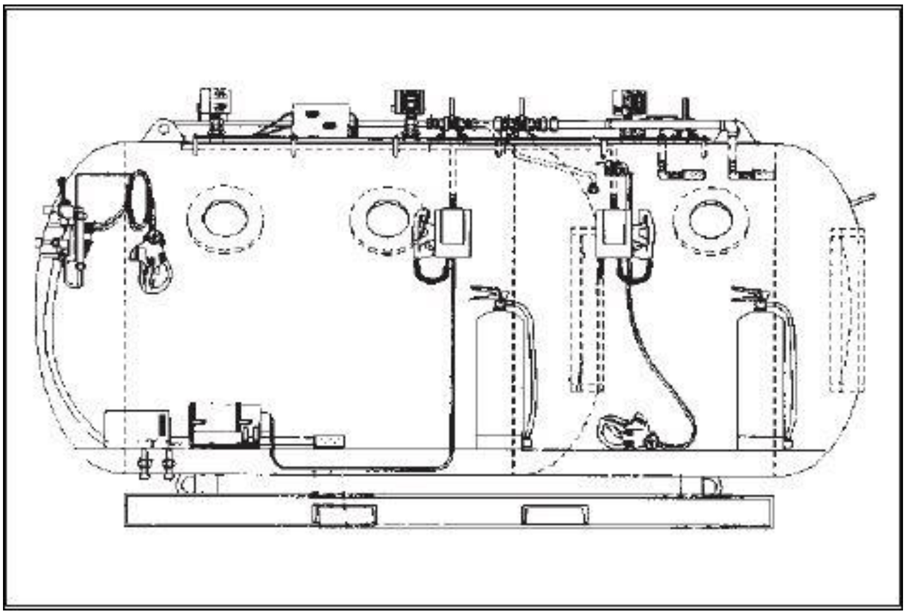

2020

Hyperbaric Health and Safety – Safe Gas Handling

SeaBourne Diving and Marine & Cumbria Hyperbaric

www.cumbria-hyperbaric.org
44 (0)79 3865 1086

Hayden Dunstan
Cumbria Hyperbaric
3/21/2020

Safe Gas Handling

The safe handling of gasses and more specifically the safe handling of oxygen and oxygen service is an important subject and hence the information in this section is a little more comprehensive than some others for a health and safety practice overview. Where external documentation can be consulted it is usually listed. Extra attention to specifics is presented here for oxygen service and safe gas handling owing to the added health and safety risks and hazards associated with the handling of oxygen specifically. Ordinarily health and safety manuals would contain a separate section detailing safe oxygen handling procedures.

Information presented here includes information relevant to the diving industry and the medical industry. It is relevant to chamber operators who find themselves in or outside of a strictly medical environment and operate chambers in service of commercial enterprises like diving or tunnelling and so on.

Oxygen must be treated with the utmost respect and understanding health and safety considerations is paramount in maintain a safe working environment.

Checking Gas on Delivery

Gases other than Air generally require transport to the chamber site and stored until they are needed. The exceptions may include oxygen generated on site by means of a Pressure Swing Absorption generator more widely called a PSA unit. Delivered gas is normally delivered in quads, super-quads or kellies. In some cases, hyperbaric units operate oxygen generation or concentration equipment which works based on molecular sieve beds which remove nitrogen and other gasses leaving mostly pure oxygen up to 95%. These systems are usually lower pressure systems than storage cylinders and hence safer. In brief, they draw air from the room or surrounds, compress it, and sieve out unwanted gasses. These systems also provide an unlimited on-site supply of almost pure oxygen and it is essentially free outside of equipment maintenance.

- A “quad” is a bank of cylinders that come in various sizes such as, but not limited to, 16 x 50 litre or 64 x 50 litres the Cylinders in the quad are all individual valves and connected to a central pipe with a king valve at each end. A king valve is a central valve which can isolate or open the entire quad. A quad doesn’t necessarily come in 4’s.

- A super-quad is multiple quads fitted together.

- A Kelly is a single frame with long large tubes or pressure vessels. Basically, bottles with an internal volume of about 2 cubic metres. These are typically supplied in racks of six or mounted in a container frame. They may be used as on-board storage for offshore use however hospital also may make use of such storage bottles. Many hospitals will have liquid

www.cumbria-hyperbaric.org
44 (0)79 3865 1086
Sunset View Aikton Cumbria
CA7 0JP
United Kingdom

oxygen on site as a matter of course and this is managed and supplied by the supplier in most cases.

Each bottle or quad should be colour coded and have the name and percentage of the contents painted on them. There will also be a label attached which gives a more accurate analysis, as this may vary by up to 5% of the minor gas.

Colour coding may vary slightly from company to company and country to country. The AODC (Association of Offshore Diving Contractors) has published a list of colour codes which is in general worldwide use for diving, and by extension hyperbarics, and is tabulated below.

• **GAS**	• **CYLINDER/ QUAD BODY**	• **NECK**
• Helium	• Brown	• Brown
• Helium Oxygen mixtures	• Brown	• Brown and White quarters
• Diving Oxygen	• Black	• White
• Industrial Oxygen	• Black	• Black
• Air/ Oxygen Nitrogen mixtures	• Grey	• Black and White quarters
• Nitrogen	• Grey	• Black
• Carbon Dioxide	• Black	• Grey
• Calibration Gas	• Pink	• Pink

When breathing gas is delivered, it can be stored in its transport quads or transferred to an onboard/on-site storage bank. Either way, it must be analysed for its oxygen content. Breathing and medical oxygen must be analysed if being purchased from an outside source to confirm purity and to make sure it is fit for purpose. Oxygen generated onsite must be subject to regular purity tests with some generators nowadays having full integrated touch screen control displaying constant flow and purity information.

An example procedure for doing this is as follows:

- Check that the king valves are closed.
- Open one bottle valve and listen for leaks.
- If there are no leaks, open all the other valves.
- Connect a gauge to the king valve and check the pressure. This should be above 180 bars.
- Fill a football bladder with gas, empty it and refill.
- Take this to the analysers, connect and analyse the gas.
- There are also small portable analysers that can be fitted to Quads to analyse the 0_2% at the quad.

www.cumbria-hyperbaric.org
44 (0)79 3865 1086
Sunset View Aikton Cumbria
CA7 0JP
United Kingdom

Portable oxygen analysers used for testing oxygen content are also available for testing oxygen percentages in diving cylinders. These are constant flow analysers and can be fitted to a system

temporarily to test oxygen levels. However, analysers are subject to accuracy deficit if flow rates are too high or too low across the sensor cell. Testing a sample in a bladder or test bag is a more reliable method since the analyser cell in this instance is surrounded by the sample rather than having it flow across the cell. It is easily possible to get purity results exceeding 100% when flow rate is too high.

Flow analysers are a good idea as part of the design and incorporation into the oxygen system. A constant monitoring of oxygen concentration would provide constant analysis and raise awareness immediately to any gas not for for purpose but ideally should not be the sole method of purity testing.

In terms of elective HBOT, oxygen percentage is somewhat less serious than in diving and diver recompression and other commercial uses of hyperbaric chambers involving decompression and inert gas scrubbing. It is important to understand though that any considerable level of inert gas in the breathing mix will incur a decompression penalty and hence the purer the better. Notwithstanding that, current medical protocols usually don't exceed 2,4 ATA or 14 meters of sea water equivalent. The table for air at this depth allows for longer than most treatments. Accordingly, if only 7% of the mix is nitrogen as is the case with Oxygen 93, then it is highly unlikely to present a decompression penalty problem.

Diving operations and emergency diving recompression treatments are largely calculated and based on pure oxygen, and for these types of treatments or decompression procedure only pure oxygen must be used if the respective table calls for it. An exception to this may be the Comex Cx30 treatment table which is a 50/50 heliox table. It does use pure oxygen as well though in the final stages, so purity applies universally for diver treatment tables. Notwithstanding that, if no medical grade oxygen will do. Even welding oxygen has a very high purity. In fact, it is higher than medical grade oxygen. Even Oxygen 93 would better than nothing though if it is all that's available.

Record in the gas logbook:

- The serial number of the quad.
- The pressure.
- The analysis.

Transferring Gas

If the gas is to be transferred to a vessel's onboard banks, this can be done using a gas booster or gas transfer pump. However, it is not recommended to pump pure oxygen or high percentage oxygen gases offshore. Furthermore, most gas transfer pumps should not be used for gases which contain more than 21% oxygen. Boosting of O2 is generally not done offshore anymore. When booting the safe ratio is 6 to 1 pressure gradient. In a land-based operation, it is unlikely chamber staff would ever be required to boost oxygen or pump from one place of storage to another outside of hyperbaric reception facilities. In this case special training should be provided.

Decanting Gas or Oxygen

It may be common to decant oxygen though from storage of higher pressure to storage of lower pressure. The golden rule applies. **Open and close all valves slowly** and allow the decant to progress slowly to avoid adiabatic compression and heating. Do not regulate high pressure gas to a reduced pressure higher than the working pressure of the downstream receiver. Always ensure overpressure valves are installed in the system and functioning as intended.

Gases containing less than 21% oxygen can be transferred safely if the following procedures are used:

- Analyse the gas before transfer.
- Always use the correct hose and fittings. Check their condition before use; particularly swivel fittings for fatigue cracks.
- Tie all whips securely before turning on the gas.
- Open valves slowly and at arm's length.
- If the quad pressure is high than the bank pressure, then decant as much gas as possible before starting the pump.

Each pump will have its own procedures for starting and these must be followed along the lines of the following example

For the Corblin gas transfer pump, the procedure for gas pumping is as follows:

- *Start the cooling pump.*
- *Ensure the Corblin has been drained then close the drain valve.*
- *Open the inlet valve and set the inlet pressure at 10-20 psi.*
- *Start the pump.*
- *When the outlet pressure becomes high than the banks, open the outlet valves.*

The procedure to stop the Corblin is as follows:

- *Close the inlet and outlet valves.*
- *Switch off the open the drain.*
- *Back off the inlet Tescom.*

OXYGEN

Transferring Oxygen

High pressure (HP) Oxygen carries additional risk and hazard and must be handled with care.
The following procedures must be followed.

- Do not smoke when handling oxygen
- Do not use stainless steel piping or fittings. Common practice is to use copper, tungum or brass.
- Keep flexible hoses to a minimum.
- Reduce the pressure as low as possible at the quad with a reducing regulator capable of the flow rate required. The recommendation is 40 bar or below. For an air chamber, 10 bar 02

pressure is enough. However, some gas blenders need a higher pressure than this to work. In these cases, keep the pressure as low as is practicable.

- Do not use quarter turn valves on oxygen lines other than as an emergency shut off. In these cases, the valve handle should be lightly taped to avoid routine use. Ball valves maximum working pressure 14 bar with oxygen and valves must have nylon 66 seats.
- Open all valves slowly as the sudden increase in pressure can heat up the gas and cause an explosion. When changing fittings avoid the use of PTFE tape (thread tape) on the first three threads as when this burns it causes Phosgene gas to be produced. Oxygen tape is preferred.
- High pressure oxygen should be stored in a well-ventilated area. Sealed compartments which have oxygen pipework in them should be fitted with an oxygen alarm.

Oxygen storage cylinders and quads are usually pressurised to 200 bar and accordingly require the use of hoses, regulators and other pipework. These hoses should be suited to the environment and where required be heat, sun UV, salt and water resistant.

Hoses should follow natural protection pathway like existing structure, conduits and walls. In cases where temporary oxygen storage necessitates the running of hose through open areas these hoses can be protected by placing lengths of angle iron over the hose. Fittings (valves etc.) and if in a potentially hazardous situation they can equally be protected by the use of guard frames or covers. Hoses should not hang on their own weight. They should be attached to a rope that does not stretch, to relieve the stress of hanging free.

All hose ends must be secured with hose checks or rope or ties when connected to equipment, A broken fitting and a loose hose can cause serious injury and damage.

5 The shortest distance between two points is not always the best and safest. Consider, consult and plan the best protected and safest route for hoses to follow.

When Handling Gas:

1. Wear clean clothes and strong gloves, and eye and face protection and any other relevant PPE
2. Do not lift a cylinder by cap, guard or lifting magnet.
3. Do not drag or slide cylinders.
4. Secure single cylinders upright.
5. Use only approved and O_2 clean equipment.
6. Use soapy water to check for leaks. Known as “Snooping”.
7. Reduce H.P. with regulator to L.P. before use (40 bar max for oxygen ideal 10 bar).
8. Use check valves (one-way valves) to prevent back flow.
9. Keep gas and hoses away from electrical devices.
10. Do not heat artificially (keep below 45 deg.C / 113F).
11. Open all gas and cylinder valves **slowly.**
12. Decanting is preferred to **boosting**.

www.cumbria-hyperbaric.org
44 (0)79 3865 1086
Sunset View Aikton Cumbria
CA7 0JP
United Kingdom

13. Do not use cylinders as rollers or supports.
14. Keep valves clean and protected.
15. No mechanical shock loads.
16. No repairs - mark clearly and return to supplier
17. Close valves when not in use.
18. Must be fire hydrant nearby (10-20m) and powder extinguisher by mixing room.
19. Do not exceed M.W.P. (Maximum Working pressure) of hoses, piping or receivers.
20. **NEVER** put O_2 in air quads/cylinders.
21. No quick connectors on gas hoses or connections.
22. No ball or quarter turn valves (except for emergency shut off).
23. Hoses must be approved for breathing and specific gases and min ⅜" ID (internal Diameter) bore.
24. Hoses must be marked both ends.
25. Hoses lay apart from other lines.
26. Lay above diving/hyperbaric system NOT BELOW with fire break.
27. Protect from damage.
28. HARD PIPE preferred.
29. Electrical Fittings (booster pumps) must be explosion prof.
30. Mixing cabin - doors open - ventilate forced air (jet flow) if below decks.
31. Vents/purges to safe areas (1/2" hoses).
32. No storage of flammable Items or fuels in the vicinity.
33. Do not use hammers on valves wheels - only proper tools
34. Never force a connection and never tighten under pressure.
35. Do not thaw frozen outlet with boiling water as it may melt fusible plug (if fitted) and vent cylinder - use warm water.
36. Never fool around with H.P. hoses - danger of combustion is high - or embolism via orifice or skin.

Gas Storage

1. Store in a dry - cool - well vented - safe area.
2. Keep away from fire risk/heat and ignition.
3. Keep access clear, and only authorised persons allowed in.
4. Display signs "No smoking" etc.
5. No smoking - naked lights – heating with radiant bar heaters not allowed. Hot water radiators and halogen OK if distant.
6. Keep away from other gases and if flammable gases present use a fire wall.
7. Protect from falling objects and corrosion (off ground)
8. Keep empties separate from full. Leave some press in empty cylinders close valves and label.
9. Check hydrostatic test dates - M.W.P. - frames and lift slings - manifold for leaks/damage.

OXYGEN SAFETY AND HANDLING FIRE AND EXPLOSION PREVENTION

When working with oxygen ensure you understand the requirements.

Oxygen Service = Oxygen Compatible & Oxygen Clean

The term oxygen service means the components or system is both oxygen compatible and oxygen clean.

Oxygen Compatible

Oxygen compatible refers to materials which are specifically selected because they meet combustion requirements and exhibit properties of non-combustibility required for use with oxygen. They are also selected with ease of maintenance in mind. Generally, copper and alloys are preferred to steel. Alloys and copper conduct heat better and hence reduce localised heating resulting from adiabatic compression. They are also less prone to sparking should there be internal particulate contaminants as discussed that may cause sparking by particle impingement.

Materials known for ineffective conduction of heat may allow local heating and build-up of temperatures presenting a clear hazard and potential for spontaneous combustion. Materials which vapour off under pressure must also be avoided. This can include most plastics, thread tape, certain types of rubber O-rings and seals and valve seats etc. Cadmium plated steel and rubber hoses must also be avoided. Only materials specifically designed and rated as oxygen compatible are to be used.

Oxygen Clean

Oxygen clean refers to items which have had ALL traces of hydrocarbons, oils, silicon's and other contaminants removed in a specific cleaning process known as oxygen cleaning. Oxygen clean extends beyond the "no oil" policy to "no contaminants" as well.

Items designated as oxygen clean are not normally supplied ex-factory in an oxygen clean condition. They must be cleaned by the person or persons responsible for system maintenance in accordance with oxygen cleaning procedures. Even those items which are manufactured oxygen clean will lose that designation during system assembly and construction processes and should be recleaned accordingly. Many suppliers offer this service now prior to delivery.

For example, a suitable copper pipe is oxygen compatible but won't be oxygen clean following manufacturing as it may contain traces of oils, or silicone and should be oxygen cleaned before use in an oxygen system.

Manufacturers of hyperbaric and gas systems are responsible for the design and construction of oxygen systems and must ensure the system is designed and constructed appropriately. As mentioned previously, special cleaning materials are required for cleaning oxygen systems and hyperbaric chambers. Internal surfaces of pipes and plumbing can be flush cleaned with products such as Biox and Hydrosol. The internal surfaces of piping are where the greatest risk comes from when using oxygen and not necessarily the chamber itself. While oxygen considerations apply to the chamber are prioritised, these are generally forgotten when it comes to the internal condition of oxygen conveyance systems where pressures are higher and the gas is more pure.

It is the responsibility of the operator, owner or other competent person to ensure the system remains in an oxygen service, (compatible and clean), state and that all components remain oxygen clean. Health and safety practice must include regular scheduled maintenance as part of the planned maintenance system.

Oxygen as a High-pressure Gas (99.7%)

Oxygen can be supplied in the following manner:

1. Liquid oxygen bulk tank as mentioned previously.
2. Liquid oxygen mini tank
3. High-pressure oxygen various size cylinders at pressures from 137 bar to 200 bar.

It was rumoured at the time of this writing that BOC in the UK were considering the introduction of 300 bar cylinders of oxygen to the market.

www.cumbria-hyperbaric.org
44 (0)79 3865 1086
Sunset View Aikton Cumbria
CA7 0JP
United Kingdom

Oxygen is an odourless, colourless and tasteless gas, it is slightly denser than air at equal temperatures. This is why we consider the settling of oxygen and the formation of gas pockets inside the chamber as discussed. Gaseous oxygen is non - corrosive in the absence of moisture. Oxygen is not flammable itself, but as discussed previously as it relates the fire triangle, it vigorously supports combustion. The higher the oxygen pressure and fraction in general, the greater the burning rate and potential for explosion.

The risks of operating a high-pressure oxygen system are at least 80% more than that of a low-pressure system. Oxygen concentrators and separators (PSA) are examples of low-pressure system often operating below the 14-bar hazard threshold, and even below the often-used lower threshold of 7 bars.

HP Air

The same general rules apply to high pressure air. Oxygen simply has greater safety considerations. These will be repeatedly discussed throughout training.

Examples of hazards in high-pressure oxygen systems:

- High temperatures resulting from improper compression or environmental conditions.
- Extremely high pressure over 200 bars is considered extreme risk factors
- System design and construction flaws resulting from improper hardware used for gas flow and improper use of, or selection of particulate filters.
- Improper or poor compression control and pressurisation rates resulting is higher than desired gas velocities through high pressure systems. – particle impingement and adiabatic compression hazards.
- High quality maintenance and cleanliness records are required for oxygen systems. This is to be constantly monitored by competent operators and supervisors.

Oxygen Fires / Explosions and Adiabatic Compression

The process of combustion requires all 3 components of the aforementioned fire triangle. A heat source, fuel and oxidiser.

By removing any of these three components fire cannot exist as previously discussed. In some cases, the system itself becomes the fuel and pipework, as well as fittings and hoses become that fuel. The oxygen is present of course, the only thing missing is a heat source or source of ignition. It is also worth noting that skin oils, hair and clothing also make fantastic sources of fuel. Various materials have different flash points, or spontaneous combustion temperatures, at which they will spontaneously burn in the presence of oxygen. If the temperature is right for a given material, fire will have no option but to exist in scientific terms. Under pressure these flash point temperatures are lowered considerably. In the case of paper, as previously mentioned, the flash point temperature is reduced by 25% at 6 atmospheres absolute even in just an air atmosphere. The presence of oxygen makes the chemical reaction we call fire exponentially faster. The higher the oxygen content the faster the burn.

Fuel Sources

In systems of proper design and construction the most likely source of fuel is hydrocarbon contamination. Condensed hydrocarbon vapour or residue from wiping of surfaces with contaminated cloths or similar oils such as excessive body oil are the most likely contamination sources as well as inappropriate lubricants and cleaning materials.

Latex glove powder, lint and fluff, and air from ventilation and drying equipment can all contain hydrocarbon and other contaminants. The system can also become compromised from working with or storing flammable substances in the same room as the chamber and oxygen equipment, and also from contaminated cylinders and supply equipment.

Fuel source and contamination source can also come from: metals, mild and stainless steel, brass if oil is present, non-oxygen compatible lubricants such as grease, sealing and thread tapes, incompatible O-rings, seals and valve seats such as soft Teflon and butyl rubber and just about anything not supplied with, and approved for use with the system. Remembering always that the system itself can also be the fuel.

Oxygen as an Oxidizer

As previously mentioned, oxygen is required for the chemical reaction we call combustion to occur. Also mentioned and repeated here, the higher the oxygen content the faster the rate of burn. Under pressure, these factors exponentially affect each other. They are force multipliers.

For example: a 6-meter length of stainless-steel pipe carrying 200 bar of oxygen under pressure can vaporise in less than a second. Oxygen pressure should be reduced at source. Low pressure systems for therapeutic chambers are highly recommended. Thus, eliminating any areas of high pressure and elevated risk in the system.

Ignition Sources besides an open flame

- Adiabatic Compression.
- High Velocity particle impingement.
- Localized frictional heating.
- Static spark or electrical arc.

Adiabatic Compression

One of the most common causes of ignition an oxygen system is adiabatic compression described previously. This is the heating resulting from rapid compression of a gas as explained by Charles Law and Gay Lussac’s Law. It is the reason quarter turn valves are not allowed on high pressure oxygen systems with the exception of emergency shutoff. When a valve is opened too quickly as is the case of quarter turn valves the gas rushes down the line until it comes to a barrier, i.e. another valve, at which point it compresses rapidly from the end of the line backward. This can cause excessive heat build-up.

The velocities of these gasses can reach the speed of sound and generate incredible heat when they are suddenly stopped or restricted inline. Similar can happen when shutting off a valve. Gas moving at high speed suddenly comes to a stop and back pressure builds too rapidly.

For this reason, blunt stem needle valves (slow opening) are the only recommended valves for use in a high pressure or low pressure (14 bar< oxygen system). They must also be opened slowly allowing a slow build-up of pressure within a system. Adiabatic compression can, and has vaporised pipework. The likelihood of fire or explosion is even higher in the presence of contaminants such as oil and grease, lint, fluff, airborne dust, skin oils, powders etc.

When oxygen is adiabatically compressed from 1 bar absolute at 20 degrees Celsius ambient temperature, the following maximum temperatures have been observed.

Pressure in bar	Final temperature Degrees Celsius
7	234
70	706
140	920
280	1181
350	1277

www.cumbria-hyperbaric.org
44 (0)79 3865 1086
Sunset View Aikton Cumbria
CA7 0JP
United Kingdom

Demonstrated here, even a system carrying 7 bars will generate incredible heat during adiabatic compression. Equally, it demonstrates just how much safer it is to transfer 7 bars of oxygen as opposed to say 280 or 350 bars. The likelihood of a flash at 234 deg.C is far less likely than at 1277 deg.C C.

!!!REDUCE OXYGEN PRESSURES AT SOURCE.!!!

For this reason, also never exceed a 6 to 1 ratio when boosting oxygen to avoid adiabatic compression

Flowing gas has a cooling effect and once gas flow is established the system will cool itself. Heat may return however by closing a valve suddenly and abruptly stopping the flow. Flowing gas can actually freeze a line if the velocities are high enough. Be cautious of very cold lines to avoid cryogenic burns. Risk of adiabatic compression is highest when initiating a system and pressurising it.

OPEN AND PRESSURISE ALL OXYGEN VALVES AND SYSTEMS SLOWLY!

Allow only competent personnel to operate, clean and maintain the equipment.

High Velocity Particle Impingement

Mentioned already, high velocity particles in the system can be another potential source of heat and ignition. Particles that may be present within the piping of an oxygen system are subject to sonic speeds and when they collide with the internal walls of pipes can cause sparking. The particle itself then also serves as a fuel source. Discussed previously under external environment, the need for appropriate particle filtration, (and oxygen cleaning), cannot be understated as particle impingement can trigger combustion. Copper based alloys are less likely to spark when compared with steel and stainless steel. They also conduct heat away from any localised heating more readily than other metals with serious fires being reported in systems containing high pressure oxygen piping made from stainless and aluminium.
Carbon steel, in the presence of oxygen, burns readily even at low pressure and should be avoided altogether.

Localised Friction Heating

Referred to as localised heating above frictional localised heating can also cause heat within and oxygen system leading to potential combustion. Sharp edges, corners and bends in pipework all present potential for frictional heating as gas flows through the system. Poorly designed pipe layout also give rise to contaminant collection at these points.

The design of oxygen system requires extensive knowledge and expertise. Design, construction and repair should be completed by competent personnel only and no repair should be attempted by anyone without the requisite knowledge. In many cases, external contracted service companies are desirable, since this mitigates responsibility for system maintenance and ensures technical staff are appropriately qualified to undertake repair and maintenance work.

No unqualified or untrained staff should be allowed to operate high pressure oxygen filling or distribution systems, Hydrocarbon contaminant build-up over time can lead to a major explosion. High pressure oxygen areas are limited access areas and should be monitored for any possible source of contamination.

Low pressure oxygen systems are far safer systems and present considerably lower risk than high pressure systems. Especially if they operate below 14 bars.

Oxygen Fire

Fire occurring in or near a hyperbaric environment or system, including diving systems, will be exponentially worsened in the presence of high concentration oxygen or enriched breathing mixes.

Some considerations to minimise risks include:

- Crane lifting of oxygen banks
- Pure oxygen lines to run in safe areas only away from possible ignition sources
- Ensuring compliance with handling procedure regarding oxygen by all staff, including any mixing and blending required and compliance with oxygen clean and compliant (oxygen service) rules and procedures.
- Storage, generation and transfer of oxygen in well ventilated areas.

General Oxygen Fire Response procedure

www.cumbria-hyperbaric.org
44 (0)79 3865 1086
Sunset View Aikton Cumbria
CA7 0JP
United Kingdom

In the event of an oxygen fire, as with other fires, but with rather more expedience, the following procedure is a guideline to an appropriate response.

Any fire in a hyperbaric unit where oxygen is present will be deemed to be a fire in an oxygen environment even if it is not a direct oxygen fire as it is highly likely to become one in short order and the same procedure will apply.

This will vary from unit to unit and specific accommodations must be considered when deciding on a fire action depending on the physical characteristics of the building and layout of the operation including escape routes.

- Sound fire alarm immediately.
- Isolate or remove oxygen supply.
- Attack fire, where safe to do so, with appropriate firefighting equipment.
- Make cool any partly combusted materials and cool other heat retaining materials to prevent re-occurrence. E.g.: Steel hulls, pipes, panels etc.
- Notify person in charge - Supervisor, medical director, manager, LSS etc.
- Report to be sent to safety department as to cause/outbreak and actions taken.
- Comply with any and all RIDDOR requirements as discussed previously.
- Activate emergency services early in cases of serious or larger fires as required.

Oxygen is primarily safe and is a common gas used in many applications including welding, burning, home medical use and so on without incidence. Without all three components of the fire triangle fire or explosion simply isn't possible. Technically, it is quite safe to bubble oxygen through a bucket of petrol. Without an ignition source it will not ignite. Not that anyone should do that, since we don't know when and how an ignition source may suddenly present itself such as static spark. When used safely oxygen is unlikely to present a problem. It can however be extremely dangerous if used randomly and with flammable materials in the presence of ignition or heat sources. Fire and explosion could result from improper use and handling.

www.cumbria-hyperbaric.org
44 (0)79 3865 1086
Sunset View Aikton Cumbria
CA7 0JP
United Kingdom

Always remember the triangle of fire. By removing any of the required three conditions for fire to exist it simply cannot happen.

- Combustible materials
- Oxidant
- Ignition source

Gases exceeding 21% O_2 burn faster.

NOTE some materials which do not burn in air may burn in Oxygen or Oxygen rich atmospheres.

Do not use oxygen in confined spaces without ventilation.

NOTE Liquid Oxygen can seep through cracks and migrate.

Liquid oxygen and very cold gaseous oxygen is heavier than air and can settle. Previously mentioned is the propensity for settled gas to form “pockets” of pure gas that don’t dissipate immediately into the atmosphere. (Chamber atmosphere or otherwise). This creates localised risk of a flash in items such as clothing that may trap gas or indeed hair, beards and other porous substances. Pockets don’t always mean large pockets; even very small pockets can trigger ignition in the presence of static spark.

These materials can become saturated and require a time to off-gas following treatments. Activities such as smoking or being near open flame should be limited for 60 minutes following treatment.

Oxygen fires are not easily extinguished and plenty of water must be used to draw heat out of the burning material. Constant flow if necessary, must be applied and re-applied to any re-occurrences that may occur.

www.cumbria-hyperbaric.org
44 (0)79 3865 1086
Sunset View Aikton Cumbria
CA7 0JP
United Kingdom

The following materials are rated according to the level of danger they present in the presence of oxygen.

Fire Hazards - Highly Dangerous

- Flammable liquids, pastes, solids, creams, fuel blocks etc. Including items containing flammable liquid
- Flammable gases
- Oils and substances manufactured from oils and containing high concentrations of oil
- Tarry substances
- All grease except silicone grease (halocarbon)
- Porous flammable material (traps micro pockets of oxygen)
- Faulty oxygen equipment (oxy/acetylene) feeding back may cause explosion on re-ignition

Unsafe

- Wood
- Asphalt
- Paint (chambers must be painted with flash proof paint only)
- Clothing
- Cotton waste
- Fine metals and carbon
- Organic solvents which all burn vigorously
- Stainless steel
- Carbon steel
- Aluminium
-

Mostly Safe

- PTFE (if 62 clean - but can ignite if not)
- Nonferrous metals
- "Monel" (a nickel-copper alloy with high tensile strength and resistance to corrosion

SAFE (Normally always)

- Copper
- Copper alloys (bronze - brass - nickel, Monel)
- Nonferrous nickel alloys

www.cumbria-hyperbaric.org
44 (0)79 3865 1086
Sunset View Aikton Cumbria
CA7 0JP
United Kingdom

- Pure asbestos
- Untreated fibre glass

Ignition Sources

- Lighted cigarettes/pipes/naked lights
- Welding torches
- Sparks (grinders)
- Molten metal (flame cutting)
- Electrical faults (spark source)
- Compression of O2 molecules – adiabatic compression
- Impact of materials and high velocity particle impingement

Misuse

Oxygen is not to be used as a substitute for air or other inert gas under any circumstances. Examples of misuse are –

- Starting engines
- Pneumatic tools
- Pressurising oil reservoirs
- Paint spraying
- Filling tyres
- Purging vessels and pipelines prior to inspection or working
- Shrink fitting
- Burner air supplies
- Enrichment of breathing atmospheres (non-diving)

General Points to Remember

- Properly trained handlers
- Do not drop or rough handle
- Comply with regulations
- Do no remove or deface I.D. labels
- Have contingency plan and emergency procedures established
- Above 25% O2 is a rich mixture

Notes for Diving Systems

Built in Breathing Systems, also called BIBS requires backup oxygen supplies for each diver “at depth”. While compressed in a chamber, occupants are considered to be at depth, and often the pressure will be referred to as a certain depth rather than using a pressure unit.

There must be 4 hours of breathing gas reserve for each diver at storage or treatment depth. This back-up supply is generally bottom mix or treatment gas depending on the situation. Calculation is based on 20 l/min or 1.2m3/h breathing rate for occupants at rest.

For example:

An occupant at 12 meters treatment depth will require the following backup volume for non-elective treatments. I.e. Emergency recompression treatments which cannot be stopped as elective treatments can.

12 meters = 2,2 ATA, per 1 occupant
1 x 4 x 1,2 x 2.2 = **10,56 M3 treatment gas.**

Accordingly, for diving chambers operating under Diving or other occupational legislation the following stored gas requirements come into effect.

Chamber oxygen reserve (inshore 40 m3)

There must be enough oxygen reserve to carry out a complete decompression from storage depth.

Offshore 90m3.

Chamber treatment gas for mixed gas and saturation diving

Treatment gases are defined in the Decompression Sickness Treatment Procedures

The minimum quantities required are:

Oxygen : 90m3

Heliox 50/50 : 90m3

Heliox 20/80 : 180m3

Heliox 10/90 : 270m3

www.cumbria-hyperbaric.org
44 (0)79 3865 1086
Sunset View Aikton Cumbria
CA7 0JP
United Kingdom

Pure gas diving quality

It is recommended where possible, to ensure the supply of breathing gas meets the national minimum standard for the operational area or the following table whichever is the safer and more stringent requirement. This does not necessarily apply to reclaimed gas.

Suppliers pure gas diving quality specifications

Diving gas	Diving quality
Oxygen	>99.5%
Nitrogen	>99.8%
Helium	>99.995%

Air compressed on site is previously discussed under environmental control and contaminates.

19 **Oxygen generated on site for elective therapy may be oxygen 93 or 97. Delivered, medical grade oxygen purchased from a supplier is usually around 99.7%. Welding oxygen often comes in at 99.9%. In the UK clinical therapy may not be carried out on welding oxygen. There is no reasonable reason for this other than the ability to charge huge amounts more for it.**

Gas Analysis and Control Reminder

- **The supervisor, or diving supervisor in charge, when receiving or producing gas is responsible for ensuring the quality of that gas. This extends to the gasman, LST, LSS and so on. Gasses must be analysed before being put online and the contents of storage bags and other storage vessels remains the sole responsibility of the supervisor in charge. Oxygen separators and concentrators should have built in analysis which would form part of the daily checks. For diving purity is more important a previously mentioned when compared with elective HBOT treatments.**

- **Equipment designed to be used on the surface usually gives the readings in percentage or parts per million. However, safety or operational limits may be expressed in term of partial pressures. Therefore, most of the analyser's readings must be converted into partial pressures, which is the relevant unit in hyperbaric conditions. It is advisable to have a familiarity with working in different modes of analysis. A thorough understanding of the primary gas laws is advisable.**

- **The only exception to the rule is the Dräger sampling tubes which are calibrated for surface, but also can be used under pressure. In that case, correction must be applied to the reading.**

OXYGEN CLEANING FOR INTEREST ONLY

Companies differ in their choice of solvent however these days most companies, at least land based operations, will have a contractor who conducts oxygen cleaning off site. It's not rocket science though and it can be done if a dedicated work area is used. Oxygen cleaning areas must be limited access areas and must be well away from contamination sources. Staff conducting oxygen cleaning must be specifically trained for it, it is beyond the scope if this training and operational material. The notes below are for interest only to provide a wider understanding of oxygen requirements. They do not qualify trainees to perform oxygen cleaning. Dive technician courses are available which specialise in this.

One of the most common solvents for oxygen cleaning in use by companies is Biox. Not as powerful as some other it can lead to the need for extra cleaning. In the UK Biox is supplied by Divex under the umbrella of James Fisher and Sons who also include The National Hyperbaric Centre among their holdings. It is also supplied by Submarine Products and Manufacturing in Lancashire.

Use of a black light will highlight any remaining hydrocarbons and help to determine if an item is properly cleaned.

Cleaning Agents Caution - COSHH Rules Apply

- Do not breathe vapours
- Close container after use
- Use in a well-ventilated area or with a ventilation hood or extractor
- Wash exposed areas of your body thoroughly after use
- Avoid contact with eyes, skin and clothing

Do not dispose of in drain contain and contact waste disposal firm.

There are many commercial brands available on the market all used for cleaning to oxygen service specification.

EnSolv® is recognized and used internationally as a preferred cleaning agent for oxygen systems by many of the leading compressed gas supply companies. NASA has used EnSolv® to clean rocket boosters prior to filling them with highly reactive and explosive hydrogen peroxide fuel. The preferred “drop in” substitute for Trichloroethylene and other chlorinated solvents used for oxygen cleaning. EnSolv® solvents have been used in the oxygen systems industry for many years to clean tubing, components, cylinders and any other parts that may come into contact with liquid or gaseous oxygen

Vertrel™ specialty fluids are used to clean oxygen service parts, which is more critical than most other cleaning applications. Particles or residue left behind may hinder the operation of valves, sensors, or controls, causing excessive friction that may lead to potential ignition or explosion.
Vertel is residue free according to the manufacturers.

AGENT

The below information dates back some years and refers to a product called AGENT. It remains in its original form from a diving textbook, although little information is available about the product, some of the procedures would share similarities with other cleaning “drop-in” solvents. AGENT contained trichloroethylene and has been banned worldwide. It is a known carcinogen and cancer causer, however at one time was the most powerful oxygen cleaning solution available.

When using AGENT for oxygen cleaning always have two containers: one for first rinse and one for second rinse. The second rinse or final rinse must always be in new clean AGENT. The problem with all solvents for oxygen cleaning, is knowing when the solvent has reached its carrying capacity. Once the solvent is saturated with oils, it spreads the excess oil, an even coat on everything it subsequently comes into contact with.

To clean 20 new bailout cylinders will take approximately 25 litres of AGENT. To check for oil a fluorescent black light can be used as oil shows up as fluorescent green or white.

- Store corrosive AGENT in reagent bottles not metallic containers as it corrodes.
- Be careful of some AGENT when cleaning Aluminium as it is corrosive.
- Remember do not discard in the drain. Arrange for hazardous material agents to collect from you or deliver to him and keep receipt or disposal

DIVING CYLINDER OXYGEN CLEANING

USED CYLINDERS: Visual inspection must be performed. If not perfect, then clean/ tumble conventionally. Hydrostatic test if required, then re-V.I.P. If cylinder is clean, then treat as new.

NEW CYLINDERS: Clean cylinder neck threads with a toothbrush using AGENT. Only use AGENT if the neck has been lubricated with a known oxygen grease.

FIRST RINSE: Pour 700 ml of AGENT into cylinder and roll the cylinder for several minutes. Empty the cylinder, ensuring all of the neck threads are rinsed. The solvent from this rinse should be poured through a paper filter / funnel into a beaker labelled ‘Rinse # 1.’

SECOND RINSE: Repeat the first rinse procedure using 350ml of new solvent. The solvent should be poured through paper filter / funnel into a beaker and labelled 'Rinse #2.'

DRYING THE CYLINDER: Once the cylinder has been rinsed twice it should be inverted for 24-36 hours, AGENT vapours are heavier than air and will run out of the cylinder neck. Cylinders must be dry as AGENT reacts with moisture. Dry with pure Nitrogen or Oxygen.

CYLINDER VALVE O_2 CLEANING

USED VALVES: Completely disassemble valve and service as per normal cleaning first, and then treat as a new valve.

NEW VALVES: Completely disassemble valve, wipe or swab off any visible lubricant. Submerge valve and parts in AGENT for 4 minutes with swishing motion or place parts and valve in ultrasonic cleaner for 1 minute. Remove parts, etc and allow to dry, or dry with double filtered air. Assemble valve wearing O_2 clean gloves and lubricate moving parts with O_2 compatible grease, eg. Halocarbon or Christo-lube. Replace all O-rings with Viton O-rings these are oxygen compatible, (try purchase green or brown Viton O-rings for easy ID.) Lubricate cylinder valve Viton O-ring and threads with Halocarbon grease as well. **Do not handle the above with bare hands.**

O_2 CLEANING of HOSES and SUBMERSIBLE PRESSURE GAUGES

Gauges and hose fittings allow for heat build-up via adiabatic compression. Clean swivels and H.P spools to remove silicone. AGENT swirl and swish the gauge end and clean the gauge module inlet with a lint free cloth. Blow it clean and lint free prior to reassemble.

Clean hose interior with AGENT quickly do not soak, blow dry asap with pure nitrogen or oxygen. Beware AGENT can and will damage hoses if used incorrectly.

Mark clean gauges and hoses for oxygen clean.

O_2 CLEANING OF REGULATORS

1. Disassemble regulator and service & clean as per normal.
2. Clean all excess silicone grease etc with swabs.
3. Clean all parts in AGENT and dry with double filtered air if needed.
4. Replace all O-rings with Viton O-rings and lubricate with O_2 compatible grease, eg Halocarbon grease.
5. Use O_2 clean gloves for the above assembly.

NOTE: For all equipment and cleaning which includes cylinders, valves, gauges, hoses and regulators the person is required to have a manufacturer factory approved course service technician certificate. Without this no servicing or cleaning is to take place.

OXYGEN SERVICE MARKINGS

All equipment which oxygen has been cleaned will, and must, be marked as such. In the absence of appropriate marking and labelling assume it is not oxygen clean. There is nothing that cannot be marked or labelled in some way shape or form.

Cylinders colour coding as above is to be observed to avoid accidental mishandling leading to accidents.

In the event oxygen service equipment becomes contaminate the labelling or marking must be removed. Equipment may only be relabelled after re-cleaning has been carried out.

A high level of responsibility is required when working with oxygen

Sample Simple Oxygen Service Sticker

Can be stuck on hose or rope

OXYGEN SERVICE

Date:

Name:

Signed:

Remove sticker if contaminated

Wrap around hose bottom section

www.cumbria-hyperbaric.org
44 (0)79 3865 1086
Sunset View Aikton Cumbria
CA7 0JP
United Kingdom