AEROSPACE INFORMATION REPORT

AIR825™/6	REV. A
Issued 2004-01 Revised 2015-12 Reaffirmed 2020-07 Superseding AS825/6	

(R) On-Board Oxygen Generating Systems (Molecular Sieve)

RATIONALE

The revision of this SAE Aerospace Information Report, which is intended to provide comprehensive reference and background information pertaining to molecular sieve on-board oxygen generating systems as part of an overall document set to address oxygen equipment for aircraft, some of the background and safety and reliability and physical effects will be reviewed and adapted to the latest knowledge and applications.

FOREWORD

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

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

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1. SCOPE

The information provided in AIR825/6 applies to On Board Oxygen Generating Systems (OBOGS) - Molecular Sieve, that utilize the ability of molecular sieve materials by using Pressure Swing Adsorption Process (PSA) to separate and concentrate oxygen in the product gas from the surrounding air, respectively air provided by any compressor or by the aircraft engine (so called: Bleed Air), and to provide this oxygen enriched air or product gas as supplemental oxygen for breathing gas supply of crew and passengers onboard aircraft. The distribution system and the provided oxygen concentration have to fulfill the respective airworthiness regulations.

Equipment using this technology is to provide supplemental oxygen for breathing gas supply of crew and passengers onboard aircraft, the suitable breathing gas oxygen partial pressure or oxygen concentration requirements are specified in AIR825/2 and the oxygen purity requirements in AS8010.

NOTE: OBOGS has never been certified for commercial aircraft. The 14 CFR/CS 25 as well as 14 CFR 121/Commission Regulation (EU) N° 965/2012, amended need to be reviewed and if necessary amended prior to introduction of OBOGS. Alternatively, such certification will likely incorporate various special conditions that address differences in performance between OBOGS and conventional systems.

These systems are intended for:

a. The on-line breathing gas supply to directly account for the normal oxygen usage of crew and passengers in terms of:

    1. Supplemental oxygen for part or all of an emergency descent

    2. Supplemental oxygen for first aid

    3. Therapeutic oxygen

b. The replenishment of the aircraft gaseous oxygen system storage cylinders to account for the normal oxygen usage of crew and passengers and system leakage

c. A combination of the above.

The possible applicability and benefit of incorporation of OBOGS-Molecular Sieve into non-military aircraft is being considered by the representatives of Civil Aviation. The intended aim of AIR825/6 is to provide a fundamental description of the function of existing OBOGS-Molecular Sieve systems with a related reference to the type of oxygen standards which would merit a review.

2. REFERENCES

2.1 Applicable Documents

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

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR825 Oxygen Equipment for Aircraft

ARP4754A Guidelines for Development of Civil Aircraft and Systems

ARP4761 Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment

AIR6036 Passenger Hypoxia Protection Utilizing Oxygen Enriched Gas Mixtures

AS8010 Aviator's Breathing Oxygen Purity Standard

AS8025 Passenger Oxygen Mask

2.2 Related Publications

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

2.2.1 STANAG Publications

Available from NATO Headquarters, Boulevard Leopold III, 1110 Brussels, Belgium.

STANAG 3865 Physiological requirements for aircraft molecular sieve oxygen concentrating systems

2.2.2 Applicable Regulations and Standards

2.2.2.1 Airworthiness Requirements

14CFR (or FAR), part 25: Airworthiness Standards, Transport Category Airplanes, Federal Aviation Administration, text available on the American Administration Web site: http://ecfr.gpoaccess.gov, title 14 (Aeronautics and Space), part 25.

NOTE: 14CFR (14th Code of Federal Regulations), often replaced by FAR (Federal Aviation Regulations).

CS-25: Certification Specifications for Large Airplanes. Text available on the European Aviation Safety Agency Web site (EASA): www.easa.europa.eu.

2.2.2.2 Operational Requirements

14CFR, part 121: Operating Requirements, Domestic, flag, and supplemental operations, Federal Aviation Administration.

Commission Regulation (EU) N° 965/2012: www.easa.europa.eu

EU – OPS: European Union (EU) regulations specifying minimum safety and related procedures for commercial passenger and cargo fixed-wing aviation.

2.3 Abbreviations and Acronyms

ETOPS Extended-range Twin-engine Operational Performance Standards

MSOC Molecular Sieve Oxygen Concentrator

MSOCS Molecular Sieve Oxygen Concentrating System

MSOGS Molecular Sieve Oxygen Generating System

OBOG On-Board Oxygen Generator

OBOGS On-Board Oxygen Generating System. In common usage, one may encounter language such as “OBOGS system” although the “s” implies “system” in any case.

OBOES On-Board Oxygen Enrichment System

PSA Pressure Swing Adsorption

RPSA Rapid Pressure Swing Adsorption, sometimes also used for a PSA with an extreme short process time

2.4 Definitions

ADSORBATE: Something that is adsorbed; e.g., nitrogen gathered on a surface of an adsorbent by adsorption.

ADSORBENT: A material, a Zeolite or other solid that can hold or condense; e.g., nitrogen molecules on its surface by adsorption.

ADSORPTION: The taking up of the molecules from a gas; e.g., nitrogen from bleed air on the surface of another substance or adsorbent.

ADSORPTION ISOTHERM: The relation between solute concentrations; e.g., nitrogen in the solute phase and the solute partial pressure or concentration in the fluid phase, while temperature conditions remain constant.

ADSORPTION SYSTEM: A process; e.g., PSA that is used to purify a substance; e.g., oxygen enrichment of bleed air, by using the physical bonding that takes place on the surface of a solid or adsorbent to selectively absorb impurities; e.g., nitrogen from it.

BLEED AIR: Compressed air tapped from an aircraft turbine.

CYCLE TIME: Period of time comprising the adsorption and desorption process.

DESORPTION: The releasing of the molecules of a gas off the surface of another substance or adsorbent.

ETOPS: Extended-range Twin-engine Operational Performance Standards

ISOTHERM: Amount of adsorbed gas in a molecular sieve as a function of its partial pressure.

MOLECULAR SIEVE: Solid used as adsorbent in separating oxygen and nitrogen.

MOLECULAR SIEVE BED: A canister, cartridge or container filled with conditioned molecular sieve, forming a bed to be used for an adsorption system.

ON-LINE: OBOG with oxygen enriched product gas directly supplied for breathing purpose.

ON-TOP: OBOG with oxygen enriched product gas compressed into high pressure cylinders for replenishment of the aircraft gaseous oxygen storage cylinders; same as Top-up OBOG.

PLENUM: Product gas buffer downstream of an OBOG.

PRODUCT GAS: Oxygen enriched air at the outlet of an OBOG with a concentration greater than ambient air.

SIEVE BED: See Molecular sieve bed.

TOP-UP: OBOG with product gas compressed into high pressure cylinders for replenishment of the aircraft gaseous oxygen storage cylinders; same as On-top OBOG.

ZEOLITE: Molecular sieve type, material comprising lattice structures of silicon oxide with aluminum oxide, electrically compensated by alkali metal.

3. MOLECULAR SIEVE TECHNOLOGY/PRINCIPLE FUNCTION

3.1 Molecular Sieve Technology

In this context molecular sieve technology is used to separate nitrogen from air to produce an oxygen enriched product gas to be provided through a distribution system to aircraft occupants. Zeolite molecular sieve material is available on the market. For a detailed description see Appendix A.

3.1.1 Pressure Swing Adsorption (PSA)

This cyclic PSA process is used for air separation, where it utilizes the preferential adsorption of nitrogen over oxygen on an adsorbent such as Zeolite. The process involves the interaction of adsorption, dispersion and pressure dynamics in the Molecular Sieve Bed.

In order to receive a continuous product gas flow, at least two molecular sieve beds must be used. By using more than two beds a smoother flow can be reached.

For the PSA process a first container filled with molecular sieve is pressurized with air. During this adsorption phase mainly nitrogen is adsorbed and oxygen and argon pass through. Therefore at the outlet opposite to the inlet a product gas with increased oxygen concentration can be tapped until all adsorption sites are occupied, at which point nitrogen would break through the first sieve bed without being adsorbed. Obviously now the first molecular sieve has to be regenerated and the previously adsorbed nitrogen to be vented outside. This is realized by decreasing the pressure in the first sieve bed to ambient, thus desorbing the nitrogen. The desorption phase is normally slower than the adsorption phase. However the rate of desorption can be accelerated by purging the first sieve bed with oxygen produced by a second, fresh sieve bed, switched on at the same time. Usually the cycle time for pressurization and depressurization of a sieve bed is a few seconds (less than 20 seconds). The amount of nitrogen adsorbed in preference to oxygen by a specific grade of molecular sieve depends on the sieve type and the adsorption isotherm, published by the manufacturer.

At very short cycle times of about 5 seconds the process is sometimes also called RPSA (Rapid Pressure Swing Adsorption). Even at this process duration the thermodynamic equilibrium depicted by the adsorption isotherm is reached.

For a typical aircraft application the system can be outlined as follows, see Figure 1: The compressed air is guided by a cycle valve to Bed 1, while Bed 2 is relieved to ambient. The pressure in Bed 1 will increase. If the pressure upstream the check valve is equal or higher than the pressure of the plenum the check valve will open and the product gas will flow through the product gas outlet. In parallel, a significant amount of product gas is directed to Bed 2 for purging. When Bed 1 is saturated, typical after some seconds, the cycle valve is activated and Bed 1 is relieved to ambient while Bed 2 is pressurized. The product gas pressure dynamically alternates due to the differential pressure conditions upon the switching between the Molecular Sieve beds.

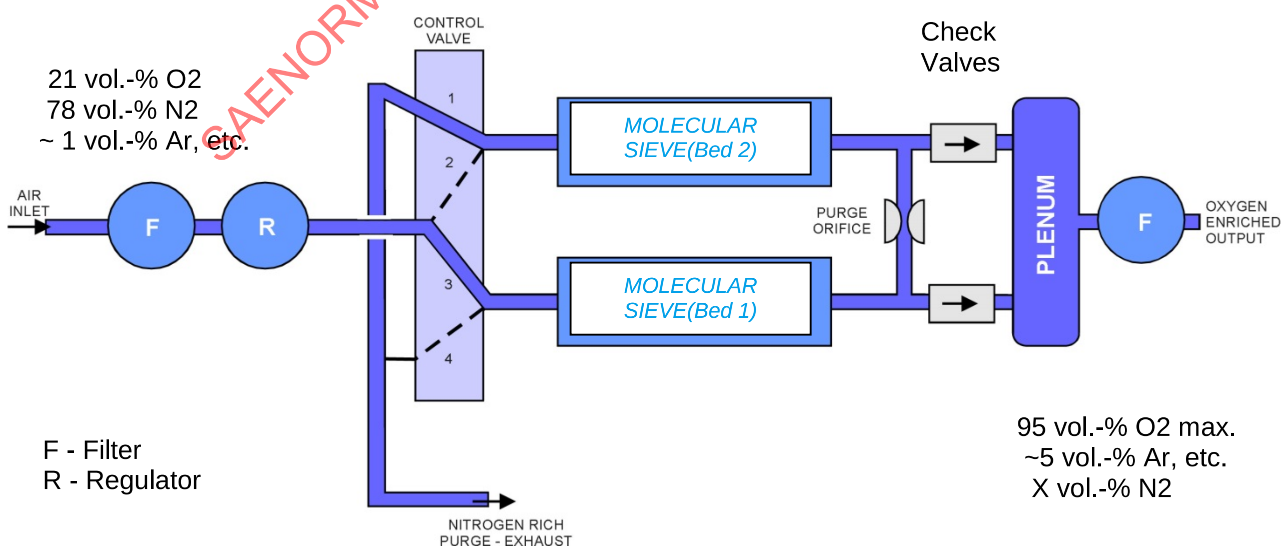


Figure 1 - PSA system schematic; e.g., two molecular sieve beds

If more than two molecular sieve containers are used the amount of product gas for purging can be reduced, since the desorption time may be increased, also providing less pressure swing within the product gas.

Practically speaking, production of a concentration less than 95% is preferred, as this increases the efficiency per unit weight of equipment. For a detailed description of the PSA Performance Characteristic, see Appendix A.

3.1.2 Maximum Oxygen Concentration and Purity Standard

With PSA Technology using Zeolite Molecular Sieves the concentration is limited to a maximum of 95 vol. - % oxygen and 5 vol. - % argon, since a separation of oxygen and argon is not possible. A further increase of oxygen concentration requires the combination of Zeolite and carbon molecular sieve. For a detailed description see Appendix A.

For the purity standard of OBOG product gas refer to AS8010 or the applicable STANAG.

3.2 OBOG-Molecular Sieve Systems

An OBOGS is a system with at least the following main components:

- Air compressor or other air source
- Heat exchanger (not further described in this document, because often part of the aircraft system)
- Water separator and particle filter
- Pressure reducer
- OBOG (molecular sieve oxygen concentrator including cycle valves, molecular sieve beds, plenum, check valves, orifice)
- Oxygen sensor or analyzer
- Electronic control unit
- Back-up oxygen, including selector valve
- Regulator to supply oxygen to the mask
- Mask

3.2.1 On-line OBOGS - Molecular Sieve

Normally bleed air 150 to 400 kPag is considered for supplying an on-line OBOGS. If no bleed air is available from the engines an appropriate air compressor or other air supply source must be used. The product gas pressure depends on the bleed air pressure and the design related pressure losses through the OBOGS.

The required bleed air consumption is much higher than the product gas rate and finally depends on the number of crew and passengers to be supplied with breathing gas. As a guideline about 500 to 700 lpm_{NTPD} bleed air is required to generate about 50 lpm_{NTPD} 80 vol. - % oxygen enriched product gas, depending on details of the particular OBOG design.

Remark: The OBOGS components must be suitably designed for a product gas flow and oxygen concentration sufficient to fulfill the applicable FAA/EASA regulation for the supplemental oxygen supply of aircraft occupants. For any operational conditions requiring higher oxygen concentrations a backup oxygen supply with 100 vol. - % oxygen is required. For a suitable oxygen supply refer to the applicable slash (/) documents within the AIR825 series.

It should be evaluated if a flow sensor would improve the design and reliability of the OBOGS.

For sufficient equipment health monitoring (state of the equipment) and control of the OBOG product gas according to the specified values, a built-in test should include at minimum an oxygen sensor or switch, the output pressure sensor or switch and an electronic control unit.

A general on-line OBOGS is described in Figure 2. The OBOG supplies the mask directly with oxygen. The oxygen sensor measures the oxygen concentration. The electronic control unit takes care of the OBOG function. If the oxygen concentration falls below the required level the selector valve closes the OBOGS supply and opens the back-up supply, reversing this process the concentration is again sufficiently high.

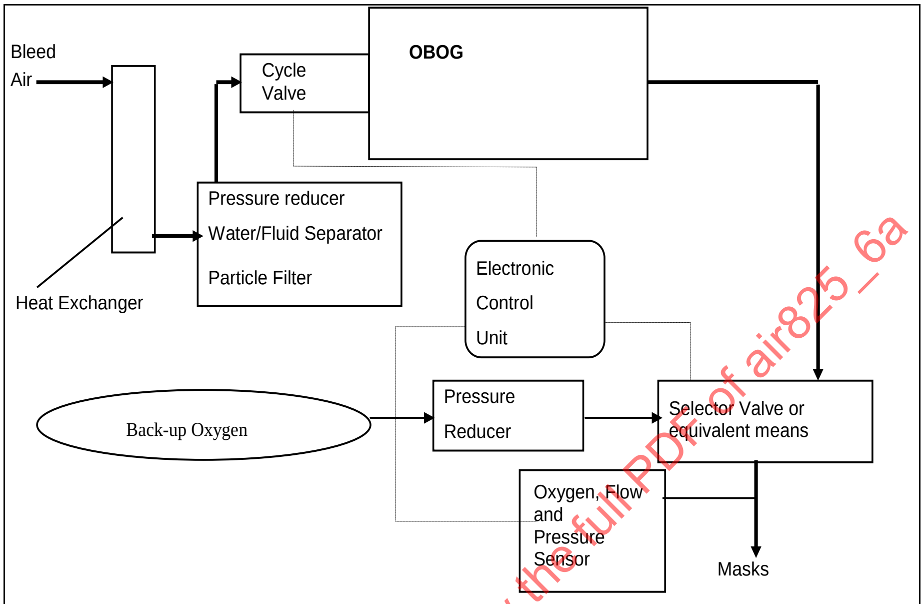


Figure 2 - On-line OBOGS-molecular sieve schematic

3.2.2 Replenishment OBOGS-Molecular Sieve

Remark: This section discusses an approach to refilling gas cylinders with gas produced by the OBOGS equipment. With respect to the actual certification requirements however, due to the current interpretation of the 14 CFR/CS25, oxygen cylinders must be refilled with essentially 100 vol. - % oxygen. Other technologies (ceramics for instance) could permit to replenish oxygen cylinders with >99.5% oxygen. These technologies are described in AIR825/7.

In an On-TOP or Top-up OBOGS, a molecular sieve system keeps the pressure in the oxygen cylinders installed in the aircraft above the minimum specified dispatch pressure. In a cockpit system normal oxygen consumption includes the pre-flight mask check, system leakage and operational usage of oxygen by crew members. In a passenger supply system the normal oxygen consumption is caused by system leakage. If not otherwise specified and depending on the individual aircraft operational condition and applicable FAA/EASA regulation and its interpretation, an OBOG generated product gas flow in the order of about 1 to 2 lpm_{NTPD} 93 vol. - % oxygen could be considered as sufficient. If less than 100% oxygen is stored and delivered, the dispensing device must be designed to operate with such a supply.

For sufficient monitoring and control of the OBOG product gas according to the specified values, a built-in test should include at minimum an oxygen sensor or switch, the output pressure sensor or switch and an electronic control unit.

A product gas valve and a high pressure oxygen compressor or intensifier are required to achieve the oxygen cylinder replenishment to the specified filling pressure.

For the filling procedure with the specified product gas the electronic control unit activates and controls the OBOG, the oxygen compressor and product gas valve. However, the use of an oxygen compressor needs particular attention regarding safety precautions.

A general Top-up OBOGS is described in Figure 3.

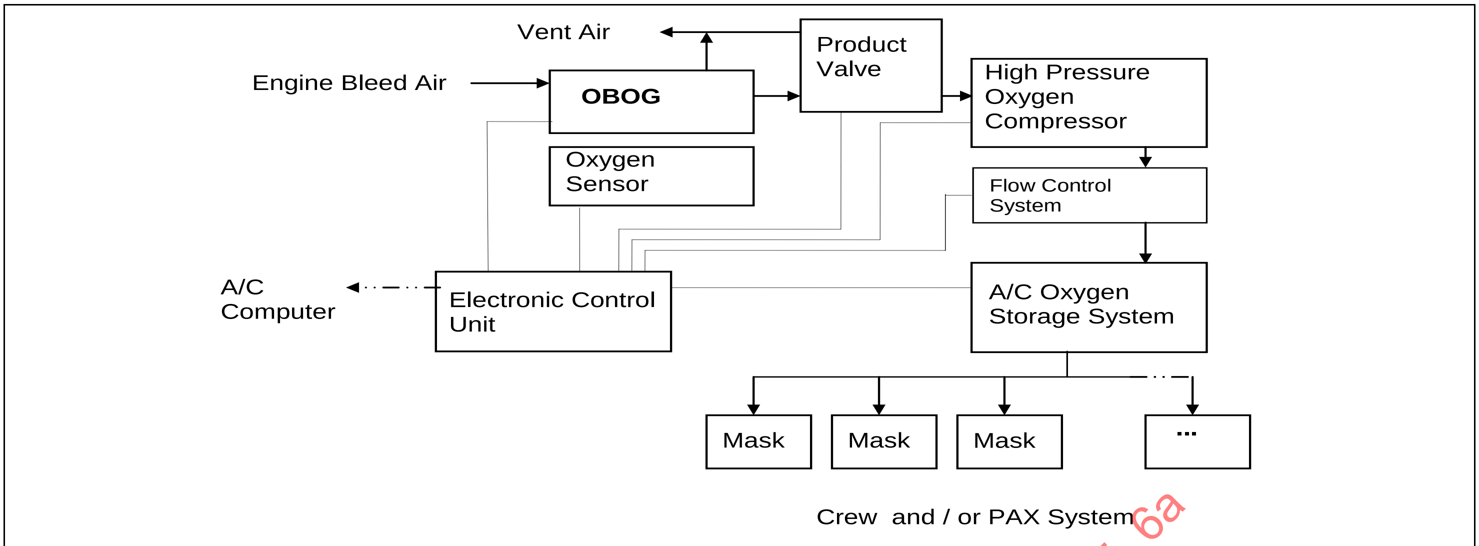


Figure 3 - Replenishment OBOGS-molecular sieve schematic

3.2.3 Oxygen Purity and Concentration, OBOG-Molecular Sieve

The OBOG oxygen purity should fulfill the requirements of AS8010 or the applicable STANAG. The bleed air which is supplied from the engines or from a compressor to the OBOGS might be contaminated. Aircraft manufacturers and compressor manufacturers might be able to provide a list of bleed air contaminants. The OBOGS needs an integrated particle filter and a water and fluid separator at the OBOG inlet which have to be suitably designed to remove the required particle sizes and fluids which are intended to be filtered. The molecular sieve concentrator is an active and reversible filter for all gases. See further explanations in Appendix A. The OBOGS has to be designed to fulfill the required product gas qualities.

The percent of oxygen or the oxygen concentration, which must be produced by the supply source or at the OBOGS outlet for a given application, depends in part on the design of the dispensing unit. It is necessary to achieve a suitably inspired partial pressure, but one can conceive of supplying the already diluted OBOGS product gas as an alternative to dilute it in the mask.

The subsequent qualification and certification program must be closely coordinated with the responsible airworthiness authorities, so that the 14 CFR/CS 25 as well as 14 CFR 121/Commission Regulation (EU) N° 965/2012, amended need to be reviewed and if necessary amended prior to introduction of OBOGS or suitably special conditions need to be approved.

3.3 Reliability and Safety issues in OBOGS Design, Lessons Learned incl. Military Aircraft

For the OBOGS Systems Engineering (see ARP4754A and ARP4761) the development should address the reliability and safety issues. The bleed air supply is typically provided by the aircraft pneumatic supply system. Depending on the system reliability evaluation, of the OBOGS and interfaced aircraft system, the necessary system development means must be foreseen in order to fulfill the required failure probabilities; e.g., a back-up oxygen supply could be required. Special effort should be spent on addressing the OBOGS single point failure concern. For example, if the engines or pneumatic supply fail on an OBOGS equipped aircraft; pressurized air will not be provided to the OBOG. The result is that oxygen will not be available to the crew member. The solution is a system design with a continuous oxygen availability of the OBOGS, permitting a continuous operation even in the event that some pneumatic supply components might fail. The worst case scenarios would be that oxygen must be available in the event of failures in the pneumatic supply when flying over the ocean, high mountain terrain or during extended operations (ETOPS). If the engine, the environmental control system, the OBOGS, or the electric power that OBOG is dependent on might fail, an adequate emergency oxygen supply must be available to the occupants to make a safe descent to an altitude where oxygen is not required. The time needed is dependent on the aircraft operation, geographic position and mission and can vary from 10 to 30 minutes for a safe descent or longer if a combat aircraft is in a hostile region where immediate descent is not a safe option. If the engine is restarted, the OBOGS will continue to operate. The OBOGS has need for electrical power, pneumatic bleed air supply or compressed air supply. So there must be an acceptable degree of reliability and redundancy. Measures need to be taken to adjust the system reliability of the OBOGS. The system supplier must work closely with the aircraft manufacturer and the certification authorities to establish an acceptable safety standard.

Another concern arising from experience in operational use is the need for an expanded Backup Oxygen System (back-up oxygen).

Another source of oxygen supply is needed for the following conditions when the aircraft is operating above 10,000 feet:

- Loss of bleed air source to the OBOGS from aircraft pneumatic supply failure or interrupt.
- Loss of bleed air source to the OBOGS from loss of engine(s).
- Loss of electrical supply that powers the OBOGS.
- Failure of OBOGS concentrator to properly operate.

In the past people logically concluded that another source of oxygen supply normally called backup oxygen is required, as been provided on past aircraft in several ways. High pressure vessels have been provided that must be replenished from ground servicing (Rafale, Harrier, B-1B, B-2, F-14, F16, and F-18). Replenishing the oxygen supply from the ground was a logistics burden as well as an increased fire hazard. For that reason efforts were put into a backup oxygen supply replenished from the OBOGS concentrator. The YA-7F program used a concentrator mounted plenum and another low pressure cylinder remotely located that was filled from the OBOGS concentrator during normal operation. Since the source pressure of air enriched with oxygen was low, the amount of backup oxygen supply provided was too limited for the volume and weight of equipment needed. The F-15E program decided to expand the concept with the use of an air pressure driven pump to pressurize the backup air enriched with oxygen supply. This method was considered to be very good as the logistics burden required from ground servicing and the fire hazards were virtually eliminated. The only new problem was that this concentrator device became heavier and more expensive. Designers then decided that for OBOGS to be competitive with contemporary Oxygen Systems it has to be less expensive on a life cycle cost basis and comparable in weight and size. Now the trend is to develop a small, inexpensive and lightweight OBOGS concentrator.

The issues involving the emergency and backup oxygen supply have to be examined very carefully. It is necessary to determine the probability of situations occurring that require another source of oxygen supply, other than the OBOGS concentrator, if e.g., oxygen is needed to be used as emergency oxygen even after the backup bottle is expended.

Even if an independent source of oxygen supply is provided for pneumatic supply failure problems, how much backup oxygen is enough? When flying over the ocean, it is conceivable that several hours of oxygen may not be enough. The best option is to provide some backup capability in the electrical power and pneumatic supply so that the breathing system may continue to function indefinitely, but at reduced capability.

Still another issue is the loss of pressure and air supply interruptions related to the pneumatic supply. Provided the time period is not in excess of a few minutes this interrupt could be handled with a plenum that is at the same pressure as the OBOGS concentrator outlet. Concepts that would increase the pressure will once again increase system weight, volume, fire and explosion hazards and costs the same as with the separate high pressure backup oxygen equipment. System reliability may also be reduced.

Another issue that has been discussed at length has been the need to have the backup oxygen supply activated automatically. The pilot will be busy with other aircraft systems and may forget to activate the oxygen supply or fail to recognize that it is needed. This could result in the crew member's loss of consciousness, leading to his or her death or loss of control. However, automatic activation of the backup supply adds complexity and could thus present reliability and maintainability concerns. These concerns could indicate an advantage to the approach of using OBOGS for passengers and retaining the conventional gaseous system for the crew.

Measures need to be taken in a joint system analysis and investigation team, including the equipment and system supplier, aircraft manufacturer and the airworthiness authorities to improve the reliability of the OBOGS to an acceptable level to be able to be certified.

For any new OBOGS design concept proposed, Failure Analysis for single point failure relative to real operating missions needs to be thoroughly evaluated. The overall system failure probability must be demonstrated to be less than the specified reliability, for failure conditions that result in severe consequences per the ARP4761 safety assessment process.

4. OBOG-MOLECULAR SIEVE SYSTEM COMPONENTS

4.1 Bleed Air Supply

The performance of the PSA process strongly depends on the optimum temperature of the bleed air and molecular sieve. Therefore special attention must be taken for the pressurized bleed air and/or compressor air to be conditioned to prevent unacceptable heating of the molecular sieve.

In addition, it must be assured by the use of a water separator and particle filter to limit the operational aircraft bleed air contamination such that absolutely no liquid water reaches the molecular sieve. Failure to do so would result in irreversible water contamination, which could quickly destroy the molecular sieve. Water is a real threat for the sieves, as the exothermic reaction with liquid water turns the molecular sieve material into dust.

Water vapor is not as critical, since it is adsorbed during the adsorption phase and is removed in the desorption phase. However the performance of the OBOG is decreased, if the adsorption sites are occupied by water and not available for separation of oxygen and nitrogen. This has to be taken into account in the OBOG design.

4.2 Oxygen Concentrator

The oxygen concentrator, often called OBOG or MSOC, consists of 2 or more molecular sieve containers. Mainly 2 and 3 bed modules are used for aircraft application. The key parameter for the molecular sieve container is the fixation of the molecular pellets or grains to prevent erosion and dust, unintended channeling and pressure drop.

4.3 Oxygen Sensor

Unless it is demonstrated that a given OBOG unit gave sufficiently consistent output, a safety-critical feature of any aircraft-mounted breathing system embodying an oxygen concentrator, is an oxygen sensor with sufficient accuracy and long term stability to continuously monitor the oxygen concentration being delivered to the aircrew, to provide warning of any inadequacy of oxygen supply and to provide for the specified reliability.

Oxygen sensors have been developed and employed for this purpose, and they range in type from one using a solid state fluidic amplifier through another using a Zirconia element to another which utilizes the paramagnetic properties of oxygen.

The common aim of such oxygen sensor is a high degree of sensitivity to variations either of OBOGS output oxygen concentration or of oxygen partial pressure, and a quick response to such variations. The electrical output signals from these sensors can be employed either to control the OBOGS process (e.g., a variation of the cyclic frequency of the PSA), to shut down the OBOG or simply to initiate a warning, when appropriate. Depending on the role of the oxygen sensor an adequate accuracy and stability have to be established.

Existing sensors receive their sample, of oxygen-rich gas from a sample point immediately downstream of the OBOG outlet. The reference gas provided for the sensor for automatic recalibration is normally taken from a bleed air sample point immediately upstream of the OBOG.

A built-in test facility can be incorporated in the form of a ‘press to test’ button, having the effect of subjecting the sensor inlet to a supply of ambient air and causing it to flag a ‘failure’ signal. Restoration of the OBOG product oxygen supply to the sensor inlet results in the cancellation of the ‘failure’ signal to verify the satisfactory performance of the sensor sub-system.

4.4 Demand Oxygen Regulators and Pressure Demand Oxygen Regulators

The purpose of these types of regulators is exactly the same when employed with an on-board oxygen generating system in an aircraft as for a system whose breathing source is high pressure gaseous, or liquid oxygen.

Their role is to govern the delivery of breathable oxygen in terms of pressure, flow rate and oxygen concentration (if deemed to be a diluter regulator) in accordance with user breathing demands and cabin altitude.

Having in principle the same design as for other than OBOGS applications, an adaptation of the performance schedule may be required for regulators employed with OBOG. They are e.g., to operate satisfactorily with oxygen inlet pressures which can be as low as 10 psig, the values of entrained air (when on dilution) and pressure breathing may have to be modified to reflect the fact that the regulator is receiving less than 100 vol. - % oxygen maximum at its inlet; e.g., even less than 95 vol. - % depending on the breathing physiologic requirements of the respective cabin altitude.

OBOGS related oxygen regulators have been developed for man mounted, seat mounted and console mounted applications in military aircraft in which these operational considerations have been addressed appropriately.

4.5 Continuous Flow Dispensing Equipment

Where the physiological protection provided for an aircraft's occupants is by means of devices which result in the delivery of a continuous flow of supplementary oxygen to the user's breathing tract the same type of equipment as is in service with existing gaseous oxygen (100 vol. - % O_2) systems may be employed. However, TSO-C64b/ETSO-C64a, requires that a passenger mask must meet the MPS qualification and documentation requirements in AS8025A, assuming an inlet oxygen concentration of 99.5 vol. - %. For an intended combination with OBOGS provisions for alternate or equivalent means of compliance to the criteria in the MPS (Minimum Performance Standard) of this TSO could be used and must be demonstrated. In order to invoke these provisions, it must be shown that the equipment maintains an equivalent level of safety (ELOS). Application is necessary for a deviation under 14 CFR § 21.609, before submitting the data package. For the ELOS demonstration the AIR 6036 - Passenger Hypoxia Protection Utilizing Oxygen Enriched Breathing Gas Mixtures in Civil Aviation – might be very helpful.

4.6 Oxygen Masks

No special provision is required from an oxygen mask to be used with OBOGS, as a change from those already in service, with the exception of those issues discussed in 4.4 and 4.5.

5. NOTES

5.1 Revision Indicator

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

PREPARED BY SAE COMMITTEE A-10, AIRCRAFT OXYGEN EQUIPMENT

APPENDIX A - SCIENTIFIC BACKGROUND

A.1 MOLECULAR SIEVE TYPES, GENERAL MATERIAL CHARACTERISTICS

Molecular Sieve material consists of porous adsorbent, with a lattice pore size similar to the molecules to be adsorbed; e.g., nitrogen. Only those gaseous molecules with a diameter less than the pore diameter have access to the adsorption site.

Due to the interaction between the adsorbate and adsorbent, it is possible that the negative loaded electron cloud of surface close to adsorbate molecules is displaced relatively to the positive loaded molecule core, forming a dipole or quadrupole molecule. This interaction and the existing energy is known as the van der Waals energy, attracting these molecules to the inner surface of the molecular sieve. The necessary energy to support this physical adsorption process is also called activation energy. In the case of air, nitrogen is more readily adsorbed, compared to oxygen and argon.

The specific amount of adsorbed nitrogen per mass of molecular sieve depends on the pressure provided to the sieve beds, following a particular adsorption isotherm of a considered molecular sieve.

The most typical operational failure is due to the influence of liquid water contained in the bleed air. In any case a water separator should be included in an adsorption system. In the ranking of molecules concerning their adsorption capability, water is the most preferred. Adsorption of water vapor is still reversible in the process. If the adsorption sites are covered with water vapor, no nitrogen can be adsorbed. In order to compensate for this lost nitrogen adsorption capacity this leads to additional amount of required molecular sieve, increased sieve bed design or additional sieve beds. Liquid water will be strongly chemically adsorbed. In this case the adsorption process is mostly influenced by Coulomb-Energy. Depending on the amount of liquid water, it could finally destroy the molecular sieve.

In a PSA the adsorption is mostly physical rather than chemical. This relatively weak interaction of the adsorbed molecules with the surface allows for a reversible process. Due to the reversibility a continuous operation of the molecular sieves becomes possible.

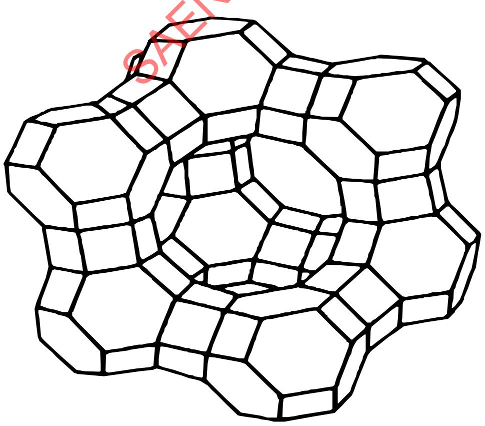
For the separation of oxygen two main categories of molecular sieve materials are available:

A.1.1 Zeolite Molecular Sieve

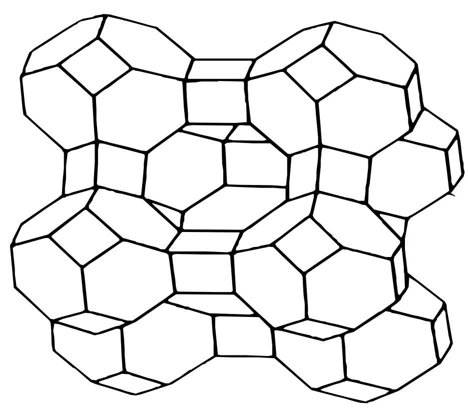
For the concentration of oxygen from air, Zeolite materials frequently are used. They consist of large arrays of aluminum oxide and silicon oxide units which form complicated lattice structures. These contain the cations of calcium, sodium, or potassium to balance the electronic charge. They also contain Li-ions.

These materials are typically formed into pellets using clay as a binder.

Zeolite minerals form two general structures, as shown in Figure A1. The materials are called either X Type or A Type Zeolites, depending on which of these structures is present.



Zeolite Type X



Zeolite Type A

Figure A1 - Zeolite molecular sieve structures and adsorption lattice sites

Molecular sieves may be treated so as to have a different Li-ion exchange rate. The molecular sieve adsorption efficiency is higher with higher Li-ion rates, however, the water sensitivity also increases. For this reason the molecular sieve beds must be exclusively assembled in dry climate rooms and the operation must exclude conditions outside the operating specifications concerning the bleed air water content.

When PSA is used for oxygen enrichment of bleed air, the physical bonding that takes place on the surface of a Zeolite, nitrogen is adsorbed in preference to oxygen and argon. Bleed air consists of 21 vol. - % oxygen, 78 vol. - % nitrogen and 1 vol. - % inert gases, mainly argon. The adsorbed amount of nitrogen is proportional with increasing partial pressure of the nitrogen, as shown by principle isotherms in Figure A2. The separation of the nitrogen from air results in an increased oxygen concentration within the product gas. For PSA cycle times of more than 3 seconds the difference of the relative rate of adsorption and equilibrium condition is negligible.

However, a separation of oxygen and argon is not possible with these types of Zeolite materials because they display nearly the same adsorption rates of oxygen and argon. So, the maximum oxygen concentration within the product gas is 95 vol. - % O_2, because the mass of initially 1 vol. - % argon of the bleed air is concentrated to maximum 5 vol. - % argon.

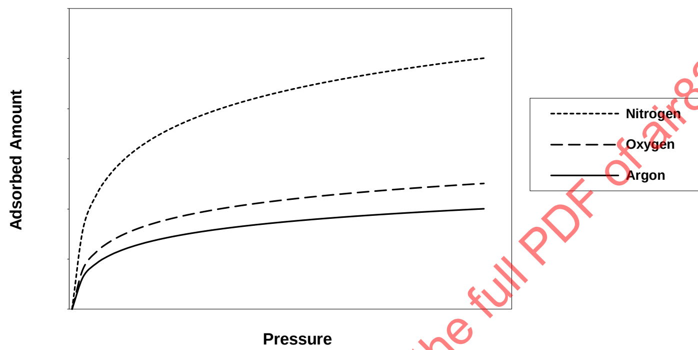


Figure A2 - Schematically adsorption curve of zeolite molecular sieve

A.1.2 Carbon Molecular Sieve

Carbon molecular sieve have pores similar to Zeolite molecular sieve, allowing the separation of a specific molecule type. It cannot be used in a PSA to enrich oxygen in the product gas, because the ratio of adsorption of nitrogen over oxygen is very low. Chemically treated or impregnated carbon molecular sieves can be used in a PSA to produce about 99.9 vol. - % oxygen from an oxygen-argon mixture in combination with an upstream PSA-Zeolite - OBOGS.

This can be achieved by taking the 95 vol. - % oxygen enriched product gas of the Zeolite - OBOGS and supplying it to the carbon molecular sieve - OBOG. The argon is then removed, because the adsorption time of argon over oxygen is lower. So, more argon is adsorbed and oxygen is then enriched in the product gas.

So far many units have run for thousands of hours with a two-stage system delivering >99.5% for the replenishment of cylinders (example: on Aircraft carriers) demonstrating the technology. For an aircraft application this is normally not acceptable due to high equipment and system weight and, therefore, is not presently contemplated for any commercial aircraft application.