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Military Aircraft Oxygen System

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Abstract: *This paper provides information on the design of an On Board Oxygen Generating System (OBOGS) for military aircrafts. It explains the physiological oxygen requirements of the human body in both a normal environment and in a hypoxic environment. It also includes an overview of gaseous oxygen system and liquid oxygen systems. A basic understanding of how each system operates is then specifically addressed in its own titled section. The charts, tables, and schematics provide a specific example of the oxygen system design and its performance. A comprehensive overview of the theoretical oxygen requirements of the human body at altitude is also provided. A detailed list of specifications and standards applicable to aircraft oxygen systems is included.*

Keywords *- GOX, hypoxia, life support system, liquid oxygen, LOX, OBOGS,* PPO_2

I. INTRODUCTION

At ground level human breathe air with a 21% oxygen concentration in order to oxygenate the bloodstream and, hence sustain life. At higher altitude it becomes more difficult for humans to take in oxygen as Partial Pressure of Oxygen (PPO_2), the pressure exerted by the oxygen equipment of air, decreases in direct proportion to air pressure with increasing altitude. The life support system of an aircraft will provide physiologically acceptable breathing gas/oxygen to pilots/ transported personnel on board. The oxygen equipment of life support system will maintain adequate supply of oxygen to the tissues of the body in case of reduction in barometric pressure consequent upon ascent to altitude, i.e. to prevent hypoxia[3].

In addition to the requirements to maintain a suitable level of oxygen concentration at altitude, life support systems also need to protect pilots against acceleration (G). In military aircrafts, the oxygen system supply shall be appropriate for the normal and emergency intended mission requirements of the aircraft. Supply types include gaseous oxygen (GOX), liquid oxygen (LOX) and on-board oxygen generating systems (OBOGS)[4]. This paper provides an over view of gaseous oxygen system, liquid oxygen system and design of an OBOGS. LOX and GOX are explained in section 3 & 4 of this paper while design of OBOGS is covered in section 5.

II. PHYSIOLOGICAL OXYGEN REQUIREMENTS

The lungs receive oxygen from the atmosphere which then diffuses into the blood. The blood, at the same time, releases carbon dioxide into the lungs to be exhaled. The partial pressure of oxygen forces oxygen through the air sacs and into the blood. The partial pressure of oxygen is approximately 20% of the total atmospheric pressure. If at sea level, this would be about 152 mmHg of pressure and 102 mmHg would be available in the lungs. The variation of PPO_2 with respect to altitudes is given in Fig.1.

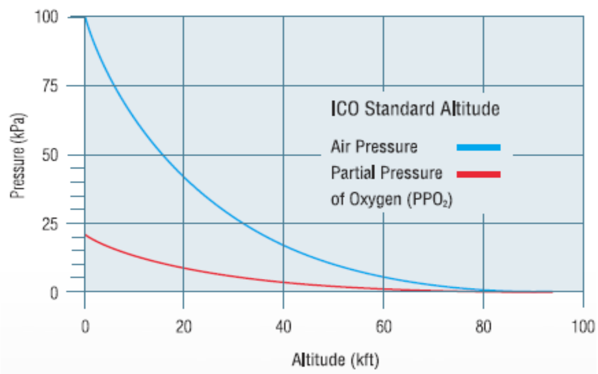

Fig.1. Variation of air pressure & PPO_2 with altitudes

When a breath is drawn into the lungs, one would expect the partial pressure of oxygen to remain at 152 mmHg. However, since the gas exchange is going on continuously in the lungs, they contain other gases that exert a relatively constant pressure which dilutes the expected 152 mmHg of oxygen. Water vapour is the largest and represents 47 mmHg and carbon dioxide represents 40 mmHg. These gases tend to displace a part of the oxygen as it reaches lung level. Therefore, these gases reduce the partial pressure of the oxygen at the air sac level down to 102 mmHg. Table 1 details composition of lung gas at various altitudes and supply conditions [3].

The life support system maintains the PPO2 by increasing the oxygen concentration between the minimum and maximum values as specified in Fig.4. In order to meet these requirements, regulator, a component of breathing system, regulates the breathing functions namely gas flow and its pressure. The flow requirement could vary from as little as 6 lpm to 60 lpm under some circumstances with a peak flow of 200 lpm.

Table 1. Composition of lung gas at various altitudes

CASE	ALTITUDE (ft)	CONDITION	ATMOSPHERIC PRESSURE (mbar)	COMPOSITION OF LUNG GAS (mbar)			
				O_2	N_2	CO_2	H_2O
1	Sea level	Breathing air	1013	137	758	53	62
2	10, 000	Breathing air	695	72	506	53	62
3	20, 000	Breathing air	465	46	316	40	62
4	33, 000	100% O_2	253	137	-	53	62
5	40, 000	100% O_2	187	72	-	53	62
6	50, 000	100% O_2 at ambient pressure	115	13	-	40	62
7	50, 000	100% O_2 at 54 mbar above ambient	115	72	-	53	62

Table 2. Oxygen requirements at various altitudes

Altitude levels	Oxygen requirements
Sea level – 10, 000 ft	Normal air can be breathed
10, 000 ft – 30, 000 ft	Progressive oxygen enrichment is required
30, 000 ft – 40, 000 ft	100% oxygen must be breathed
Above 40, 000 ft	100% oxygen must breathed at increased pressure above ambient

III. GASEOUS AND LIQUID OXYGEN SYSTEM

As mentioned earlier, the supply source shall be gaseous oxygen, liquid oxygen or OBOGS. Each system has its own merits. But comparing the first two the later has more advantages. In gaseous oxygen system [1], the first generation system, oxygen is stored at 1800 – 2200 psi in high pressure containers. Oxygen is fed to the occupants through NRV, pipe lines, fittings and the regulator after first being reduced to 70 - 90 psi. The major disadvantage of this system is the weight and bulk of the storage containers which may become an issue in smaller aircraft. The cylinders are charged (replenished) by means of a charging point on the side of the aircraft, to which an external source of GOX is connected.

To allow greater oxygen storage, second generation systems store oxygen in a cryogenic dewarat -183^{o} degC. The LOX is then converted into vapour by passing through a heat exchanger, where temperature ox oxygen is increased to nearly cabin temperature. Then the gaseous oxygen fed to the regulator and to the masks. Storage in liquid form allows approximately five times as much oxygen oxygen to be contained in a given volume when compared to GOX. The LOX container, however, has to be removed from the aircraft to be refilled.

IV. LIMITATIONS OF GOX AND LOX

The amount of oxygen that can be carried on the aircraft limits both mission duration and flexibility when GOX and LOX are used. In an aircraft with in-flight refuelling capability, oxygen content determines the mission duration rather than fuel level. Additionally LOX system requires considerable infrastructure or plant at the bases to replenish the LOX converter, which prevents deployment of aircraft to the unprepared bases [6].

The LOX depletion is another limitation which requires frequent replenishing which further increases the maintenance cost of the system. Less than one eighth of liquid oxygen produced in plant reaches the aircraft. LOX is potentially at risk from contamination by toxic materials, most commonly oxides of nitrogen, carbon monoxide, hydrogen sulphide, trichloro ethylene and hydrocarbons. The following table compares these systems with OBOGS.

Table 3. Comparison of GOX, LOX and OBOGS

SL. NO.	GASEOUS SYSTEM	LOX SYSTEM	OBOGS
1	OCCUPIES MORE SPACE	< 86% OF GASEOUS	SAME AS LOX
2	WEIGHT IS MORE	< 68% OF GASEOUS	SAME AS LOX
3	STORED AT HIGH PRESSURE, BURST DANGER	CHANCE OF FIRE HAZARD AND FROST BITE.	NO STORAGE, NO DANGER
4	NO LEAKAGE	LEAKAGE DUE TO EVOPORATION	NOT APPLICABLE
5	REGULAR MAINTENANCE	REGULAR MAINTENANCE	MAINTENANCE FREE
6	NEEDS REPLENISHMENT	NEEDS REPLENISHMENT	UNLIMITED USAGE

V. DESIGN OF OBOGS

Due to the limitations present in GOX and LOX, the third generation system, On-Board Oxygen Generation system is developed. The breathable gas is produced on board by the use of Molecular Sieve Oxygen Generator (MSOG). MSOG take ambient air and separates oxygen from inert gases. The material used as molecular sieve is zeolite, which filters nitrogen molecules when air passed through it. In OBOGS this device is called as concentrator [5]. The crystalline zeolites are of tetrahedral in structures linked by sodium or calcium to form cages or cavities. These cages have affinity to adsorb molecules. Since nitrogen molecules are bigger than oxygen and other molecules, they are filtered by molecular sieve.

In concentrator, oxygen and nitrogen are separated by virtue of the fact that nitrogen is hold strongly within the sieve cage than oxygen. By using pressure swing technique, where by molecular sieve bed is alternatively pressurised and de-pressurised and complete separation can be achieved. In reverse cycle, the bed is de-pressurised and nitrogen molecules are purged out and bed becomes usable for next cycle. The product gas of the concentrator contains a maximum of about 90 to 95 % of oxygen and remaining argon. Oxygen concentrator of this type usually consist of two or more beds of molecular sieve [5] through each of which compressed air is passed. This compressed air is taken from the environmental control system of the aircraft which takes the bleed from engine compressor. A typical two bed system is shown in Fig. 3.

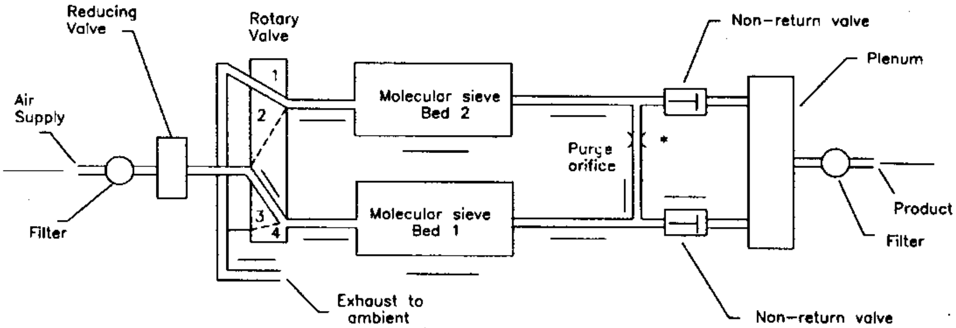

Fig.3 Typical two bed molecular sieve system

When one bed is de-pressurised and purged of its nitrogen the other bed is in pressurisation cycle producing oxygen enriched breathing gas. In next cycle the roles of the beds are reversed hence the supply is continuous. The output of OBOGS is measured to determine the level of PPO_2 and this value is then converted into an oxygen concentration in conjunction with the output from a cabin pressure sensor. The main disadvantage of this system is the the failure of engine bleed air which results in failure of OBOGS. The system can operate in temperature range of -40^o C to 80^{o}C and pressure supply from 1 to 8 bar. The Table.4 below shows the flow rate and concentration levels requirements from OBOGS. The OBOGS meets all the steady state requirements of inspired gas as specified in Fig.4.

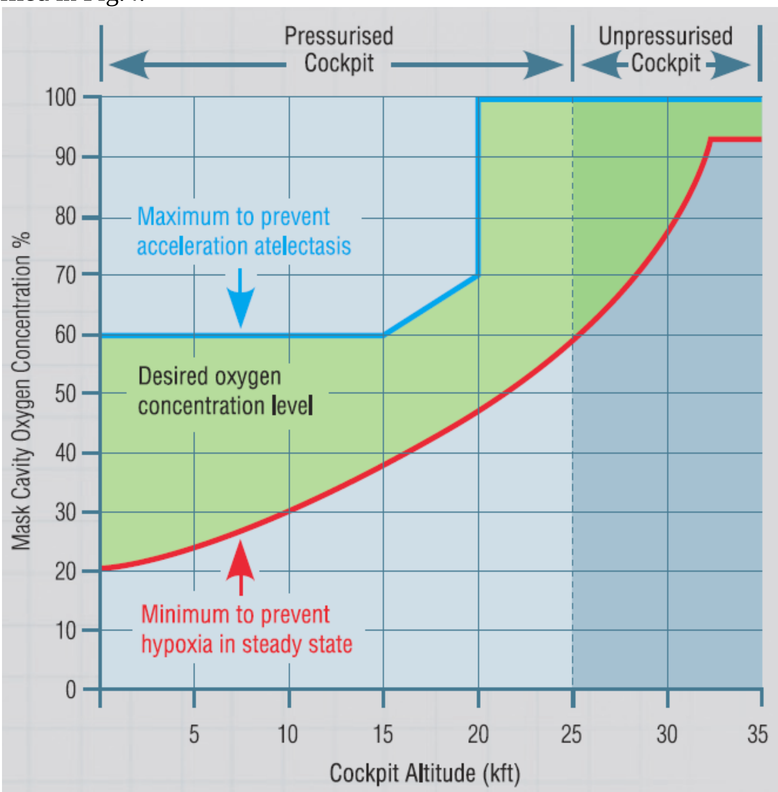

Fig.4. Variation of oxygen concentration with altitudes

Table 5. Oxygen concentration requirements

Inlet Pressure to OBOGS (bar.g)	Flow output from OBOGS (LPM, NTP)	O_2Concentration level (%)
1.5	5	90
	16	62
	28	41
	51	30
	70	26
2.5	5	92
	16	73
	28	51
	51	39
	70	30
5.0	5	92
	16	73
	28	51
	51	39
	70	30

VI. CONCLUSION

The OBOGS reduces the dependence for heavy, bulky oxygen bottles that add more stress and weight to the aircraft, as well as eliminate the risks associated with the handling and use of LOX. High mission duration is also attained with the use of maintenance free OBOGS. The main disadvantage is the purity of product gas, which is not 100%. However, the future aircraft oxygen system design relies on the development of OBOGS especially for light aircrafts or high endurance aircrafts.

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