has been given to LOX systems in the current commercial jet transport aircraft designs, but the need to constantly replenish supply due to losses from boil off has made them impractical for use on commercial aircraft.

### 3.1 LOX Properties:

LOX is a light, blue, transparent, water like fluid, produced by the fractional distillation of purified liquid air. AS8010B, MIL-PRF-27210, and STANAG 3545 define the requirements for quality of the LOX.

At sea level, atmospheric pressure 101.3 kPa (760 mm Hg or 14.7 psia), LOX has the following properties:

a. Boiling Point:

-183 °C (-297 °F)

b. Density:

1140.5 kg/m<sup>3</sup> at -183 °C (71.2 lb/ft<sup>3</sup> at -297 °F)  
1.14 kg/dm<sup>3</sup> or 2.5 lb/L (9.54 lb/gal (US) (11.32 lb/gal (Imperial)))

c. Volume Expansion:

1 L LOX = 860 L gaseous oxygen at 21.1 °C, 101.3 kPa  
= 30.36 ft<sup>3</sup> gaseous oxygen at 70 °F, 14.7 psia

d. Latent Heat of Vaporization:

213 J/g (91.7 BTU/lb)

At higher pressures, the boiling point of LOX will increase. The critical temperature of -118 °C (-180 °F) is attained at a pressure of 5.07 MPa (735 psi) (50 atmospheres). Regardless of further pressure increase, oxygen will not remain in a liquid state above this temperature.

Pure LOX does not produce irritating vapors but adsorbs various types of odoriferous substances that may be in containers or the ambient. These odors can be released when LOX is converted into the gaseous state for breathing. Additionally, LOX can contain substances that would pose a risk of combustion if the contaminate level is allowed to be excessive. These reasons are why quality control of contaminants must be addressed when purchasing LOX for aviation breathing systems.

### 3.2 LOX Converters and Ground Servicing Equipment:

The utilization of LOX in airborne installations has been facilitated by the development of a practical system for the conversion of cold LOX to gaseous oxygen at an acceptable ambient temperature for breathing. This system depends on no external source of energy other than the surrounding atmosphere for converting the LOX to gas. Ground storage and airborne containers operate on the same basic principle of liquid to gaseous state conversion for their respective purposes. Operation of a typical LOX converter and component parts of the system to provide gaseous oxygen to the aircraft supply line is shown in Figures 1 and 2.

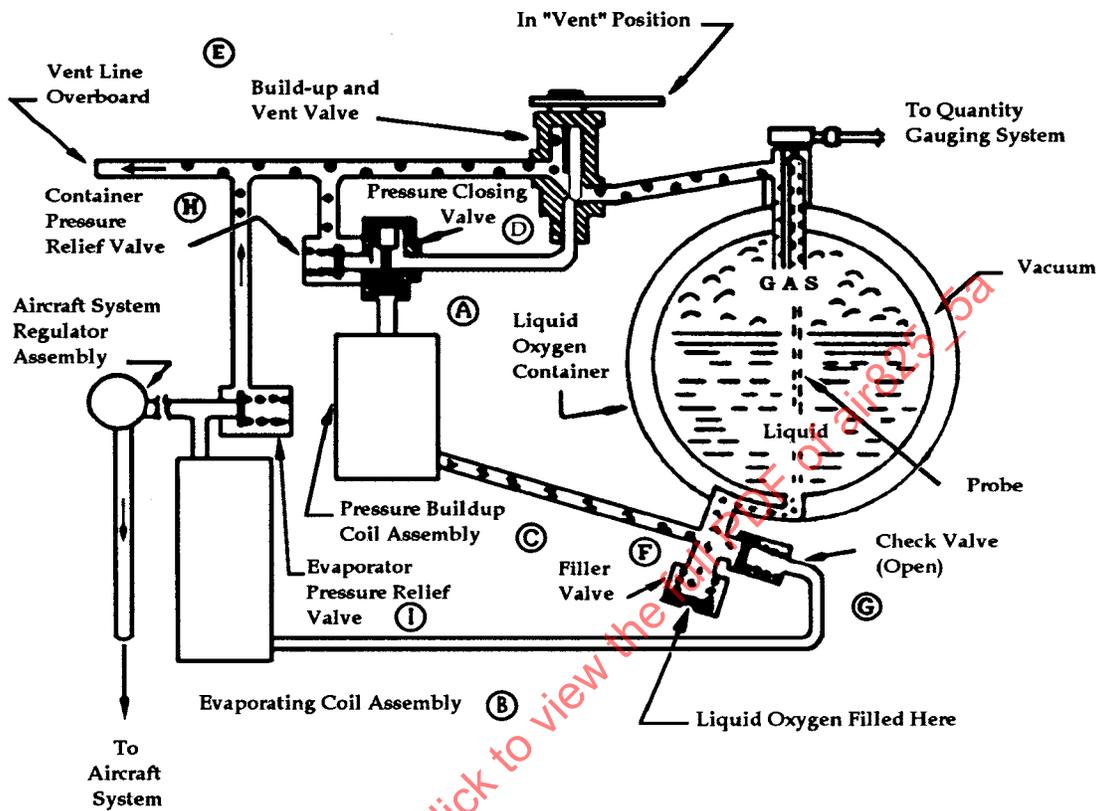


FIGURE 1 - Converter Filling Procedure

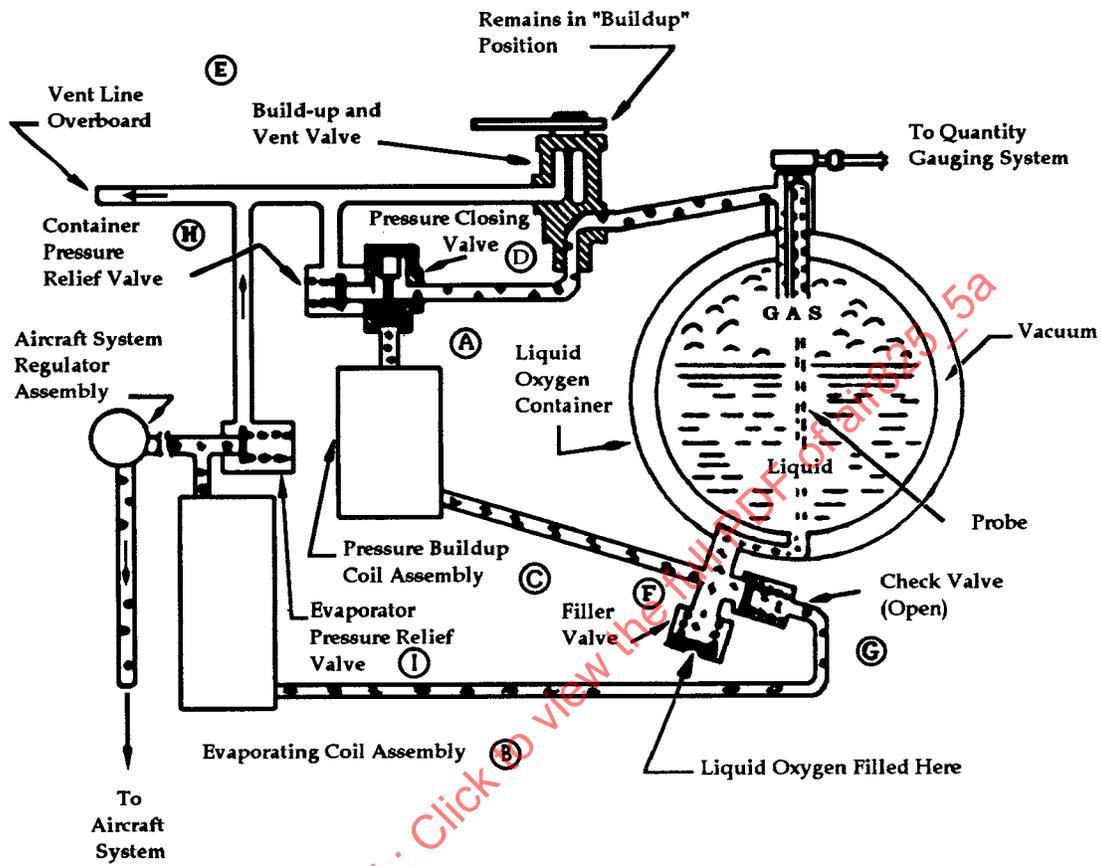


FIGURE 2 - System Supply Procedure

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### 3.2.1 LOX Converter Assembly:

3.2.1.1 Characteristics: A converter assembly is a self-powered system for the storage of LOX and for its conversion to gaseous oxygen when required. Major parts of the assembly package (Refer to Figures 1 and 2) are:

TABLE 1 - LOX Converter Parts

|  |                |
|--|----------------|
| a. A double-walled container                                 | Item A         |
| b. An evaporation coil (or coils)<br>Can be remotely located | Item B         |
| c. A pressure build-up coil                                  | Item C         |
| d. Build up and vent valve                                   | Item E         |
| e. Filler valve  | Item F         |
| f. Liquid check valve  | Item G         |
| g. Pressure control valves                                   | Item D & H     |
| h. Pressure relief valve                                     | Item I         |
| i. Volume gauging probe                                      | not referenced |
| j. Mounting brackets   | not shown      |
| k. Economizer circuit (optional design)                      | not shown      |
| l. Purge Valve (for large containers)                        | not shown      |

3.2.1.2 LOX System Operation Details: LOX is supplied to the container through the spring-loaded Filler Valve (F) from the service cart. As LOX flows into the warm container (A), it vaporizes very rapidly and cools down the inner area of the container, eventually to the LOX temperature of  $-183\text{ }^{\circ}\text{C}$  ( $-297.4\text{ }^{\circ}\text{F}$ ) if at atmospheric pressure. The oxygen gas developed by the cool down process is forced through the top of the container into the Build-Up-Vent Valve (E), which is set on the "VENT" position during the filling operation. This valve setting permits the escaping gas to flow overboard through the vent line. This procedure continues until LOX flows overboard in a steady stream from the vent line, which is a visual indication that the container is full of LOX.

During the filling operation as shown in Figure 1, some LOX could flow into the pressure Build-Up Coils (C) and through the Check Valve (G) into the Supply Evaporator Coils (B). The minor quantity of LOX so trapped will remain in these lines until a demand for gaseous oxygen is created in the supply line. If the trapped gas (vaporized LOX) does build up a pressure exceeding the relief valve settings, in the respective systems, the relief valves will open and vent the gas overboard.

### 3.2.1.2 (Continued):

To develop pressure within the container and permit the Converter Assembly to supply breathing oxygen to the aircraft system as shown in Figure 2, the Build-Up-Vent Valve (E) is manually set in the "Build-up" position. This action blocks the line from the top of the container to the overboard vent and connects the LOX supply to the gaseous side of the container. The LOX flows by gravity into the Pressure Build-Up Coils (C) and vaporizes because of exposure to ambient temperature surrounding the coils. The gas flows through the Pressure Closing Valve (D) and the Build-Up-Vent Valve (E) into the top of the container where it collects and assists in a higher-pressure development. This cycle continues until the working pressure of the system is reached the Pressure Closing Valve (D) closes and prevents additional flow of LOX from the container. Pressure in the gaseous area of the container is regulated by the Container Pressure Relief Valve (H) that will reduce excessive pressure levels by venting the gas overboard.

When oxygen is required in the aircraft system, LOX flows into the supply system, through the Check Valve (G) into the Supply Evaporation Coils (B), where it is vaporized. The gas then flows into the aircraft system until the demand is shut off. Pressure source for the flow is the pressure on the gaseous side of the container. If this pressure value drops below the required system pressure, the Pressure Closing Valve (D) opens and admits more vaporized LOX into the gaseous side of the container, raising the pressure level and continuing the cycle operation.

Purpose of the Check Valve (G) is to prevent gaseous oxygen in the supply system from backing up into the LOX within the container. This will increase the vaporization rate of the LOX by exposure to the gas. This condition can develop during a period of large oxygen demand on the aircraft system with a high flow rate. Then a sudden cutoff in oxygen delivery to the aircraft system would be met. Modern smaller size (i.e., 5, 10, and 12 L) converters may have flow modulating check valves which permit LOX to backup into the converter at a slow rate. This extends the amount of supply available. A relief valve (I) is installed in the system to prevent excessive build-up of system pressure.

- 3.2.1.3 Stabilization: After replenishment, it is a desirable practice to use a special vent tool or cap that allows the LOX to sit in the LOX converter at ambient pressure for a short while. This allows the LOX that has flashed or boiled on filling to vent to the atmosphere without exercising the relief valve(s) unnecessarily. Experience has shown that the LOX converter valves chatter and freeze up easily if the vent tool or cap is not used. The extra activity of LOX and cold oxygen on the LOX converter valves immediately after filling can cause the valves to fail or a LOX converter explosion is possible if the pressure relief valves freeze up and become inoperative. Continuous overboard venting of LOX could also result from a malfunctioning valve. After a short time the vent tool or cap is removed to allow the converter to reach operating pressure. Time periods of 10 min to 1 h are used throughout the world. An alternate method is to leave the fill hose connected to the fill-build-up and vent valve, shutoff the supply, open the fill hose to atmosphere and allow the LOX in the fill hose and ship system to vent for the specified time before disconnecting. This procedure is used in some organizations in lieu of the vent cap.

- 3.2.1.4 **Destratification:** Destratification refers to getting all the oxygen in a LOX converter to the same temperature to prevent a possible loss of operating pressure. Density of LOX varies with its temperature. After a LOX converter has stabilized, the LOX is at approximately 90 °K (-297.67 °F), which is the boiling point at 0 kPa (0 psig). If after disconnecting the vent tool or cap the operating pressure of the converter is 49.31 kPa (340 psig), then the boiling point of oxygen increases to approximately 135 °K (-216.67 °F). At the surface of the LOX the temperature of the LOX increases to 136 °K (-214.87 °F) while just below the surface the LOX is still at 90 °K (-297.67 °F). This is known as stratification. If the LOX converter is shaken then the colder LOX comes in contact with the gaseous oxygen and cools it back to a liquid. This drops the pressure in the converter substantially even possibly to 0 kPa (0 psig) robbing the converter of the pressure head it uses to push the LOX out of the converter and into the system. Destratification is normally carried out by allowing the ambient heat to migrate into the converter and warm the LOX to a uniform temperature. It has been found to be a good practice to replenish small converters off the aircraft and allow them to destratify before putting them back on the aircraft. On aircraft with fixed LOX converter installations, it is best to service them 8 to 12 h before flight. Allowing plenty of time for LOX destratification. There has been much debate on the time period needed for LOX destratification and time intervals of 5 to 12 h are used throughout the world. Since smaller LOX converters need to adsorb less heat to destratification, the time interval used for the smaller converters is less than the larger LOX converters. The time required to destratify a converter can be shortened by adding heat to the LOX inside the converter after it is pressurized. This can be accomplished by adding a heater inside of the converter or by bubbling gaseous oxygen up through the LOX inside of the converter.
- 3.2.1.5 **Filler Valve Assembly:** Two additional assemblies must be provided with the converter assembly as part of the over-all system; that is, the filler valve assembly and the build-up and vent valve assembly. In portable converter designs, these assemblies may be part of the converter assembly. Most designs that are available now combine the functions of the two assemblies into one unit.
- 3.2.1.6 **Converter Vacuum:** The principle part of the converter is a vacuum insulated container. It consists of an inner and an outer shell with an evacuated air space between the two walls. Connections for filling and removing the LOX, and for venting the gaseous oxygen are provided between the two concentric containers. Heat transfer from outside the converter to the inner shell can be reduced by the following design features:
- Evacuated space between the shells.
  - Most aircraft containers within the converter have a molecular "getter" in the near vacuum evacuated space to provide adsorption of air molecules at cryogenic temperatures. This improves the insulation for the required efficiency to be practical for use with smaller containers on aircraft. Most ground support and transfer storage containers use insulating powder between the walls for additional insulation. Both types of storage containers use silvered and/or highly polished surface treatment of the walls forming the evacuated space.
  - Use of low thermally conductive materials in the assembly and a minimum number of support and/or assembly points between the two shells.

- 3.2.1.7 Pressure Relief: Despite the low heat transfer through the walls and assembly points of the converter assembly, there will always be some heat transfer and some evaporation of LOX. Pressure relief valves must be provided to allow the escape of gas and to prevent dangerously excessive pressure build-up when the oxygen in the oxygen converter is not being expended to the supply line. For reasons of safety to prevent a LOX converter explosion, two pressure relief devices are usually included. The customary design practice on smaller LOX converters is that one is LOX converter mounted and the secondary pressure relief is aircraft mounted. On larger LOX converters, both pressure relief valves are on the LOX converter. One pressure relief valve called secondary relief is set at a slightly higher pressure setting than the primary relief valve. This enables the system to vent a greater amount of oxygen gas if needed to prevent over pressurization of the LOX converter while at the same time minimizing LOX overboard venting for the much longer time periods when slow oxygen gas venting is needed.
- 3.2.1.8 Purge Valve: On larger containers it may be necessary to purge the container for maintenance. It would be impractical to let the liquid oxygen evaporate by the normal means of loss of supply through the pressure relief from the gradual warming of the LOX supply. This would take many days. Therefore a purge valve is fitted to the lower part of the container to evacuate the remaining liquid before maintenance
- 3.2.1.9 Oxygen Losses: In present day equipment, losses of LOX from a converter assembly range from 5 to 20% in 24 h depending on size and insulation efficiency of the container. Smaller LOX converters have a greater loss than larger converters as they have less volume of LOX per surface area of the container. Five (5) liter LOX converters lose up to 20% and 75-L LOX converters lose up to 5% in 24 h with existing LOX converters. There will be a maximum 15% filling loss on servicing the LOX converter depending on the skill of the person doing the servicing operation and the method and time period of stabilization of the LOX converter. The evaporation losses given above are percentages of LOX container size irrespective of the loss encountered during LOX servicing and stabilization.
- 3.2.1.10 Converter Types: Most existing airborne converters' designs that are smaller deliver gaseous oxygen at a pressure of 0.48 MPa (70 psig). These converters hold about 5, 8, 10, or 12 L of LOX. The 8-L converters have the same outline dimensions as the 5-L converters. The 12-L converters have the same outline dimensions as the 10-L converters. A number of larger converters that hold 25 or 75 L of LOX have been produced that deliver 2.07 MPa (300 psig) gas for use on aircraft with more persons. The higher operating pressure is needed to support many oxygen outlets normally provided on transport aircraft. The higher-pressure assemblies are also installed on transport aircraft to permit the crew to refill their portable oxygen bottles directly from the aircraft's oxygen system. Proper function of all downstream valves and regulators is provided with the 300 psig, as pressure losses in large systems are unavoidable. The higher-pressure airborne converter assemblies have also been studied for use in the commercial jet transport aircraft. Long supply tubing runs are required with associated line pressure drop. Also, high flow rates are required during emergency use of this system. A pressure of 300 psig is essential to allow higher delivery flow rates.

- 3.2.1.11 Servicing Converters: Converter assemblies may be filled at the aircraft or removed and filled at a remote location depending on converter design. Removable converters are designed with a wedge plate mounting that enables rapid removal and replacement. Removable converters are mainly used on smaller military aircraft and can be filled with LOX at the aircraft or at the flight line location. The almost universally accepted practice now is to remove the converters the night before and fill them all at once. This is done at the flight line where they are stabilized for several hours. They are reinstalled before the next aircraft flight. This keeps all servicing LOX risks and hazards minimized. Fixed installation converters must be filled at the aircraft where the fill build-up and vent valves are mounted to the aircraft exterior versus on the converter for removable converters. Hazards are minimized through training and procedures.
- 3.2.1.12 Converter Displays: Liquid quantity indicating equipment used with converters is available in three types using different design features: Capacitance gauging, electro-mechanical transducer indication, and differential pressure type. Many modern LOX converters use capacitance gauging with a probe mounted vertically in the LOX within the converter. The height or level of the LOX sets the value of the capacitance enabling an electronic signal to be transmitted to the cockpit gauge or display. Differential pressure gauging was used in the past and is still used. It measures the difference of pressure between the top and bottom on the LOX container that is a function of the liquid volume. Pressure gauging is often used on the gas side of the aircraft LOX system.
- 3.2.2 LOX Ground Servicing Equipment: Special storage tank and transfer cart assemblies provide ground-servicing equipment for aircraft LOX systems. LOX can be stored indefinitely at sea level as long as it is kept at a temperature below its boiling point. Maintaining a temperature below  $-182.8\text{ }^{\circ}\text{C}$  ( $-297\text{ }^{\circ}\text{F}$ ) by mechanical refrigeration is expensive and impractical. Therefore, LOX is usually stored and handled in vacuum-insulated containers. The pressure buildup within a LOX storage container is obtained by vaporization of the LOX. Control valves can regulate this. This energy can be used to provide the optimum pressure 0.21 to 0.27 MPa (30 to 40 psig) for transfer of LOX from the ground equipment to an aircraft converter installation or to another storage tank. For larger converters it may be necessary to service with a higher pressure. When servicing to a container of lower pressure and higher temperature through the plumbing, the phenomena of "flashover" is observed where the LOX is bubbling and boiling and is greatly agitated. Safe existing practices are to install a vent tool or cap on the container after servicing to keep pressures nearly atmospheric until stabilization occurs to preclude freeze up of the converter valves. To provide destratification the converter must be then stabilized at the converter head pressure usually 5 to 12 h after servicing. The vent tool or cap can then be removed and allow stable pressure build up to occur within the storage vessel.

- 3.2.2.1 Ground Equipment Characteristics: A typical LOX ground-servicing assembly consists of a double-wall container with the space between the walls filled with an insulating material such as silica-aerogel and evacuated to a very low pressure. An adsorbent "molecular getter" such as activated charcoal or activated alumina may also be placed within the evacuated space to supplement the mechanical evacuation process. This is not a common design practice on ground storage containers and transfer carts. Component equipment in the assembly such as pressure buildup coils; vent, check and relief valves; and capacitance gauges serve the same function as similar units in the airborne converter assembly. Multiple safety devices are incorporated in this equipment to ensure safe and proper operation.
- 3.2.2.2 Transfer Carts: A storage and transfer cart assembly as shown in Figure 3 is a unit commonly used for servicing aircraft LOX converters when installed or not installed in the aircraft. These carts are mobile assemblies mounted on steerable three wheel trailers and have a capacity of 189 L (50 gal). The cart is a complete self-contained LOX transport, storage and servicing unit with a typical total empty weight of approximately 327 kg (720 lb). Other types of transfer carts have been developed for the U.S. Navy and NATO.

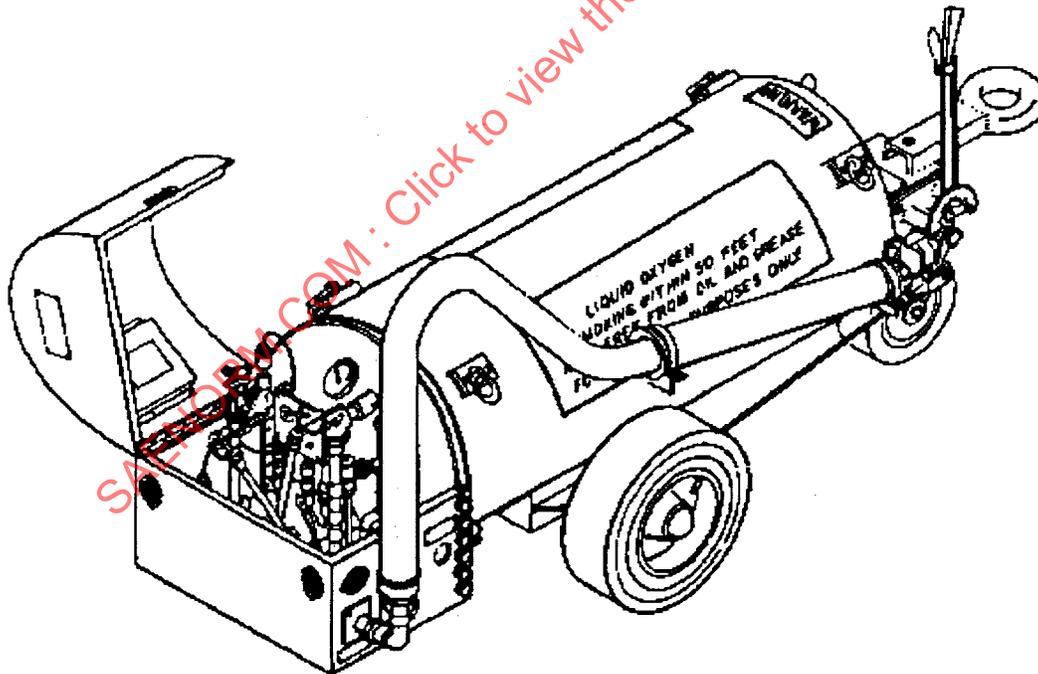
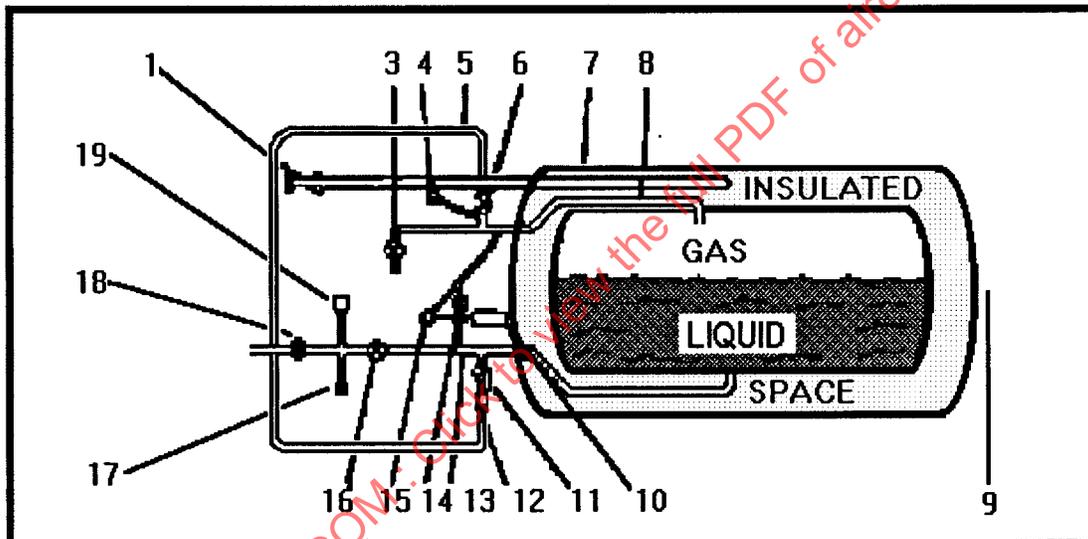


FIGURE 3 - Storage and Transfer Tank, One Type

3.2.2.3 Storage Tanks: LOX storage tanks having capacities of 1892, 7570, and 18,920 L (500, 2000, and 5000 gal) are generally used at military aircraft bases for bulk storage. The 500 gal tank can be skid mounted and semi-permanently installed or trailer mounted on four wheels steerable trailer, to receive, hold, transport and dispense LOX. The 7570 and 18,920 L (2000 and 5000 gal) tanks are permanently installed. Currently there are different configurations of these tanks, each configuration requiring a different type designation. A functional arrangement is shown in Figure 4. One type of LOX storage installation of a moderate size is shown in Figure 5. Other types of storage tanks have been developed for the U.S. Navy and NATO. NATO cart and storage tank sizes are 150, 800, 3200, and 4200 L size.



- |                               |                         |                                |
|-------------------------------|-------------------------|--------------------------------|
| 1. Vacuum Valve               | 7. Vacuum Line          | 14. Capacity Gage Valve        |
| 2. Deleted                    | 8. Vent Line            | 15. Capacity Gage              |
| 3. Vent Valve                 | 9. Rupture Disc         | 16. Fill and Drain Valve       |
| 4. Pressure Gage              | 10. Dampener Tank       | 17. Hose Pressure Relief Valve |
| 5. Pressure Build-up Coil     | 11. Pressure Build-up   | 18. Filter                     |
| 6. Tank Pressure Relief Valve | 12. Safety Disc         | 19. Safety Disc                |
|                               | 13. Fill and Drain Line |                                |

FIGURE 4 - Liquid Oxygen or Nitrogen Storage or Transfer Tank Showing Components, One Type



FIGURE 5 - LOX Ground Storage Containers, One Type

### 3.3 Precautionary Measures:

The general precautions to be observed in the handling, storage and use of compressed gaseous oxygen shall also be observed with LOX and are covered in National Fire Protection Association Standard No. 410 B. Listed below are precautions peculiar to LOX that should be followed:

- 3.3.1 Possible Injury from Cold: Due to the extremely low temperature of LOX, all personnel working with the product should take proper safeguards. Severe frostbite which produces lesions identical to a burn will result if LOX comes in contact with the skin too long during any handling operation. Burns will also result if a non-insulating container, tubing, valves and other equipment containing LOX is handled without the minimum protection.
- 3.3.2 Clothing and Protective Equipment: Personnel handling LOX should be protected by loose-fitting, clean coveralls of tightly woven material with cuffless trousers, a cotton helmet, gauntlet-type gloves of leather or rubber with loose-fitting cotton inner liners, high-top shoes under the trouser legs and a face shield. Having the trouser legs over the shoes will prevent entrapment of LOX inside the shoes. There should be no clothing such as an exposed pocket that would entrap LOX to cause burning of the skin. The clothing worn should not produce static electricity potentially causing a fire and explosion hazard.
- 3.3.3 Clothing Safety Measures: If LOX is spilled on the clothing, the garments should be shed quickly. Any LOX trapped in a pocket, glove, or boot can cause serious frostbite injury. Also, a fire hazard may be created by the combination of concentrated oxygen and a combustible material. Allow any clothing that may become saturated with LOX to dry overnight in a safe region so that if a fire ensues, it will not spread.
- 3.3.4 Treatment for LOX Contact: If LOX is spilled on exposed skin, wash it off immediately with cold water, apply cold compresses on the affected area and get immediate medical attention.
- 3.3.5 Precautions on Transferring LOX: When transferring LOX from one container to another, the receiving container should be filled very slowly until it has been cooled to a temperature comparable to that of the LOX. Rapid filling might, besides causing boiling or splashing, result in damage due to thermal shock. The vent valve should be left open with a special vent tool to allow LOX thermal stabilization at ambient pressure before pressurizing the container. A metal catch pan should be used to collect the over board venting of LOX as it is a normal part of the servicing operation that some LOX spill overboard when topping off the LOX converter.
- 3.3.6 Material in Contact with LOX: Caution must be exercised in introducing any material or object at normal room temperature into LOX. This action will cause violent ebullience and evolution of gaseous oxygen with considerable boiling and splashing.

- 3.3.7 Ground Surfaces in Transferring LOX: In filling LOX systems, the liquid should not be allowed to spill on the ground, especially on a ramp surface contaminated by oil or grease. If spillage does occur, the area should be isolated until all the LOX (especially that trapped in cracks or crevices) has evaporated. Service the converter at the aircraft only on an approved surface such as concrete, which has special LOX compatible expansion joints. Never service the converter on an asphalt surface. This procedure should apply even if a metal catch pan is used to collect the over board venting of LOX. There have been occurrences in the past where an aircraft or vehicle drove over asphalt or concrete joint divider, which was saturated with LOX. Explosions have sometimes resulted from the combination of pressure caused by the weight of the vehicle and a hydrocarbon with LOX.
- 3.3.8 Electrical Grounding Requirements: LOX equipment and aircraft being serviced must be electrically grounded during the servicing operation to prevent an accumulation of static electricity and discharge. LOX is a very good conductor of electrical energy. Non grounded servicing procedures have been known to result in fireballs and flash fires.
- 3.3.9 Lubricants in LOX: It is emphasized that no lubricant should be used on LOX system male pipe fittings. Lubricants pose a combustion hazard in contact with LOX. Any sealant used should be with the greatest precautions. Teflon tape thread sealant is recommended on male pipe fittings. Additional information concerning the use of lubricants in LOX systems is contained in STANAG 3976.
- 3.3.10 Storage Requirements of LOX: LOX must be stored in the containers designed for the purpose that will maintain the vapor above the liquid at atmospheric pressure of at a low positive pressure level. The temperature of the liquid will thus remain at or near its boiling point of  $-183\text{ }^{\circ}\text{C}$  ( $-297.4\text{ }^{\circ}\text{F}$ ). Evaporation of LOX in a closed, unvented container could develop a potentially dangerous pressure condition of 82.0 MPa (860 atmospheres or over 12,000 psi). Refer to military documents for additional details on designing LOX ground storage containers.
- 3.3.11 Location of Storage Containers: Bulk LOX storage containers should be located in a well-ventilated area to prevent high concentration of gaseous oxygen in the atmosphere. Outdoor storage remote from any other installations that have combustible substances or people is strongly recommended. Indoor storage area where required, should be force-ventilated. Indoor storage is not recommended. On the other hand, transfer of LOX in the rain should be avoided. Rainwater can freeze on the cold surfaces preventing proper connections or not allowing disconnection's. Water can get into the LOX possibly causing malfunctions of the LOX transfer valves.
- 3.3.12 Vacuum Failure: If the inner container leaks, liquid and/or gaseous oxygen may get into the vacuum space. Leakage of LOX into the space between the inner and outer containers of storage vessels or converters can result in a pressure build-up. To prevent an explosion, a safety "rupture" disc or pressure relief device should be added that relieves pressure from the vacuum space.