FIRE HAZARDS OF OXYGEN AND OXYGEN ENRICHED ATMOSPHERES

AIGA 005/10

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Table of Contents

1 Introduction

This document explains the fire hazards resulting from handling oxygen and the relevant protective measures that should be taken.

2 Scope and purpose

This document consists of three parts.

Part I is intended for line managers and supervisors. It provides the background to the subject and a description of the fire and explosion hazards associated with oxygen and oxygen enriched atmospheres.

Part II, is Appendix B, and is a summary of Part I suitable to be produced as a pamphlet to be handed to those involved in daily operations involving oxygen or used in training presentations.

Part III, is Appendix C, and lists some accidents which have taken place in recent years and which can be used as examples underlining the hazards of oxygen and oxygen enriched atmospheres.

It is recommended that the document be used as the basis for training programmes.

3 Definitions

3.1 Oxygen

Oxygen for the purpose of this document includes not only pure oxygen but all oxygen/air mixtures containing more than 21 % oxygen.

3.2 Pressure

In this document "bar" shall indicate gauge pressure unless otherwise noted – i.e. "bar" for absolute pressure and "bar, dif" for differential pressure.

4 General properties

Oxygen, which is essential to life, is not flammable in itself, but supports and accelerates combustion. The normal concentration in the air which we breathe is approximately 21 % by volume.

4.1 Oxygen supports and accelerates combustion

Most materials burn fiercely in oxygen; the reaction could even be explosive.
As the oxygen concentration in air increases the potential fire risk increases.

4.2 Oxygen gives no warning

Oxygen is colourless, odourless and has no taste hence the presence of an oxygen enriched atmosphere cannot be detected by normal human senses. Oxygen also does not give any physiological effects which could alert personnel to the presence of oxygen enrichment.

Increasing the oxygen concentration of the air at atmospheric pressure does not constitute a significant health hazard.

4.3 Oxygen is heavier than air

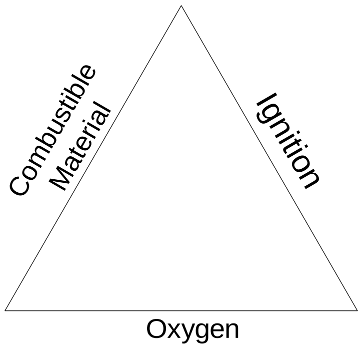
Being heavier than air, oxygen can accumulate in low lying areas such as pits, trenches or underground rooms. This is particularly relevant when liquid oxygen is spilt. In this case the generated cold gaseous oxygen is three times heavier than air.

5 Fire hazards with oxygen

5.1 Necessary conditions for a fire

In general for a fire or explosion to occur three elements are required: combustible material, oxygen and an ignition source.

The “fire triangle” is the normal way of representing these conditions:



When one of the 3 elements is missing a fire cannot occur.

5.2 Oxygen

Oxygen reacts with most materials. The higher the oxygen concentration and pressure in the atmosphere or in an oxygen system then:

a) the more vigorously the combustion reaction or fire takes place;
b) the lower the ignition temperature and the ignition energy to get the combustion reaction started;
c) the higher the flame temperature and destructive capability of the flame.

Causes of oxygen fires can be categorised as follows:

a) oxygen enrichment of the atmosphere;
b) improper use of oxygen
c) incorrect design of oxygen systems
d) incorrect operation and maintenance of oxygen systems
e) use of materials incompatible with oxygen service

5.2.1 Oxygen enrichment of the atmosphere

Oxygen enrichment of the atmosphere can be the result of:

a) Leaking pipe connections, flanges, etc. This can be particularly hazardous in areas where there is not sufficient ventilation thus causing the oxygen concentration to increase;

b) Breaking into systems under oxygen pressure.
A sudden release of oxygen under pressure can result in a relatively large jet of escaping oxygen. This may result in a torching fire.

c) Oxygen used in cutting and welding processes.
In processes such as cutting, gouging, scaring and thermal lancing, oxygen is used, in quantities greater than necessary for the burning process. The unused oxygen remains in the atmosphere, and if ventilation is inadequate the air can become enriched with oxygen.

d) Oxygen used in metallurgical processes.
Incorrect practice in the use of blowpipes can lead to oxygen enrichment, especially in confined spaces.

e) Desorption.
Oxygen can be released in appreciable quantities when cold materials which have absorbed oxygen such as absorbents (molecular sieve, silica gel, etc.) or insulation materials are warmed to room temperature.

f) Cryogenic liquid spill.
A spill of liquid oxygen creates a dense cloud of oxygen enriched air when evaporating. In an open space hazardous oxygen concentration usually exists only within the visible cloud associated with the spill.
The cold gas may collect in nearby low lying spaces such as ditches or drains, which are not well ventilated; atmospheric checks should also be carried on such any nearby spaces after a spill.

g) Liquefaction of air.
When using cryogenic gases with boiling points lower than oxygen, e.g. nitrogen, hydrogen and helium, oxygen enrichment can also occur.
Ambient air will condense on uninsulated equipment where the temperature is lower than the liquefaction temperature of air (approx –193 °C). This will also occur on pipework lagged with an open cell insulant. The liquid air so produced can contain up to 50 % oxygen and, if this liquid drips off and evaporates, the oxygen concentration in the last remaining portion can be over 80 %.

h) Oxygen vents.
Areas near oxygen vents can be particularly hazardous. A sudden release of oxygen can occur without warning. Note that the non-cryogenic production of oxygen or nitrogen might involve an occasional or continuous venting of oxygen. See AIGA 067/10, 'Safe location of oxygen and inert vents'.

5.2.2 Improper use of oxygen

Serious accidents have been caused by the use of oxygen for applications for which it was not intended.

Examples of improper use of oxygen are:

a) Powering pneumatic tools
b) Inflating vehicle tyres, rubber boats, etc.
c) Pressurising and purging systems
d) Replacing air or inert gas
e) Cooling or refreshing the air in confined spaces
f) Blowing oxygen inside clothing e.g. by a welder in an attempt to create a cooling breeze
g) Removing dust from benches, machinery and clothing
h) Starting diesel engines

In each case the fire and explosive risk is the same and results from exposing combustible materials e.g. flammable gases, flammable solids, rubbers, textiles, oils and greases to oxygen.

5.2.3 Incorrect design of oxygen system

The proper design of oxygen installations is critical. Inadequate designs can and have lead to serious accidents.

Examples of inadequate design

a) Use of rapidly opening (ball) valves. This can lead to ignition caused by the heat generated by high velocity gas or adiabatic compression, (see below).
b) Allowing too high a gas velocity which can cause ignition of incompatible materials in the system due to particle impact, etc.
c) Opening the main shut off valve in an oxygen supply pipeline without equalising the pressure before.
d) High pressure gas in the presence of sharp edged orifices, rapid expansions or reductions.
e) Poorly located vents causing accumulation of oxygen in the vicinity.

5.2.4 Incorrect operation and maintenance of oxygen equipment

Incorrect operation and maintenance of oxygen equipment is one of the most frequent causes of fires in oxygen systems.

Examples of Incorrect Operation

a) Failing to reset pressure regulators to the closed position when the oxygen cylinder valve has been closed. This results in extremely high oxygen gas velocities when pressurising the regulator next time it is used.
b) Rapid opening of valves can result in momentarily high oxygen velocities, sufficient to project any debris present in the system through the system, at sonic velocity causing frictional heat, sparks, etc..
c) Opening a valve rapidly against a closed valve (or pressure regulator) downstream in a system – high heat can be generated through adiabatic compression of the oxygen causing a fire.
d) Start-up of an oxygen compressor erroneously with oxygen. (This is incorrect operation only relevant to special cases – see references 7 and 8)

Examples of Incorrect maintenance

a) Working on pressurised systems.
b) Venting oxygen into restricted, enclosed or confined spaces.
c) Allowing systems to become contaminated. Contamination by particulate matter, dust, sand, oils, greases or general atmospheric debris creates a potential fire hazard. Portable equipment is particularly susceptible to contamination and precautions shall be taken to prevent ingress of dirt, oil, etc.
d) Failure to completely remove cleaning solvents from components which are to be used in oxygen service. The solvent residues are not compatible with an oxygen enriched atmosphere.

5.2.5 Use of incorrect materials

Design of oxygen equipment is very complex and the “why and how” is not always obvious. In essence nearly all materials are combustible in oxygen. Safe equipment for oxygen service is achieved by careful selection of suitable materials or combination of materials and their use in a particular manner.

Any modifications to a design must be properly authorised to prevent incompatible materials being used.

Substituting materials which look similar is extremely dangerous and many accidents are reported where the cause was incompatible replacement parts. Examples of this practice could be:

a) Replacing o-rings and gaskets with similar looking items. There are hundreds of different types of elastomers and most are not compatible with oxygen.
b) Replacing a metal alloy with a similar type of alloy. The composition of particular alloys has a significant effect on its mechanical properties and oxygen compatibility. “Bronze”, which covers a wide range of alloys, has several varieties that are compatible with oxygen and even more which are not; e.g. tin bronze is used in liquid oxygen pumps while aluminium bronze is considered hazardous.
c) Replacing PTFE tape with a similar white tape. Not all white tape is PTFE and not all brands of PTFE tape are safe for use in oxygen., see EIGA Doc 138, PTFE Tape as a sealant for Cylinder/Valve Connections
d) Replacing parts/components with non-approved equipment is not allowed. The geometry of certain components is sometimes critical and approved manufacturer’s parts shall always be used when maintaining oxygen equipment.
e) Replacing or installation of combustible material in filters e.g. plastics, paper, adhesives. Filters in oxygen systems are very sensitive to ignition due to presence of particles and complicated flow conditions. Therefore filters should be made of materials that demand very high ignition energy e.g. Monel.
f) Lubricants are generally not allowed in oxygen service except for special applications. Specialist expert advice shall always be obtained before applying such lubricants.

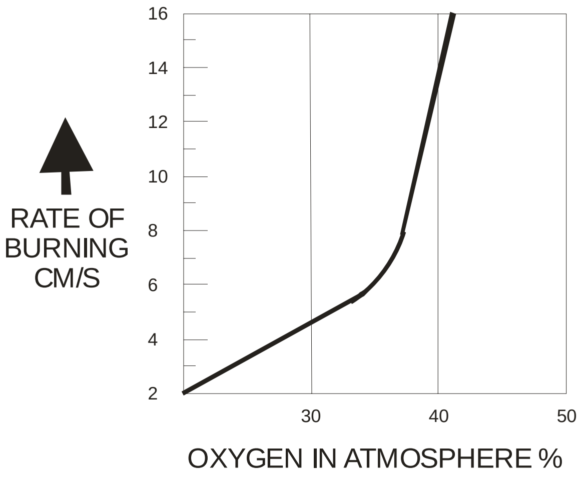
5.3 Combustible material

In oxygen enriched atmospheres

Materials that do not burn in air including fire resistant materials, can burn vigorously in oxygen enriched air or pure oxygen.

In enriched oxygen atmospheres a common combustible material that most directly affects safety of personnel is clothing. All clothing materials will burn fiercely in an oxygen enriched atmosphere. The same applies to plastics and elastomers.

An example of this increased reactivity can be seen below, for cotton overall material exposed to fire in atmospheres containing increasing levels of oxygen (Ref. No. 8).



Similar curves, indicating the same kind of behaviour could be drawn for other materials – in particular for plastics and elastomers.

In pressurised oxygen systems

In principle all organic materials will burn in oxygen and so do most of the metals and metal alloys. Pressure affects the behaviour of materials, e.g. by reducing ignition temperatures and increasing combustion rates. It is for these reasons that pressurised oxygen systems are only allowed to be constructed from materials and equipment whose design has been approved for the relevant operating conditions.

Oil and grease are particularly hazardous in the presence of oxygen as they can ignite extremely easily and burn with explosive violence. In oxygen equipment, oil and grease ignition often causes a chain reaction, which finally results in metal burning or melting. In such cases the molten or burned metal residue is projected away from the equipment and may be followed by an oxygen release. This in turn can lead to fierce and rapidly spreading flames in any adjacent combustible material external to the equipment. Hydrocarbon oil and grease shall never be used to lubricate equipment that will be in contact with oxygen, and any lubricants shall have been approved for the application

5.4 Ignition sources

In oxygen enriched atmospheres

Ignition sources in oxygen enriched conditions could be:

a) Open fires or naked flames (cigarettes, welding or other hot work, petrol driven engines, furnaces etc.)
b) Electrical sparks
c) Grinding or frictional sparks

In pressurised oxygen systems

In systems containing oxygen under pressure the potential sources of ignition are not as obvious as naked flames and hot surfaces.

The following ignition sources have caused fires in oxygen systems:

a) Heating by adiabatic compression
b) Friction
c) Mechanical impact
d) Electrical sparks

e) High gas velocity with presence of particles

6 Prevention of fires in oxygen systems

6.1 Information/training

Any personnel using oxygen equipment should be aware of the hazards. The minimum information for safe use of oxygen is included in AIGA 009/10 "Safety training of employees".

All personnel should also have read the safety data sheet and safety information provided by the gas supplier.

For a greater insight into the hazards of oxygen with materials the following information is also recommended:

a) "Oxygen pipeline systems" AIGA 021/05
b) "Prevention of hose failures in high pressure gas systems" IGC Doc 42
c) "Reciprocating compressors for oxygen service. Code of practice" AIGA 048/08
d) "Installation guide stationary, electric motor driven centrifugal oxygen pumps" AIGA 55/08
e) "Centrifugal compressors for oxygen service. Code of practice" IGC Doc 27
f) SAG Info 15: "Safety principles of high pressure oxygen systems".
g) Flammability and sensitivity of materials in oxygen-enriched atmospheres – American Society for Testing & Materials (ASTM) symposium series
h) "Cleaning of equipment for oxygen service" AIGA 012/04
i) "Selection of personal protective equipment" AIGA 066/10
j) "Fire Hazards of Oxygen Enriched atmospheres" TP 12

All maintenance and repair work shall be performed by experienced and fully trained personnel.

All persons who work in areas where oxygen enrichment can occur shall be given adequate instructions as to the risks involved. Special emphasis on shall be given drawn to the insidious nature of the risks and to the almost immediate consequences. Practical training shall be given in the means by which such risks can be minimised, stressing the importance of identifying sources of oxygen enrichment and their isolation.

6.2 Proper design

In oxygen systems only equipment that has been specifically designed for oxygen shall be used, e.g. nitrogen regulators shall not be used in oxygen service. The proper design of equipment intended for oxygen service takes into account materials to be used and their configuration, in order to minimise any risk of ignition. The reasons for a particular design and choice of material are not always obvious and expert advice shall be sought before considering a change of materials.

Oxygen equipment shall never be lubricated with oil or grease. For specific, well defined cases, a few special lubricants may be available. Specialist advice from the supplier shall always be sought.

Oxygen systems shall be designed in such a way, that the flow velocity is as low as possible. If the velocity is doubled the energy of a particle in the gas stream will increase four times.

Oxygen systems should be positioned in well ventilated areas away from primary ignition sources such as boilers, etc. Liquid systems should be located away from cable trenches, drains and ditches.

6.3 Prevention of oxygen enrichment

6.3.1 Leak testing

Newly assembled equipment for oxygen service shall be thoroughly leak checked using air or nitrogen e.g. by timed gas pressure drop test, leak detection test (e.g. with approved leak spray or diluted soap solution) or other suitable methods, see AIGA 070/10, Leak detection fluids, gas cylinder packages. Periodic retests to check for leaks are recommended.

6.3.2 Operation and practice

When the work period is over the main oxygen supply valve shall be closed to avoid possible oxygen leakage when the equipment is not being used.

Filters, where fitted, shall not be removed to obtain higher flows. Filters should be inspected at frequent intervals and all debris removed.

6.3.3 Ventilation

Rooms where there is a risk of oxygen enrichment of the atmosphere shall be well ventilated. Examples of such rooms are:

a) Filling stations
b) Rooms in which oxygen vessels or cylinders are stored, handled, maintained, etc.
c) Rooms in which oxygen is used or analysed
d) Rooms for medical treatment with oxygen in hospitals, home care, etc.

In many cases natural ventilation can be sufficient e.g. in halls or rooms provided with ventilation openings. The openings should have a flow area greater than 1/100 of the room’s floor area, be diagonally opposite each other and shall ensure a free air circulation with no obstructions. Where natural ventilation is not possible a ventilation unit, with a capacity of approximately 6 air changes/hour shall be provided. Special consideration shall be given to the ventilation of underground rooms, vessels, pits, ducts and trenches. There shall be a safety warning to indicate if the ventilation unit fails.

6.3.4 Vessel entry/ blanking procedures

Prior to entry into any vessel which is connected to a gas source other than air, the vessel shall be emptied, disconnected from such a source by the removal of a section of pipe, by the use of a spectacle plate or by inserting blind flanges and the space shall be thoroughly ventilated so as to maintain a normal atmosphere. Piping lock-out devices need to be documented in the Hazardous Work Permit. Reliance on the closure of valves to prevent oxygen enrichment is not sufficient. Permission to enter such a space subsequent to completing the steps indicated above shall be given only after the issue of an entry permit certificate signed by a responsible person. An analysis of the vessel atmosphere shall always be requested as part of the work permit requirements.

6.3.5 Isolation equipment

When an oxygen pipeline enters a building, an isolation valve should be provided outside the building in an accessible position for operation. This valve and location shall be clearly marked and identified. The purpose is to enable operation of the valve from a safe location, in the event of an oxygen release inside the building.

Disused oxygen lines should either be dismantled or completely severed and blanked off from the supply system.

6.4 Oxygen cleanliness

One of the fundamental safety procedures in preventing oxygen fires is to ensure that all equipment is properly cleaned before it is put into oxygen service. There are several methods for cleaning oxygen equipment. The AIGA 012/04 “Cleaning of Equipment for Oxygen Service” covers this subject in detail.

Oxygen equipment also must be free of solid particles. In order to remove particles new oxygen equipment before start-up shall be purged with oil free air or nitrogen.

6.5 Control of hot work

Any hot work which has to be performed close to any oxygen equipment or in an area where oxygen enrichment could occur shall be controlled by a written permission (hot work permit), which is part of the work permit system. Hot work includes operations such as welding, brazing, drilling, grinding, etc.

7 Methods of oxygen detection

The method selected must offer a high degree of reliability of operation and be sufficiently sensitive to provide warning before a hazardous concentration of oxygen is reached. The normal method is to use an approved atmospheric monitoring instrument to confirm the effectiveness of the isolation and purging procedures prior to entry into the area, and periodically during the course of the working to confirm that changes have not occurred.

A possible method of oxygen detection could be odorisation. Odorisation is occasionally used in shipyards, because there is a real risk of oxygen enrichment when welding in restricted spaces inside ships. (For details see Ref.9). However, odorisation must only be viewed as a possible supplement to effective risk analysis, isolation and atmospheric monitoring, not as an alternative to them.

7.1 Measuring Instruments

Oxygen measuring instruments should be used as warning devices only, and should not be regarded as protection against the risks of oxygen enrichment. They should be seen as an addition to normal good practice of eliminating the causes of enrichment. Appropriate measuring instruments for the determination of the oxygen content indicate an increase as well as a decrease of the oxygen concentration in the ambient atmosphere and have, for example, a range from 0 to 40 % by volume of oxygen.

Various measuring techniques and methods are used giving visible and/or audible warning and they can be used for continuous or intermittent measurement.

7.2 Choice of the measuring method

When working in rooms where the oxygen content can rise to a dangerous level continuous measuring methods shall be used during the working time.

Intermittent measurement should only be chosen if it is considered that the rate of build up of oxygen in the atmosphere is slow enough to allow an increase to be detected well before a dangerous level is reached. The time interval between measurements needs to be carefully chosen to ensure an appropriate safety margin. Instruments should be checked in fresh air before use and adjusted in accordance with the manufacturer's instructions.

7.3 Utilisation of measuring instruments

The directions of the manufacturers for the use and maintenance of the measuring instruments shall be carefully observed.

The measuring instrument shall be located in the working area and as near as possible to the worker. In confined spaces, it is recommended that the worker is equipped with a personal monitor attached to his working clothes which will give an audible and/or visual alarm if the oxygen content of the atmosphere deviates from that of normal air. In areas with high noise levels, visual alarms are recommended.

8 Protection of personnel

8.1 Clothes

Many so-called "non-flammable" textile materials will burn fiercely in oxygen enriched air.

Some synthetic materials can be fire-resistant to some extent, but may still melt and cause serious burns due to the adhesion of molten material to the skin. Synthetic materials are not recommended, even as underclothes.

Using flame retardant clothing can be useful, but washing can reduce the effectiveness of some flame retardant treatments.

Protective work clothing alone is not sufficient to avoid danger from an oxygen fire.

From the practical point of view, wool is probably the best material for normal work clothes, because it is readily available and it quickly becomes extinguished when brought into normal air.

Clothing should be well fitting, yet easy to remove and free from oil and grease.

Persons who have been exposed to an oxygen enriched atmosphere may not smoke or go near naked flames, hot spots or sparks until they have properly ventilated their clothes in a normal atmosphere. A ventilation period of 15 minutes minimum with movement of the arms and legs and with coats unbuttoned is recommended.

8.2 Analysis

Before persons enter a space which can be subject to oxygen enrichment, the atmosphere shall be analysed for oxygen by a reliable and accurate analyser (see section 7). Entrance is permissible only if the oxygen concentration is equal to that of normal air. Any higher concentration, especially over 23·5 % is potentially dangerous. However, as a warning against local or temporary variation in concentration, it is recommended that anyone entering such a space should be issued with a personal continuous automatic oxygen analyser which sounds an audible alarm when the oxygen concentration in the atmosphere varies above 23·5% or below 19·5%. (For details see Ref [10].Definitions of Oxygen Enrichment/Deficiency EIGA PP-14)

Fire fighting equipment

The only effective way of dealing with oxygen-fed fires is to isolate the supply of oxygen. Under oxygen-rich conditions, appropriate fire fighting media include; water, dry chemical (powder) or carbon dioxide. The selection needs to take into account the nature of the fire, e.g. electrical, etc. Burning clothing for example shall be extinguished by water as covering in a fire blanket will still allow oxygen enriched clothing to burn.

Fire fighting equipment should be properly maintained and operating personnel should know where it is located, how to operate it, and which equipment to use for which type of fire.

8.3 Smoking

All personnel shall be informed of the dangers of smoking when working with oxygen or in an area where oxygen enrichment can occur. Many accidental fires and burn injuries have been initiated by the lighting of a cigarette; it is therefore imperative to emphasise the danger of smoking in oxygen enriched atmospheres or where oxygen enrichment can occur. In such areas smoking shall be forbidden.

8.4 First Aid

A person entering a space to rescue someone who is alight in an enriched oxygen will almost certainly also catch fire. Instead the victim shall be deluged with water from a shower; hose or series of fire buckets and be brought into fresh air as soon as possible.

9 Summary of recommendations

The key points to avoid accidents due to oxygen enrichment are summarised below:

a) Ensure that people, who are expected to work with oxygen, are properly trained and informed of the risks caused by an excess of oxygen.

b) Make sure that the proper equipment is used, that it is leak-tight and in good operational order.
c) Use only materials and equipment approved for use in oxygen. Never use replacement parts which have not been specifically approved.
d) Use suitable clean clothing, free from oil and easily combustible contaminants.
e) Never use oil or grease to lubricate oxygen equipment.
f) Check that all existing fire extinguishing equipment is in good condition and ready to be used.
g) When working in confined spaces where oxygen is normally used, isolate the equipment, provide good ventilation and use an oxygen analyser. Entry shall only be allowed by means of a permit issued by a trained responsible person.
h) Smoking shall be strictly forbidden where there is any possible risk of oxygen enrichment.
i) People catching fire in enriched oxygen atmospheres cannot be rescued by a person entering the area to pull them out, as the rescuer will almost certainly also catch fire.
j) People who have been exposed to oxygen enriched atmospheres shall not be allowed to approach open flames, burning cigarettes, etc., until after adequate ventilation of their clothing.
k) Make sure that all oxygen apparatus and equipment is properly identified.

Escape routes shall be kept clear at all times.

APPENDIX A

References

[1]. Cleaning of equipment for oxygen service - AIGA 012/04

[2]. The probability of fatality in oxygen enriched atmospheres due to spillage of liquid oxygen - BCGA Doc TR2, 1999

[3]. Reciprocating compressors for oxygen service - AIGA 048/08

[4]. Centrifugal compressors for oxygen service - IGC Doc. 27/10

[5]. A method for estimating the offsite risks from bulk storage of liquefied oxygen - BCGA Report TR 1, 2004

[6]. Safety principles of high pressure oxygen systems – EIGA Safety Information 15

[7]. Fire in regulators for oxygen in industrial service – EIGA Safety Information 16

[8]. Hazards of oxygen enriched atmosphere / EIGA campaign highlighting the hazard of oxygen enriched atmospheres - Safety Newsletter NL 79, Safety Leaflet SL 02 AIGA Training Package TP 02/05 – Fire hazards of oxygen & oxygen enriched atmospheres

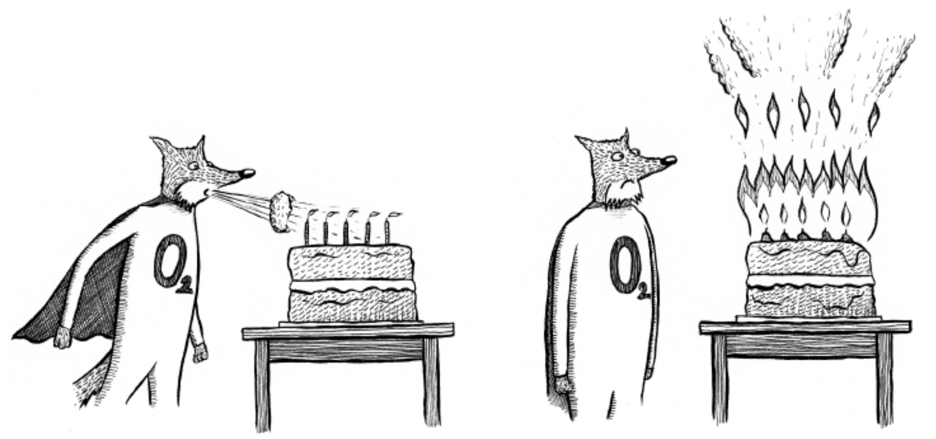
[9]. Odorisation of oxygen in combustion applications EIGA Doc 911

[10]. Definitions of Oxygen Enrichment/Deficiency EIGA PP-14

APPENDIX B

Properties of oxygen
Oxygen supports combustion

- Oxygen is essential to life; the normal concentration in the air we breathe is approximately 21 %.
  It is not flammable but supports combustion. Most materials burn fiercely sometimes explosively in oxygen. As the oxygen concentration in air increases, the potential fire risk increases.



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Properties of oxygen
Oxygen gives no warning

- Because oxygen is colourless, odourless and has no taste, oxygen enrichment cannot be detected by the normal human senses.
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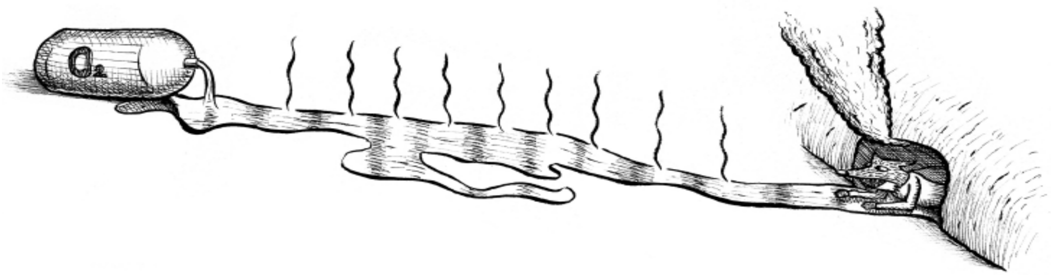
Properties of oxygen: Oxygen is heavier than air

- Being heavier than air, oxygen can accumulate in low lying areas such as pits or underground rooms, especially in during or after a liquid spill.



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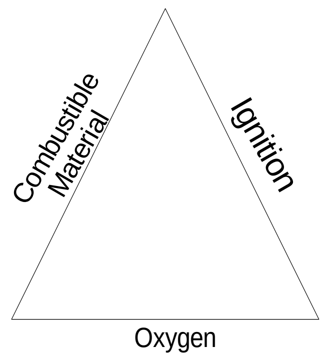
Conditions needed for a fire

In general for a fire or explosion to occur, three elements are required:

combustible material, oxygen and an ignition source

The Fire Triangle is the normal way of illustrating these conditions



When any one of the 3 elements is missing a fire cannot occur.

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Causes of oxygen fires

- Oxygen Enrichment of the atmosphere
- Improper use of oxygen
- Incorrect design of oxygen systems
- Incorrect operation and maintenance of oxygen systems
- Use of materials incompatible with oxygen service

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Compatibility of materials

- Only certain materials are suitable for use in oxygen service.
- Most materials will burn in pure oxygen, even if they cannot be ignited in air.
- Oils, grease and materials contaminated with these substances are particularly hazardous in the presence of oxygen, as they can ignite extremely easily and burn with explosive violence.

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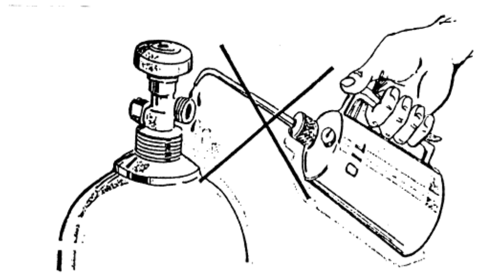
Never use oil or grease to lubricate oxygen equipment!

- Equipment contaminated with oil and grease shall be cleaned using approved cleaning agents/methods.



Check with your supervisor that any material/part or substance you intend to use is approved for oxygen service.

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Leaking equipment is very dangerous

- It could lead to oxygen enrichment, i.e. increased fire hazard.
- Leaking connections, flanges, fittings are hazardous causing the oxygen concentration to increase especially where there is not sufficient ventilation
- Leak test equipment, newly assembled or after maintenance, before bringing into service.

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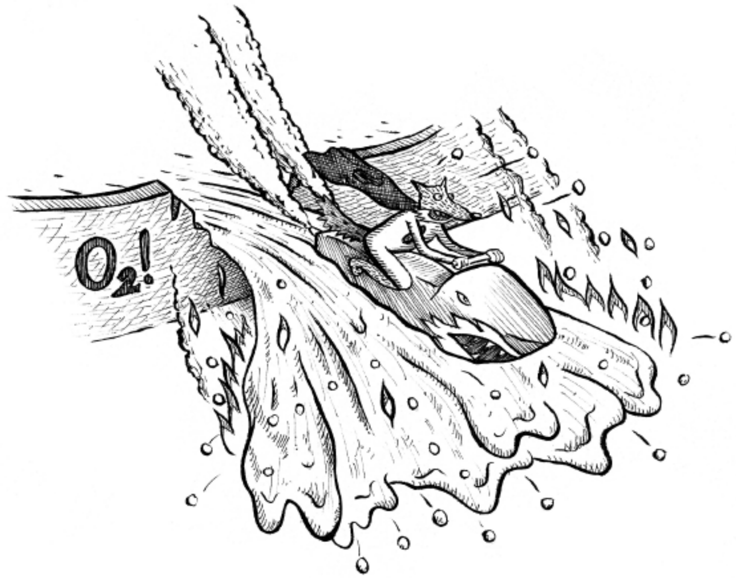
Liquid Oxygen spill

- A spill of liquid oxygen creates a dense cloud of oxygen enriched air as it evaporates.
- The clothing of personnel entering the cloud will become enriched with oxygen.
- When liquid oxygen impregnates ground which contains organic material such as wood or asphalt, there is a danger that the organic material may explode if impacted.



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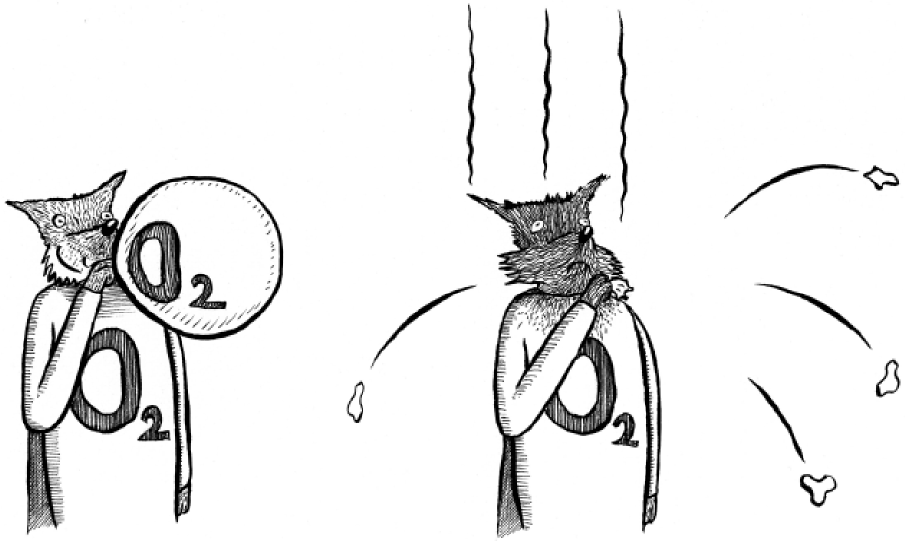
Do not use oxygen for applications for which it is not intended!

Do not use oxygen as a substitute for air, e.g. when:

- operating pneumatic tools
- inflating tyres
- starting diesel engines
- dusting benches, machinery or clothing



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In areas where oxygen enrichment can occur, do not smoke and do not use naked flames

If hot work (welding, flame cutting, soldering, grinding, etc.) has to be carried out, ensure that the atmosphere has been checked and confirmed as safe and obtain a Permit to Work.

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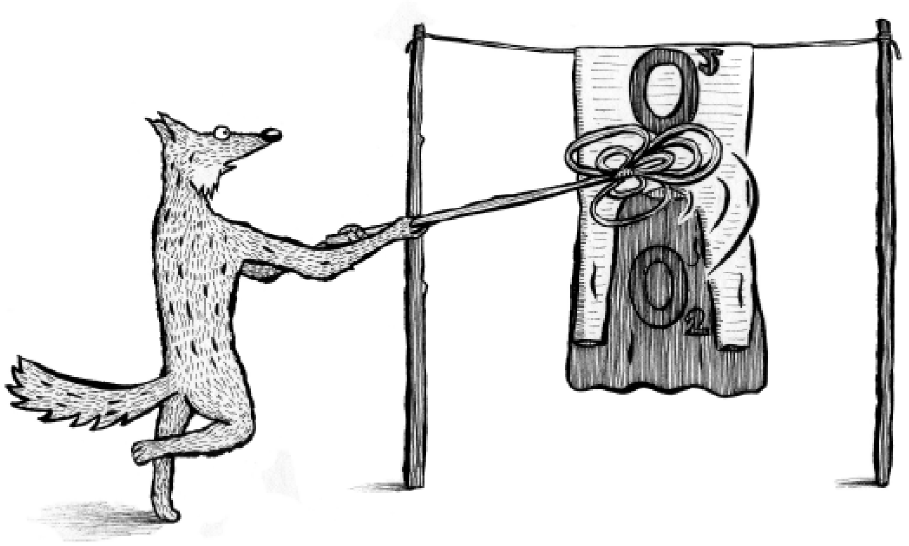
If you have been in an oxygen enriched atmosphere ventilate your clothing in the open air for at least 15 minutes before smoking or going near a source of ignition.



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APPENDIX C

C 1 Examples of oxygen enrichment accidents.

1. At a factory, a valve on an oxygen feed line which ran into the plant shop was left open. A man's clothing ignited when contacted by electric welding sparks. He ran out and rolled on the grass but was seriously burnt. Several others who assisted were slightly burnt.

2. A worker attempted to change a blowpipe by nipping the oxygen hose. Escaping oxygen caused fire resulting in serious burns to the worker.

3. Men were working on the roof of an oxygen factory near a main oxygen vent which was operating. One man began to smoke, his clothing ignited and he was burned to death.

4. A contractor employee had to grind away a piece of railing on a platform at the air separation column.
   A Work Permit had been issued and a pre-job discussion had been held. The ambient temperatures were low and while waiting for a colleague he leaned over and partially sat down on an oxygen vent warming himself on the escaping relatively warm oxygen leaking through the valve. The moment he started grinding, a spark set his oxygen saturated clothing alight, causing burns on his total body of 2nd and 3rd degree resulting in months of hospital treatment.

5. When using an oxygen lance in a steel foundry, an operator realised that the coupling between hose and lance was leaking, but did not mind because it provided some cooling on his stomach. A spark of hot metal was projected towards the operator and ignited the oxygen saturated clothing at his stomach, resulting in serious burns.

6. Oxygen was vented from a PVSA plant at a customer. The location of the vent outlet caused an oxygen enriched area. The working cloths of a maintenance contractor caught fire at grinding causing burn injuries.

7. At a gas company site cryogenic air separation plant production area, a steam pipeline was being welded in a pit. The pit was enriched with oxygen so that the clothes of the fitter caught fire and he subsequently died. The welder sustained burns trying to extinguish the fire. Risks were not identified and a work permit was prepared but not followed.

8. When internally inspecting an oxygen cylinder, the used lamp ignited a flammable gas or material in the cylinder. The operator suffered burn injuries.

9. A patient was smoking a cigarette whilst receiving oxygen therapy via a nasal cannulae and oxygen from an Oxygen Concentrator in his own home. The cigarette caused ignition of the Nasal cannulae and subsequent burning of the plastic caused small scale scalding of the upper respiratory tract. The patient was seen by a medical practitioner and returned home soon afterwards. Contact with the patient led to an admission that he had been smoking against warnings instructions and training.

10. A patient was using Oxygen Concentrator at home. Patient's daughter telephoned to state that Mother had lit a cigarette and the cannula and tubing ignited burning nose. Cannula had adhered to nose. Patient taken to hospital via ambulance.

11. A worker in the maintenance shop of a filling station was grinding when his clothes caught fire and he was seriously injured. The worker had brought an oxygen bundle inside to make it possible to check a leak with detection fluid. It was cold weather outside. After the leak check he vented the bundle inside the work shop which was against the instructions.

12. A local fire officer advised that a patient supplied by an EIGA member company had been victim of a fatality in fire at home. The first elements of investigation suggest that he might have been smoking while having oxygen.

13. A homecare (oxygen concentrator) patient fell asleep with cigarette igniting bedclothes.

14. A driver was driving a home care liquid and gas oxygen delivery van. He tried to light a cigarette which consumed instantly. Incandescent ashes transmitted the fire to the cabin. Driver stopped and tried vainly to extinguish fire which spread quickly to the whole vehicle. A few minutes later a small aluminium oxygen cylinder exploded and pin-index of 2 other cylinder valves were ejected.

15. A person who was wearing proper clothing was working in an oxygen enriched atmosphere. He went to a smoking area and immediately lit a cigarette, whereupon his clothing ignited.

16. Several instances have been reported of deaths in hyperbaric chambers due to smoking or electrostatic sparking under enriched oxygen conditions. In one case 10 people were killed when a fire broke out caused by a portable hand warmer being used.

C 2 Examples of improper use of oxygen

1. An air powered rotary drill was connected by means of an adapter to an oxygen line. After several hours, the air in the working compartment had become so enriched with oxygen that when one of the workers lit a cigarette it flared up, ignited clothing, resulting in four fatalities and five other men being injured

2. A welder was working in a tank car. After a while, he interrupted his work in order to renew the air in the tank by introducing oxygen. When he resumed his welding a spark ignited his clothing. The worker succumbed to fatal burns.

3. A steelworker attempted to repair his car which had a blockage in the fuel line. He used oxygen to clear the blockage and the fuel tank exploded killing one person.

C 3 Examples of incorrect design of oxygen system

1. A filling panel with ball valves was temporary, and against the standard procedure, used for the filling of oxygen mixtures. The ball valve ignited due to adiabatic compression and the operator was injured.

2. An oxygen pressure regulator burnt out. Use pressure regulators with metal membrane and with type approval according to EN 961.

3. When the oxygen cylinder back-up system at a hospital switched on due to low LOX tank contents, an ignition of a PCTFE valve seat occurred and the patients were exposed to the products of the combustion. The valve did not have the correct seat for the oxygen application.

4. A weak design of the lower spindle of an oxygen cylinder valve caused an ignition after the cylinder had been filled to 200 bar.

5. A customer station installation team and some customer employees were severely burnt during the commissioning of an oxygen supply installation. The oxygen supply installation was set up to provide an oxygen backup supply during the maintenance shutdown of the customer owned and operated oxygen PSA units. The oxygen supply system was designed, engineered and constructed by the local merchant customer station installation team, without an appropriate engineering design review. During the commissioning there were four employees and six customer's employees standing around the oxygen supply system, as the intention was to carry out the customer training during the commissioning process. The release was caused by particles travelling at high velocity through the piping and impinging onto a stainless steel mesh in a 'Y' type strainer. The resultant fire burnt through the piping and control valve downstream of the strainer and as a result eight people were severely injured.

6. A defect weld in a LOX pump caused a fatigue crack, LOX leakage and an ignition of the pump. The pump manufacturer subsequently informed all customers of this pump type and recommended improvements.

7. While making a delivery of liquid oxygen the driver noticed a glow in the enclosure for the hydraulic pump drive compartment caused by wear and failure of a rubber seal due to misalignment of the pump drive. There was a failure to design a location spigot required to assist alignment.

8. A 50 m3 LOX tank was to be emptied but the connection to the ejector failed. It was wrongly decided to use the stone pit instead and slowly empty the tank. After 5 tonnes had been emptied, an explosion was heard and a fire seen close to the pit. Review of the design of new and in operations stone pits.

9. A 150-bar cylinder of 1% nitrogen in oxygen connected to analysis with a stainless steel needle valve resulted in oxygen combustion. Laboratory official stance on the valve seat material is unsuitable for extended use in oxygen and should be replaced.

C 4 Examples of Incorrect operation and maintenance of oxygen equipment

1. A worker was welding on the outside of an oxygen pipeline. Before starting the work the welder isolated the pipeline by closing the valve, purging the pipeline and checking the atmosphere. Suddenly the welder was engulfed in flames and subsequently died of his burns. The valve was later found to be leaking allowing oxygen to enter the isolated pipeline.

2. A mechanical failure of the turbo oxygen compressor caused rubbing and high local temperature which resulted in a total burn of the oxygen compressor. The compressor was installed in an enclosure which was damaged but prevented damage or injuries outside the enclosure.

3. At a customer site a regulator burned out when an operator opened the valve of a 300 bar bundle filled with 280 bar residual oxygen. Due to the incorrect procedure not to shut the regulator before opening, the sudden oxygen gas stream caused a burn out of the regulator and of the hose at the low pressure side. One employee suffered minor burns on a hand and his face.

4. Flash fire on the switchboard of a filling ramp when starting to fill oxygen cylinders.

5. In a filling station a valve of an oxygen cylinder burned out during pressure equalization procedure. Cause was iron powder inside the valve and cylinder that ignited. Valve and filling connector burned out. The operator suffered burns at hand and forehand.

6. A person suffered seriously burn injuries caused by an oxygen fire. The fire was caused by a modification done at the regulator by the customer.

7. The connector of a check valve in the high pressure oxygen line caught fire. The Viton O-ring in a radial groove was leaking.

8. Fire on the lubrication system of an O2 compressor.

9. After the filling of oxygen cylinders were completed and the cylinder valves closed, the operator opened the vent valve. The vent valve ignited, probably due to remaining particles after recent maintenance

10. After completing the filling of oxygen cylinders, the operator closed all RPV cylinder valves but one. When opening the vent valve the adaptor connected to the open cylinder valve ignited.

11. The third stage of an oxygen piston compressor manufactured in 1976 ignited. The compressor cover and emergency shut down worked very effectively protecting the surroundings.

12. An operator heard a noise at the end of filling 200 bars 5 l cylinders. When he approached the cylinders, there was a sudden flash fire from the top of one of the cylinders, probably due to a damaged O-ring.

13. A LOX semitrailer turned over. The tank was emptied. When it was connected to the truck an explosion occurred, killing three persons. Some diesel oil had leaked on the road and the safety valve, directed downwards, was venting GOX. When a wire was thrown under the trailer the oil/oxygen mixture exploded.

14. A liquid oxygen high pressure pump caught fire probably due to a leakage of cold liquid into the crankcase. The crankcase ruptured and an operator was hit on the finger by a peace of metal.

15. A LOX pump ignited during transfer of LOX due to excessive speed, 7200 rpm instead of the allowed 6800 rpm. Only pump and transmission damage.

16. An ignition had occurred at some time in the sensor of a liquid oxygen flow meter. Possible causes were poor cleaning for oxygen service at commissioning or dry-boiling leading to build up of hydrocarbons over a long period.

17. A LOX tank at a cylinder filling station was going to be emptied for maintenance by applying the usual cylinder filling procedure. Suddenly the pump ignited due to dry running. The dry running protection system was not correctly designed.

18. A LOX pump caught fire during its normal operation. The pump had been running dry for a time without being detected by the safety devices.

19. While supplying liquid oxygen at a customer's premises the driver noticed smoke in the pump cabinet. Electric arcing inside the power plug of the pump had burnt away the insulation of the wires. The extra insulation used in these cases had not been provided for the affected pump.

20. Further to a LOX leak when unloading a LOX trailer at a hospital facility, the trailer caught fire and the patients were evacuated.

C 5 Use of incorrect materials with oxygen service

1. A safety valve on a gaseous oxygen supply line was greased during repair. When the safety valve was later checked under oxygen pressure, the grease ignited and the operator was badly injured.

2. A worker wanted to check the pressure of oxygen cylinders. He used a pressure gauge filled with glycerine, not suitable for oxygen service. When opening the valve the pressure gauge exploded, resulting in nearly total blindness of the worker.

3. A fitter lost the Teflon gasket of his oxygen regulator. Arriving at the place where he had to do a repair, he made a rubber gasket from a car inner tube and connected the regulator to the cylinder valve outlet. When he opened the cylinder, due to the use of a non oxygen compatible gasket, a flash occurred burning his upper arm and shoulder.

4. An ambulance was completely destroyed because of a fire in the regulator of an oxygen cylinder. Probable cause was a non-compatible seal (rubber) in the regulator.

5. When opening the valve of an oxygen cylinder bundle, the connected high pressure flexible hose, made from rubber or plastic, ignited and burnt.

6. A safety valve in an oxygen filling station burnt out when the filling pump was switched on. The cause was an operation fault and perhaps incompatibility of the safety valve with oxygen. The installation and the type of safety valve will be changed.