

### Introduction

Mishaps On Board an Aircraft are unfortunately often catastrophic because of the mass of highly flammable fuel vapors transported.

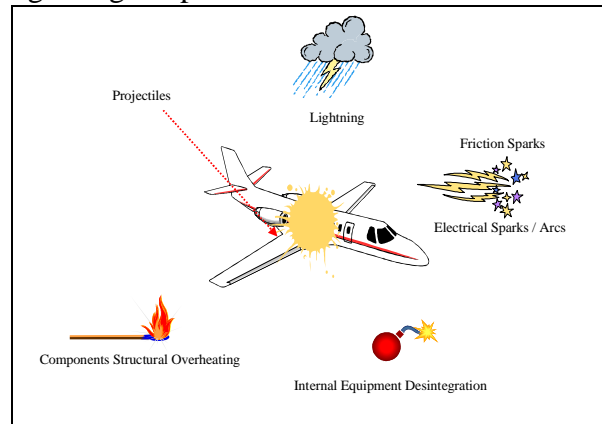
Empiric studies consisting of shooting fuel tanks or scientific studies were performed for a better understanding of fuel tank explosion and for enhancing their protection. Both kinds of studies pointed out that fuel tanks shall be inerted to decrease the oxygen content under 9% when protected by nitrogen to avoid any risk of explosive reaction in the tank.

### Thermochemical Reminder of Inerting.

In a reaction of combustion, typically fuel vapors and air, the oxidizing agent (here oxygen) reacts together with the component to be oxidized (here hydrocarbons). Those components will need energy to enable the ignition, and will release energy during the combustion. Yet, in this example, as air is composed of 21% of oxygen, 1% argon and 78% nitrogen, nitrogen will be present in the thermal balance of this reaction. As Oxygen and hydrocarbons will have to be heated to react, nitrogen will also absorb energy. Since nitrogen is not modified during the combustion and does not affect the oxydo reduction equation, the reactive components have no effect upon nitrogen: nitrogen is “**inert**” and will not release energy. Thus nitrogen only absorbs energy and makes it more difficult for the reaction to happen.

### Ignition Source.

The major threat will depend on the kind of aircraft. Military will fear gunfire bullets while airliner will be concerned by lightning or spark.

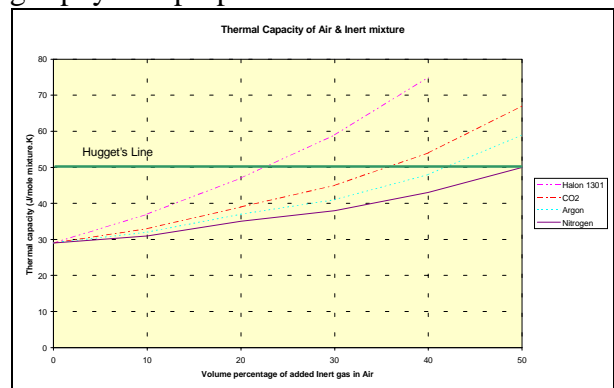


*Summary of Ignition Sources*

### Huggett's law.

For a given ignition source and given conditions (total pressure), one can assess the minimum thermal capacity of the gas mixture for the mixture not to explode: this minimum thermal capacity is called Huggett's point.

The thermal capacity of a given gas will depend on the characteristics of the bonds between the atoms that constitute the gas molecule. Thus each gas will have its own thermal capacity, and the quantity of inert gas to add to the gas mixture to reach the Huggett's point will depend on the inert gas physical properties.



*Thermal capacity of inert mixing*

### **Inert gas candidates.**

On the chart located here above, the authors have drawn the thermal capacity of a gas mixture as a function of inert gas added (for example 10 in abscissa means that in the considered mixture, one has 90% of air and 10% of inert gas).

The family of Halon have the best thermal capacity. Hence they used to be considered as the most efficient fire suppressor agent. Yet governments fear Halon may have a destructive effect upon the ozone layer; the production of Halon is now forbidden.

The other candidates to be studied are Argon, Carbon Dioxide and Nitrogen. The Aircraft Fuel Tank Protection point of view is exposed in the next section.

### **Stored Inert Candidate for Aircraft Fuel Tank Protection.**

- Argon: air is constituted of about 1% of Argon. Thus Argon production is quite expensive.
- Carbon Dioxide: the quantity of CO<sub>2</sub> needed to reach the Huggett's point is lower than the quantity of Nitrogen, but the mass of CO<sub>2</sub> required is heavier than the required mass of Nitrogen. Furthermore, CO<sub>2</sub> has a corrosive action, and may account for electrostatic discharges.
- Nitrogen: can be stored either in a gaseous or liquid phase.

### **On Board preference in the Aeronautical Industry.**

The goal to be achieved is different between commercial and military aeronautical industry. For commercial aeronautical business, the goal is to reduce the time on ground and the maintenance and the induced costs. Thus capacity to refill is a disadvantage, because it means time spent on ground.

Military need more and more the capacity to be projected abroad, far away from the home base. Gas may be hard to be found on the theatre of operations, except for nitrogen, since Air Liquide has developed Nitrogen ground cart generator.



*Nitrogen Ground Cart Generator*

Furthermore, whatever the storage capacity of gas on board, this will limit the duration of flight.

For those exposed reasons the trend in aeronautical business is to prefer On Board Generation that allows a higher flexibility and autonomy, as already proved by the choice of On Board Oxygen Generating System (OBOGS).

### **On Board Inert Gas Generated Candidate for Aircraft Fuel Tank Protection.**

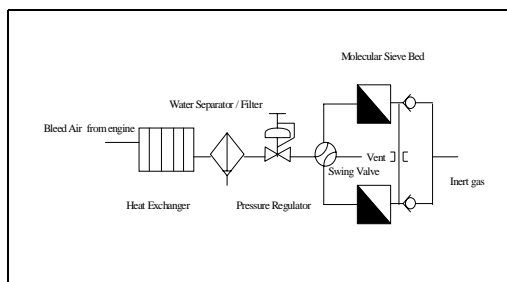
A gas enriched in Carbon Dioxide could be found On Board by using exhaust gases of the engine. This would mean powerful heat exchangers, water separators. CO<sub>2</sub> even when produced On Board has still the same problems of electrostatic and corrosive effects.

Since air is composed of 78% of Nitrogen, this gas is "cheap" to obtain. Today, two technologies have been developed for On Board Inert Gas Generating System (OBIGGS): Pressure Swing Adsorption (PSA) and Polymeric Membrane. Both technologies will be presented in the next section.

**OBIGGS based upon Pressure Swing Adsorption (PSA) technology.**

Pressure swing adsorption units for air and gas separation mostly rely on molecular sieves. These are microporous solids with molecular size pores that can be used to adsorb and desorb gases. This occurs mostly because of the different forces of attraction between different gas molecules and the micropores, but also because of the different size of the gas molecules the adsorption differs between gases and can be used as the basis for their separation.

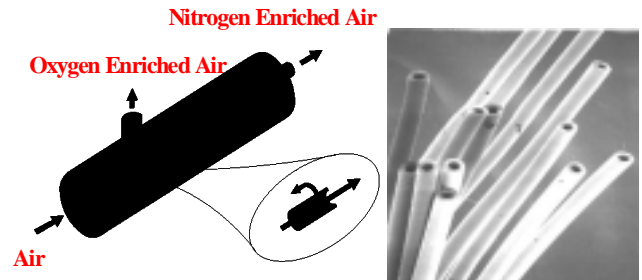
Pressure-swing adsorption (PSA) is a simple concept in which gas is admitted to an adsorber bed at high pressure then desorbed at a lower pressure. There is either a difference in adsorption rate or a difference in the static amount of adsorption. Hence the two gases present in the input mixture are differentially adsorbed; one is concentrated in the bed whilst the other is released in the depressurisation stream. After the depressurisation stream has been flowing for a preset time to the outlet the depressurisation is diverted to waste until it is at near atmospheric pressure, releasing the adsorbate, perhaps with the aid of a purge stream.



*PSA OBIGGS Schematic*

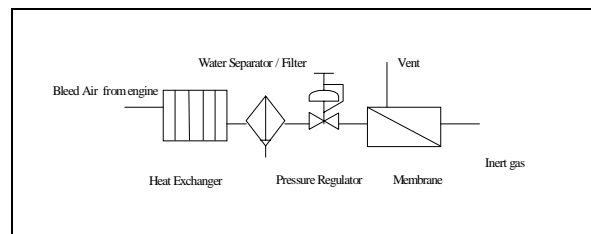
**OBIGGS based upon Membrane technology.**

The air separator based upon Membrane is constituted of hundred thousands of polymeric hollow fibers. Each fiber is as large as a hair. Oxygen diffuses through the wall of the fiber faster than Nitrogen. This diffusion will depend on the pressures inside the fiber and outside the fiber.

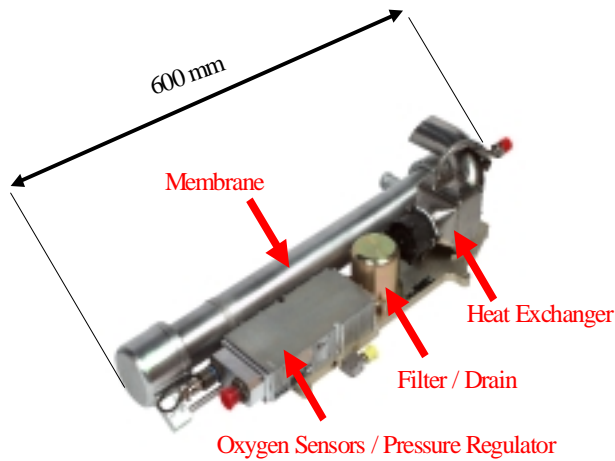


*Membrane principle and Fibers magnified photography*

Membrane is the proven technology currently used in the industry for Nitrogen production. Indeed, this solution has the best economical qualities for industrial use: reliability, recovery, nitrogen purity.



*Membrane OBIGGS Schematic*

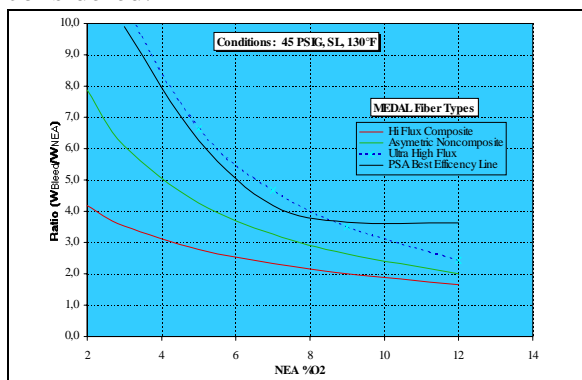


*Helicopter Membrane OBIGGS*

**Trade Off between PSA and Membrane.**

Membrane uses passive diffusion; PSA uses moving pieces which affects its reliability. In the industry, Membrane life is higher than 30,000 operating hours. PSA, which is sensitive to water pollution has to be changed more frequently.

The following diagram shows a comparison between PSA and membrane in terms of recovery. This diagram explains how much bleed air is to be consumed to get a given quantity of Nitrogen at a given purity. For example, to get one pound of Nitrogen with 8% Oxygen, PSA will consume four pounds of bleed air while membrane will consume two pounds of bleed air. Bleed Air is expensive when provided on board; thus the recovery is a major criteria to be considered.



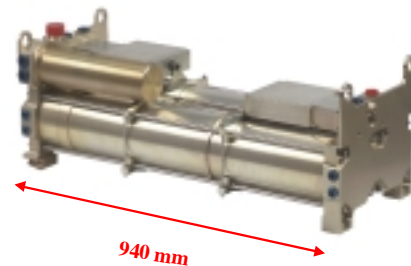
*Air Separation Technologies: Recovery Comparison*

For a given space envelope or a given mass of air separator, membrane will have a much higher production of Nitrogen.

As proven by the functional schematics, membrane OBIGGS is a much simpler system as the PSA. Thus an OBIGGS based upon membrane will be far more reliable which accounts for a possessing cost much lower.

**Flying references.**

Membrane OBIGGS are installed On Board aircraft such as the Tiger helicopter from Eurocopter, the G222 cargo from Alenia, the L159 light fighter from Aerovodochody or the F22 from Lockheed.



*Cargo Membrane OBIGGS*

**OBIGGS perspectives.**

Even if the aeronautical components are more and more secure and precautions are taken against hazards, TWA 800 recalls us that a 100% security has not been achieved yet. Commercial Aircraft are usually not subject to bullets. The phase of the flight considered as the most dangerous is from engine start until the beginning of the cruise, while the tanks are still hot. FAA is presently considering ground inerting on ground in order to assure maximum safety during the most risky phase of the flight.

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