BRITISH STANDARD AEROSPACE SERIES

Aircraft oxygen systems and equipment –

Part 5: Guide to fire and explosion hazards associated with oxygen, including handling, storage and replenishment

ICS 49.090

British Standards

Publishing and copyright information

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ISBN 0 580 49312 1

The following BSI references relate to the work on this standard:
Committee reference ACE/38
Draft for comment 06/30140682 DC

Publication history

First published as BS N 100:1967

Second edition BS 2N 100:1973

Third edition BS 3N 100:1985

Revised as BS 4N 100-5:1999

This publication BS 5N 100-5:2006

Amendments issued since publication

Amd. no.	Date	Text affected

Contents

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 17 and a back cover.

Foreword

Publishing information

This part of BS 5N 100 was published by BSI and came into effect on 31 October 2006. It was prepared by Technical Committee ACE/38, *Aircraft oxygen equipment*. A list of organizations represented on this committee can be obtained on request to its secretary.

Supersession

This part of BS N 100 supersedes BS 4N 100-5:1999, which is withdrawn.

Information about this document

This new edition of BS 5N 100 incorporates technical changes only. It does not represent a full review or revision of the standard, which will be undertaken in due course.

BS N 100 consists of the following parts:

- *Part 1: Design and installation*
- *Part 2: Tests for the compatibility of materials in the presence of oxygen*
- *Part 3: Testing of equipment and systems*
- *Part 4: Guide to the physiological factors*
- *Part 5: Guide to fire and explosion hazards associated with oxygen, including handling, storage and replenishment*
- *Part 6: Guidance and recommendations on the selection of materials for use with oxygen*
- *Part 7: Guide to cleaning, labelling and packaging*

NOTE The latest revision of an aerospace series standard is indicated by a prefix number.

Hazard warnings

WARNING. This British Standard calls for the use of substances and/or procedures that can be injurious to health if adequate precautions are not taken. It refers only to technical suitability and does not absolve the user from legal obligations relating to health and safety at any stage.

Use of this document

It has been assumed in the preparation of this British Standard that the execution of its provisions will be entrusted to appropriately qualified and experienced people, for whose use it has been produced.

Presentational conventions

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

1 Scope

This part of BS N 100 provides guidance on the dangers, and avoidance of, fire and explosion hazards associated with oxygen.

Annex A provides additional guidance and recommendations on liquid and gaseous oxygen handling, storage and aircraft replenishment.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS N 100-1, *Aircraft oxygen systems and equipment – Part 1: Design and installation*

BS N 100-2, *Aircraft oxygen systems and equipment – Part 2: Tests for the compatibility of materials in the presence of oxygen*

BS N 100-6, *Aircraft oxygen systems and equipment – Part 6: Guidance and recommendations on the selection of materials for use with oxygen*

BS N 100-7, *Aircraft oxygen systems and equipment – Part 7: Guide to cleaning, labelling and packaging*

3 General

3.1 With few exceptions, metallic and non-metallic materials continue to burn in oxygen-rich atmospheres when once ignited. The resulting release of energy can cause very high local pressures and temperature and weakening of the surrounding materials, with resultant explosive failure of the pressure-containing envelope.

3.2 Ignition conditions can result from the internal or external application of sufficient heat energy and spontaneous combustion can be caused by the adiabatic compression of oxygen in the vicinity of certain non-metallic materials. Friction rubbing, certain gas flow phenomena (e.g. gas and material resonance), impact of particles (e.g. contamination) and electrostatic discharge are also possible causes of oxygen fires.

3.3 In any oxygen system, materials should be selected to withstand the maximum temperature and pressure likely to be experienced under the most adverse operating conditions. The tests described in BS N 100-2 should be used for the selection and quality control of all non-metallic materials. However, consideration should be given to the possible interaction between two relatively “safe” materials, for example the reaction between aluminium and fluorinated greases.

3.4 Despite the most careful attention given to the selection of the materials, and of the construction of components, there remains a potential risk that combustion will occur. The possibility of sustained combustion can be greatly reduced by selecting materials in accordance with BS N 100-6 and employing designs in accordance with BS N 100-1.

3.5 The effects of combustion can be minimized by ensuring that it is contained, and heat generated is rapidly dissipated, before the adjacent metals reach ignition temperature.

3.6 From data reported to HSE under the *Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1995* [1] (RIDDOR) over a five year period (1990 to 1994), 95 incidents involved gaseous oxygen (see **5.4**).

4 Factors affecting an incident

NOTE See ASTM Standard Guide for Studying Fire Incidents in Oxygen Systems [2] *for further information.*

4.1 Local area enrichment

Oxygen is not a flammable gas but supports combustion. Most materials, including those normally regarded as fire resistant, burn vigorously in an oxygen enriched atmosphere. They are also more easily ignited. These effects are evident even if the enrichment is only a few per cent. Oxygen enrichment of the atmosphere is generally the result of leakage from damaged pipes, hoses, valves, connections, etc.

4.2 Contamination

4.2.1 Low level contamination

When contamination is present in an oxygen system, the contaminant might serve to start the incident. Then, the ensuing fire involving the polymers, metals, non-metals and contaminant can consume the contaminant fully, leaving no indication of its original presence.

4.2.2 High level contamination

When the contamination level is high, it can produce so large and explosive an event that the system integrity can be breached, and the fire extinguished without complete combustion of the contaminant, thus leaving evidence of its presence.

In these instances, the flammability of the contaminant can be so much greater than that of the metals and non-metals that there might be only scant damage to the system materials.

4.2.3 "Carbon" or black dust

In many incidents, a black powder is present on many surfaces. The powder could be unreacted carbon from incomplete combustion of organic materials either inside or outside the components. However, some powders that look like carbon are not. For example, fires involving aluminium in gaseous or liquid oxygen produce a black (and in some cases grey) powder that is largely unreacted aluminium. Indeed, such dust might be present as a result of a fire involving aluminium or because of fabrication processes. In metal inert gas (MIG) welding, aluminium is vaporized and condenses as a black dust in the region of the bead.

If this powder is present in an oxygen system, it could be the cause of ignition, because it is very flammable and has even been observed burning in air.

4.2.4 Oil

Oil in oxygen systems can be a severe hazard. Many oils, hydrocarbons in particular, are relatively volatile in comparison to metals and polymers, especially in aerosol form. Their spontaneous ignition temperatures are much lower than those of most other materials (metals and non-metals) used to fabricate oxygen systems, including many materials not generally regarded as oxygen compatible. Therefore, heat of compression can ignite oils much more easily. Furthermore, many oils burn very rapidly, even explosively, and they are often the likely cause of an oxygen incident. Obvious presence of oil near an oxygen incident is a strong indicator of probable contamination.

4.3 Particle impact

Impact and subsequent ignition of particles in oxygen systems have been demonstrated to have been the cause of several fires. This ignition mechanism is especially likely at, and just downstream of, locations where the velocity of the oxygen is sonic (any location across which there is a 2:1 absolute pressure drop), and has been demonstrated at velocities as low as 150 ft/s (50 m/s).

4.4 Debris sumps

Many systems contain regions where debris tends to collect. Particle debris can accumulate at low points or stagnant side branches. If the piping for a by-pass valve is connected to the bottom region of a horizontal run of pipe, debris that passes through the system could drop into the stagnant upstream legs of the by-pass run. If this valve is then opened, accumulated debris is injected into the high-velocity valve and could possibly cause a fire either in the by-pass run or further downstream.

4.5 Heat of compression

When a gas is compressed rapidly, its temperature rises. The pressurization of a system tends to produce the greatest temperatures within the gas initially in the system. The increase in temperature can cause spontaneous ignition of some system components. This compression is nearly adiabatic and typically occurs at system end points or trapped volumes. In extreme cases, heat of compression has produced some of the most explosive (rupturing and fragmenting components) and most probable mechanisms of oxygen fires. In severe cases, a heat of compression fire might occur on the very first pressurization of a system. Every incident should be examined for a mechanism that could have enabled rapid gas compression and for where the compressed gas might have been located relative to the fire damage.

4.6 Over-pressure

4.6.1 Loss of containment

A fire in an oxygen system can produce over-pressurization leading to possible loss of containment of the oxygen. Among the characteristics that can be seen are bulging (see **4.6.2**), bursting (see **4.6.3**), venting, explosion, and fragmentation (see **4.6.4**).

4.6.2 Bulging

Bulging or swelling of components can occur at the site of explosions, at weak regions of the system, or both. In brazed copper systems, it is common to see over-pressure effects at annealed regions, such as just outside brazed joints, where hardened tubing is annealed and therefore be of lower strength. The presence of such bulging in brazed copper joints in a local region only suggests a localized explosive event. Bulging at copper joints throughout the system can also indicate a systematic pressure increase.

4.6.3 Bursting

Vessels that burst into several large pieces typically have failed along weak regions or flaws and have been exposed to either a small explosive event or to a general systematic pressure rise that has been relatively slow.

In some metal alloys, such as aluminium, piping is extruded with dies and mandrels in a way that can produce weak longitudinal seams. Over-pressurization, either slow or fast, can cause tears along these seams, yielding several similar pieces. This can occur at pressures much lower than those normally expected to cause fragmentation.

4.6.4 Fragmentation

When a vessel is fragmented into many small pieces of dissimilar shapes and sizes, it usually suggests a very fast combustion that produced pressures well above the burst pressure of the vessel, before the vessel actually fails. This type of failure is also commonly known as a “brittle” failure.

Fragmentation can be associated with detonations where the propagation velocities are greater than the speed of sound and this makes the presence of relief valves and vents ineffective.

4.7 Time delays

Transient events, e.g. the operation of a valve, can lead to the unexpected consequence of an oxygen fire. Most of the time the fire occurs almost simultaneously with the event, but there can be appreciable delays between its cause and effect.

4.8 Crevices and cavities

A crevice can be a potential ignition site in liquid oxygen (LOX) systems if it fills with liquid, especially through a narrow passage or pore. When the vessel is drained and warmed, high pressure and high velocity develops in the liquid, if the passage is small, as it tries to escape. If the crevice is in a weld of a metal that produced MIG weld dust, it could contain fine, easily ignited particles that might become entrained in the flow and impact a piping inter-section or valve seat, causing ignition (see also **6.2**).

4.9 Surface discoloration

During a fire, brass alloys might be exposed to brief, intense temperature or to corrosive chemicals, resulting in a surface depletion of the volatile zinc constituent known as "pink brass". The result can be a pink hue on the brass surface that is not contamination and that is also not likely to be associated with the cause of the incident.

4.10 Flash fire

4.10.1 There are often two distinct phases in an oxygen incident: an initial flash fire of the most flammable portion of the system followed by slower, more enduring general combustion.

4.10.2 The prospect of an initial flash fire involving surface contaminants is one reason that low levels of oil in an oxygen system might not be discovered after an incident, despite the possibility of having played a crucial role either in ignition or in the related kindling chain.

4.11 Gas permeation

When a gas permeates or dissolves into a material at high pressure and the pressure is suddenly released, the material can behave like a pressure vessel. If the material is an elastomer, it can swell like a balloon, sometimes more than doubling its apparent size. The internal pressure can cause the elastomer to exceed its tensile strength, and it can burst. Consequent leakage of oxygen can lead to potential ignition.

4.12 High surface area to volume ratio

Components with a high surface-area to volume (SAV) ratio suffer from a greater propensity for combustion. High SAV systems include sintered filter media, porous/foam media, thin sections, etc.

4.13 Fresh metal exposure (FME)

4.13.1 Fresh metal exposure is an often-considered ignition source. In theory, the surface of a system is damaged by two parts rubbing together, by spalling of an oxide, by development of a small crack, etc., to expose fresh metal which reacts with the oxygen to form oxides. This oxide formation initiates an exothermic chain reaction, eventually leading to ignition.

4.13.2 FME is believed to be a factor in multi-gas compressor fires, or in fires involving compressors that have been initially run-in with inert gases prior to conversion for oxygen use. Standard practice in cases where compressors are being changed over to oxygen service after inert gas use is often to operate the compressor with gases that contain progressively greater levels of oxygen to passivate any particles and rubbing surfaces and hence reduce their flammability.

5 Illustrative case histories

5.1 A fire and explosion occurred at an oxygen filling plant when a valve to a cylinder pack was opened after being connected to a filling hose. As a result of the accident an operator received serious chest, arm and leg burns.

The cylinder pack, a mobile supply used for filling aircraft life support systems, was due to be filled with oxygen to 24.8 MPa (3 600 lbf/in^2). The procedure to fill the cylinder pack involved a prior inspection to check for valve contamination, residual pressure, damage and odour. Occasionally cylinder packs are returned to the filling station with residual pressure up to that attained at the original filling. If a cylinder pack contains a cylinder with residual pressure, the procedure states that the operator should "top up" this to the fill pressure.

The incident occurred when the filling hose was connected to the cylinder pack and the valve to the first cylinder had just been opened. It appears that cylinder No. 1 contained residual oxygen at pressure. Upon opening the valve the filling hose rapidly filled with oxygen. Then, as the filling hose was not pressurized, the flow of oxygen into this closed volume resulted in a rapid temperature rise caused by the adiabatic compression of the oxygen. It was suspected that this temperature rise exceeded the spontaneous ignition temperature of the hose lining material and ignition occurred.

5.2 The design of an oxygen pressure reducing valve assembly, for use with an ejection seat mounted system, incorporates a blanking cap over the valve adjusting head. This cap is secured by five screws and sealed by a silicon rubber "O" ring; its maximum operating pressure is 14.5 MPa (2 100 lbf/in^2) at 70 °C. The blanking cap and valve body are made from high strength aluminium alloy, anodized black for functional and protective purposes. During manufacture, as the reducing valve assembly is being adjusted, it is necessary to remove the cap and replace it again after adjustment before the assembly can be pressurized. An incident occurred during this stage of the process. At about 11.0 MPa (1 600 lbf/in^2) a sudden drop in the supply pressure accompanied the noise of escaping gas. The supply was turned off and the reducing valve assembly examined. Immediately obvious was a gap of approximately 1.5 mm (.059 inches) between the blanking cap and valve body. On removal of the cap, the seal was found to have burned away to nothing, leaving a scorch mark on the body. Each of the tapped holes in the body showed evidence that it had been plugged and re-tapped during manufacture, the plugs having been partially extracted during the incident.

The conclusion of the incident investigators was that the seal combusted due to resonance caused as a gap between the blanking cap and valve body opened when the plugged tapped holes failed. The machinist was subsequently reprimanded for making unauthorized repairs.

In this incident a more serious fire involving the aluminium components was probably avoided for two reasons: firstly, the supply gas flow rate was significantly less than that through the failed cap, secondly, the valve assembly volume is very small. Both reasons indicate that the oxygen available to support combustion was exhausted before the aluminium could ignite. There were no injuries.

5.3 In this incident, the operator, with customary practice, "cracked open" the outlet valve of a portable oxygen cylinder assembly momentarily to produce an audible hiss of gas to check its contents and function. As the operator replaced the assembly in its storage, it burst into flames causing severe facial injury. Examination afterwards showed considerable damage to the operating head with loss by combustion to a sizeable part of the outlet valve housing, seat and seal. To aid the investigation, other portable oxygen cylinder assemblies of a similar age were withdrawn from use, stripped and examined. The design, for use at 12.4 MPa (1 800 lbf/in^2), has an aluminium body integrally machined with the valve seat being finish-cut after anodizing. A PTFE seal is rigidly attached to the end of a rotating spindle made from austenitic stainless steel. All of the assemblies examined showed particulate contamination of the PTFE, presence of an unknown grease and sharp edges to the cut seat. Further detailed examination revealed the particulate as being aluminium and the grease as being a silicone type normally applied to the spindle thread.

The failure mode was concluded as being adiabatic heating of the gas as the valve was closed, in the presence of non-compatible lubricant and possible fresh metal exposure (FME). The consequent fire was exacerbated because the kindling chain included metal particles (high SAV ratio) and the entire contents of the oxygen cylinder were discharged.

Three design change recommendations resulted: the body/seat to be manufactured from a more compatible material (brass), the PTFE seal to be attached by a floating joint to the spindle (in order that the shearing action be eliminated) and the removal of the non-compatible grease or its replacement with a more suitable lubricant. Operator re-training was also recommended to eradicate the (bad) practice of cracking the valve.

5.4 Further examples of oxygen incidents

The majority of oxygen incidents tend to involve the following:

- cylinder filling;
- substitution of compressed air or nitrogen with oxygen;
- oxy/fuel equipment, e.g. welding, cutting, etc.

Examples of typical incidents reported to the HSE under RIDDOR in the period 1990 to 1994 are given as follows.

a) An incident occurred at a ball valve located between a compressor and a cylinder filling pack. The ball valve had been closed prior to maintenance work on the compressor. When the compressor was started up again supplying oxygen at 24 MPa [1], the valve did not open fully. The combination of high pressure oxygen and a restricted orifice resulted in a fire and explosion at the valve.

b) An operator was filling oxygen cylinders connected to a manifold. On closing one cylinder there was an ignition and the operator received burns to the abdomen. The ignition was thought to be due to contamination on the valve spindle. The injured person was not wearing protective clothing.

c) An oxygen cylinder was being refilled when there was an ignition at the valve of the cylinder. The considerable burning of the valve suggested oil or other contamination.

d) An explosion occurred whilst oxygen was being charged into the emergency breathing system of a light aircraft. The cause was attributed to contamination with hydraulic oil.

e) A pressure test was being carried out on oil field drill equipment. The nitrogen had run out, so compressed oxygen gas was connected to the tool. The tool reservoir contained oil. An explosion resulted and an operator was killed.

f) At an open cast coal quarry, an operator was attempting to recharge the front suspension leg of a dump truck. An oxygen cylinder was attached to the assembly instead of a nitrogen cylinder, the braided hose and regulator valve exploded causing severe wounding to the operator's lower abdomen.

g) An experienced mechanic was injured when he used oxygen to pressure test an engine cylinder of a diesel truck. Compressed air should have been used. The injured person suffered injuries to chest and face and a perforated ear drum.

h) A flexible hose was used to connect two oxygen cylinders into a system at a power station. The flexible hose exploded burning a plant attendant. The cause was considered to be the use of nylon lined hose, adiabatic compression being the source of ignition.

i) A welder was replacing the oxygen cylinder of some oxy-acetylene welding equipment. The welder fitted the regulator and then opened the cylinder valve. Flame erupted from the regulator causing burns to the hands, face and chest. The cause was attributed to grease contamination of the regulator.

j) Many incidents have occurred where poorly maintained or damaged oxygen hoses for welding or other oxy/fuel equipment have burst or have leaked into gloves and onto clothing. Subsequent ignition of the oxygen has caused burns to personnel and/or damage to plant and equipment.

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[1] 24 MPa = 240 bar = 3 5001bf/in^2.

6 Common incident causes

NOTE See ASTM Standard Guide for Studying Fire Incidents in Oxygen Systems [2] *for further information.*

6.1 Incident statistics

Incident statistics indicate that a number of common prime causes can be identified. These include operator performance as well as instrument, process and plant deviations.

6.2 Particle impact

Small amounts of particulate matter, including organic contaminants, can accumulate due to many causes, the general “wear and tear” of components and the dislodgement of oxide coatings from metals. The loose particulates can be picked up by a gas stream and can quickly reach sonic velocities. Upon striking a material they can release part or all of their kinetic energy, also the material impacted can release chemical or molecular energy by ignition or destruction of the particle itself. (See BS N 100-1 for design and BS N 100-7 for cleaning.)

6.3 Electrostatic discharge

An electrostatic charge can build up from the rubbing action between two materials, one which is insulated and so prevents the charge from leaking away. Examples of this are; high fluid flow especially where particulate matter is present, the static charge that can be accumulated on the human frame. Where this charge is discharged in an oxygen system, i.e. through an insulated valve spindle, there could be just enough energy to ignite combustible materials, e.g. a non-metallic valve seat.

6.4 Frictional rubbing

The rubbing together of two solid materials results in the generation of heat. This can arise from the rubbing of a centrifugal compressor rotor against its casing, or from the rubbing of a compressor piston gasket within a cylinder head. The frictional energy produced can be large enough to ignite a combustible material.

6.5 Gas resonance

Resonance cavities, under flowing gas conditions, produce acoustic oscillations, this resonance can produce rapid temperature rises. This occurs when gas flows through a tee “piece” where one of the ports forms a resonant cavity. It has been found that particulate matter within these cavities can accentuate the heating effects, and can be sufficient to initiate an ignition.

6.6 Material resonance

The heat generated by the action of a gas being forced through a small gap consisting of a piece of flexible material can cause a resonant vibration and consequent heating of the materials. This can occur through the leakage of a gas across an ill-fitting O-ring.

6.7 Dry boiling of liquid oxygen

6.7.1 Many chemicals (hydrocarbons, ozone, nitrous oxide, etc.) are soluble or can exist as particles in liquid oxygen (LOX). Normally, very low levels of such materials do not pose a fire hazard. However, if a substantial portion of liquid is contained in an enclosed, "dead-ended" region of a system (including vaporizers) and allowed to evaporate, the oxygen distils preferentially, leading to a progressively increasing concentration of these chemicals until a flammable mixture occurs. Further evaporation ultimately leads to stoichiometric mixtures that ignite quite easily. Solutions of liquid oxygen and colloids of liquid oxygen with flammable materials are highly explosive and can fragment the vessels that contain them, even if the vessels vent to atmosphere.

6.7.2 Other than inadequate maintenance and purging procedures, direct causes of events involving dry boiling of LOX include the following:

a) the initial liquid contains a level of contamination that is too high;

b) the LOX mixes with other streams (gas, solid, or liquid) that contain flammable materials; and

c) contaminated LOX evaporates in volumes so large that an appreciable amount of it still remains when its trace flammable contaminants concentrate into the flammable region.

6.8 Condensation of air

Air exposed to very low temperatures condenses. When air condenses, the first drops appear at a concentration of about 50 mol-% oxygen, a level that already presents a significant fire hazard. If enough of this oxygen-enriched "liquid air" is formed, it can be further enriched during vaporization, increasing the hazard. Liquid air has a boiling point lower than that of liquid oxygen, so liquid air will not form on liquid oxygen lines. However, liquid air forms easily on low pressure liquid nitrogen lines and on lines of liquids with still lower boiling points (such as liquid hydrogen or liquid helium). Enriched liquid air can condense within the porous structure of insulation used on the piping itself and represent an explosion hazard. Liquid air draining on to asphalt pavement can be a significant explosion risk. Oxygen can be concentrated in liquid air by dry boiling (see **6.7**).

6.9 Gauge swapping

A common source of oxygen fire occurs when gauges that are not adequately cleaned are installed on oxygen systems. The worst of these situations appears to be when the gauge installed was previously used on a system used with an oil or hydraulic fluid. A similar risk is present when gauges are tested or re-calibrated and a flammable oil is used to perform the operation and then not removed prior to returning the gauge to service. Heat of compression is well established as the direct cause of these incidents. Often, the gauge explodes and fragments on the first pressurization or an early pressurization after installation. If the system is not exposed to rapid pressurization initially, the oil can migrate from the gauge and contaminate much of the system and thus put other parts of the system at risk from compression, particle impact, resonance, or other ignition mechanisms.

6.10 Oxygen substitution

A severe hazard can occur when oxygen is introduced into systems normally operated with other (non-oxidant) gases. In these instances, all four of these precaution levels are likely to be absent: cleanliness, compatible lubricants, compatible polymers, and compatible metals.

6.11 Improper repair and lubrication

6.11.1 Lubricants

Oxygen equipment might be repaired by persons unfamiliar with the oxygen hazard. When equipment is difficult to operate or when there are rubbing parts, there is a common tendency to use lubrication. Such lubricants should be oxygen compatible and only used where intended in the original design. Otherwise, notice should be taken of the “Use No Oils” labels.

6.11.2 Thread sealants

Repair of oxygen hardware often requires disassembly. Re-assembly might require the use of fresh (oxygen compatible) pipe-thread sealant materials.

Only PTFE tape that is oil free and is, therefore, oxygen compatible should be used (see BS 7786 for an acceptable standard).

Sealant pastes and added greases often are applied in large amounts, which typically result in extrusion of a bead of sealant/lubricant ahead of the fitting into the oxygen system (a very undesirable practice). This bead of paste could be at a dead end, where heat of compression is most able to produce ignition, or it might migrate to other vulnerable regions.

6.11.3 Compression and pipe fittings

There is a tendency to use sealants (including greases and PTFE tape) on such fittings, despite efforts to discourage such use. These fittings are intended to rely on a metal-to-metal seal or an installed O-ring. Lubricants can be applied provided they are oxygen compatible, compatible with the fitting material (see **3.3**) and that care is exercised to avoid excessive application which can lead to migration throughout a downstream system. Tape can also cause mechanical damage to the fitting.

6.12 Missing components

Following some oxygen incidents, components have appeared to be absent, leading to speculation that the component was not installed or that its mechanical failure and passage through the system were at fault. Sometimes, the damage is so negligible that there is no apparent evidence of there having been a fire. In an oxygen-enriched atmosphere, combustion can be remarkably clean and a simple polymer could be converted totally into carbon dioxide and water, leaving no trace of its prior presence. If the component is small or it has a low heat of combustion, there might be no evidence of heat damage. For example, PTFE seats (which are large but have low heat of combustion) in valves have burned completely in some incidents, with no melting of metal components, no appearance of residual carbon, and no remains of the polymer itself.

7 Summary

7.1 Incidents of fire and/or explosion in oxygen systems occur infrequently and are seldom described in the published literature. Most incidents appear to occur either very early or rather late in a systems' service life.

7.2 Following an incident in an oxygen atmosphere, the equipment, operating procedures and area should be considered in terms of previous incidents, potential contributing factors, suggested analytical strategies and demonstrated laboratory results. The goal is to determine direct cause(s) of the incident to prevent recurrence.

7.3 Analysis of the direct cause of an incident should include the mechanical or thermodynamic event (such as breakage of a component or near-adiabatic compression), the physico-chemical property (such as heat of combustion), the procedure (such as a valve opening rate), or any departure from the intended state of any of these items.

Annex A (normative) Liquid and gaseous oxygen handling, storage and aircraft replenishment

A.1 General

The storage of oxygen, whether liquid or gaseous, and the charging of aircraft oxygen systems on or off the aircraft requires special instructions in order that it can be carried out safely. These recommendations should be considered before preparing any special instructions (which could be specific to aircraft type or installation), prior to which a risk assessment should also be conducted. Such an assessment should include the risk and effect of a fire, either caused by or affected by oxygen released from the storage system or during the charging process.

A.2 Personnel

The handling of oxygen, whether liquid or gaseous, on or off an aircraft, should be carried out by personnel specifically trained for the task.

The correct personal protection equipment (PPE) should be used (see **A.4** for liquid oxygen charging and **A.5** for gaseous oxygen charging). Clothing that is worn during oxygen charging should conform to the best practice for working in an oxygen enriched atmosphere, for example clothing should be made from non-flammable materials (especially fleeces) that are lint-free and that do not shed loose fibres. Clothing should be aired for 30 min afterwards. Before the clothing is aired, the wearer should not smoke, even if outside the controlled area (see **A.3**).

During charging, if one person cannot see and/or operate the storage system and receiving equipment at one time or from the same position, then there should be two people allocated to carry out the charging operation. If two people are required, they should have direct communication between each other.

The need for the presence of a separate safety person should be considered during the risk assessment.

A.3 Controlled area

A.3.1 General

A controlled area of 15 m radius should be established around the oxygen equipment and/or charging process.

Signage, hazard tape and cones, etc., as necessary, should identify the controlled area.

Access for non-approved personnel should not be permitted.

Radios and mobile telephones should not be used within the controlled area.

Smoking should not be permitted within the controlled area.

No running engines or other heat sources should be within the controlled area.

The area should be freely ventilated. If charging is to be carried out in a confined space (e.g. inside an aircraft), the use of an oxygen monitor is recommended with the alarm setting at 23–25% depending on the height of the monitor above the floor.

The area should be clean and free from combustible materials.

A.3.2 Controlled areas for LOX systems

In addition to the recommendations of **A.3.1** the storage and charging of LOX systems should only take place in an area where there are no trenches, manholes or basements within 6 m radius.

NOTE For further information see BCGA Code of Practice 19 Bulk Liquid Oxygen Storage at Users' Premises [3].

A.3.3 Controlled areas for gaseous systems

In addition to the recommendations of **A.3.1** gaseous systems should be stored as follows.

- Cylinders should be protected from direct sun, rain and snow.
- Cylinders should be stored upright and be restrained from toppling.
- Cylinders should be prevented from standing on wet ground.

A.4 Charging with liquid oxygen (LOX)

Storage and charging of gaseous systems should only take place in a controlled area (see **A.3**).

In the event of an emergency, call the appropriate emergency services immediately.

A water supply and CO_2 or powder extinguisher should be available for fire control. Fires fed with LOX can be difficult to extinguish but the use of water assists in preventing the fire spreading; take care with regard to vaporization. The first priority is to protect any personnel from a fire.

The bulk storage facility should include a cold water shower, operated by depressing the shower platform. Personnel contaminated by LOX should shower the affected parts for at least 5 min, as soon as possible after the contamination occurs.

Charging of LOX systems should only take place when the following operational conditions are met.

a) All equipment should be oxygen compatible in accordance with the recommendations and requirements of BS N 100 parts 1 to 7.

b) There should be no evidence of equipment unserviceability.

c) All parts should be clean and free from oil or grease.

d) It is essential that the tanker/servicing dispenser is electrically grounded to the receiving equipment.

e) Filters (nominal rating < 40 micrometer, μm) should be fitted to the transfer line.

f) Appropriate personal protection equipment (PPE) is used.

PPE for LOX normally comprises a full-face visor, full depth non-absorbent apron, non-absorbent gauntlets and slip-on footwear that extend up the leg inside splash-resistant trousers. All PPE and associated clothing should be clean and free from oil and grease.

Oxygen valves are to be opened slowly to prevent rapid pressure rises downstream that could lead to adiabatic heating and ignition.

It is usual during LOX transfer for large amounts of oxygen vapour to be released through the receiving equipment vent. If there is little or no wind to dissipate the vapour quickly, the operator should consider whether the controlled area needs extending. In the event of a LOX spillage, the controlled area should be maintained until it is clear of all evidence of LOX, oxygen vapour and frost.

If, at any time during the charging process, there is evidence of leakage (other than through the receiving equipment vent during LOX transfer) and/or a relief valve operates, the transfer line is to be depressurized as quickly as possible in a safe way. This can normally be achieved by closing the transfer/charging valve on the storage system.

The charging operation should never be left unattended.

A.5 Gaseous oxygen charging

Storage and charging of gaseous systems should only take place in a controlled area (see **A.3**).

In the event of an emergency, call the appropriate emergency services immediately.

It is essential that a water supply and CO_2 or powder extinguisher is available for fire control. Fires fed with oxygen can be difficult to extinguish but the use of water assists in preventing the fire spreading. The first priority is to protect any personnel from a fire.

Cylinders containing compressed gaseous oxygen can rupture violently if overheated as a result of exposure to fire. Unless cylinders can be removed safely to an unaffected area, every effort should be made to keep them cool by spraying them with large quantities of water.

Charging of gaseous systems should only take place when the following operational conditions are met.

a) All equipment should be oxygen compatible in accordance with the recommendations and requirements of BS N 100 parts 1 to 7.

b) There should be no evidence of equipment unserviceability.

c) All parts should be clean and free from oil or grease.

d) It is essential that the cylinder trolley is electrically grounded to the receiving equipment.

e) Filters (nominal rating < 6 micrometer, µm) should be fitted to the transfer line.

f) Appropriate personal protection equipment (PPE) is used.

PPE for gaseous oxygen charging comprises thick gloves and eye protection. All PPE and other clothing should be clean and free from oil and grease.

Oxygen valves are to be opened slowly to prevent rapid pressure rises downstream that could lead to adiabatic heating and ignition.

The receiving equipment (cylinder) heats during the charging process due to the rapid compression of oxygen within. Excessive heating can be dangerous and should be avoided by controlling the rate of pressure rise.

The final charge pressure is also affected by the ambient conditions. To ensure that the correct quantity of oxygen is transferred into the receiving equipment (cylinder), due account should be made of the ambient temperature during and after the charging procedure.

If, at any time during the charging process, there is evidence of leakage and/or a relief valve operates, the transfer line is to be depressurized as quickly as possible in a safe way. This can normally be achieved by closing the transfer/charging valve on the storage system.

It is unusual during gaseous charging for oxygen to be released. If there is evidence of oxygen leakage (noise generated or evidence from leak detection fluid) and there is little or no wind to dissipate the gas quickly, the operator should consider whether the controlled area needs extending.

The charging operation should never be left unattended.

Bibliography

Standards publications

For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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