THE PROVISION OF OXYGEN TO SEA HARRIER PILOTS ONBOARD THE CVSG

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ABSTRACT

This article examines the difficulties experienced in supplying Sea Harrier pilots with breathing oxygen whilst embarked in the CVSGs. It provides a historical perspective as well as detailing current improvements and describing future, envisaged work.

Introduction

Sea Harrier pilots require a supply of pure oxygen above a certain altitude. On board aircraft carriers this has traditionally been supplied by a liquid oxygen (LOX) plant. Earlier aircraft carriers were fitted with 2 LOX plants, but the current Carriers Vertical Strike Guided (CVSGs) are fitted with only one. This article will first consider the current position, before describing alternative technologies that are now available which could provide a more reliable, safer and cost effective supply of oxygen to the Sea Harrier pilots.

Responsibilities

The oxygen systems within the Sea Harrier aircraft are the responsibility of the Directorate Aircraft Support Executive (DASE), which is part of the Director General Air (Navy) (DGA(N)) organisation. ES235 is the section within the Director General Fleet Support (Equipment and System) (DGFS(ES)) which sponsors the LOX plant, whilst DGFS(Ships) Marine Systems Manager/ Warships 1 (MSM/W1) is responsible for its configuration within the ship. On board the ships it is the ship's marine engineering staff who are responsible for the operation and maintenance of the LOX plant and it is they who issue the squadrons with LOX or gaseous oxygen (GOX).

Standards

One of the recurring problems with oxygen is its potential hazard. It is hazardous whether stored as LOX, at cryogenic temperatures, or as GOX. Many materials which will not burn in normal air can burn in an oxygen rich environment. Stainless steel for example can act as a fuel in a high pressure oxygen environment. There are no internationally agreed standards for oxygen compatibility with materials and different companies use a variety of 'in house' standards. These standards are continually tightening and many of the materials used in the existing LOX plant could no longer be used if the plant were to be designed today. In an attempt to provide unbiased advice, the MoD has produced a Design Guide that will eventually become a Defence Standard[1]. This guide provides advice on material compatibility with oxygen. The Naval Engineering

Standard (NES), concerned with oxygen cleaning techniques and approval standards, is NES 372.

THE RS500 LOX PLANT

Background

In the 1950s and 60s, to support the operation of a large number of fixed wing aircraft, each aircraft carrier had 2 LOX plants—a large one for routine use and a smaller one for emergency and abnormal operations. In the 1960s the decision was taken to cancel CVA01—the follow on strike carrier and instead it was decided to construct 'Through Deck Cruisers', now known as the CVSGs. These vessels were originally designed to operate only helicopters. Helicopters do not require a supply of pure oxygen as they fly at lower altitudes than fixed wing aircraft. Therefore the CVSG was not originally designed to be fitted with a LOX plant. During the build of HMS *Invincible*, the decision was taken to operate Sea Harriers from the CVSG. As no new plant had been developed for this purpose, the old small plant from HMS *Eagle* was taken out of store and fitted to HMS *Invincible*. HMS *Illustrious* and *Ark Royal* had new plants built, which were copies of the *Invincible* installation.

Since build, many operational problems have been experienced by the ships. They are caused by a number of factors, including:

- Lack of redundancy.
- Inadequate support and documentation.
- Obsolescence.
- Poor overall reliability.

The availability of the plant has always been of great concern to the operators. The equipment is extremely specialised, (there are only 3 in existence), and the MoD rely heavily on the plant's manufacturer for technical help.

Technical Description

The RS500 Lox Plant is a large ship mounted unit, that uses the technique of the fractional distillation of liquid air to separate the oxygen from other gases. Air is supplied to the plant from a dedicated HP air compressor. It then passes through air driers and carbon dioxide absorbers, before being expanded and hence cooled and passed to the distillation columns. The end product can then be stored either as LOX or if vaporised as GOX. The plant is operated by ship's staff who supply the squadrons with 'packs' of oxygen. LOX is a cryogenic liquid and is stored in large tanks at a temperature of −186 °C.

As a result of problems experienced in the Falklands Conflict, with supplying the Sea Harriers with LOX, the Naval Staff Requirement (NSR) was changed. The change required the ships to supply GOX instead of LOX. This change was intended to help the squadrons maintain their flying programme, as GOX can be stored indefinitely where as LOX boils off. The Director General Marine Engineering then carried out studies, in conjunction with industry[2], to address meeting the new NSR. The study concluded that the most effective solution was to extensively modify the existing plant by replacing unreliable components, such as the air driers and carbon dioxide absorbers, with more modern and more reliable ones, e.g. a molecular sieve unit. In addition the plant was altered to enable GOX to be produced from stored LOX.

This package of work (Additions & Alterations (A&A) 306) is presently being undertaken in HMS *Illustrious*' special refit and the resulting plant is known as the RS500 Mark 2 LOX plant. A number of other A&As have been introduced to improve the safety and reliability of the LOX system. These include:

- A&A 331, which involves the addition of a geographically separate GOX storage and charging facility.
- A&A 365, which addresses potential deficiencies in the LOX and GOX vent systems

To support the CVSGs into the next century it is likely that further A&As and modifications will be necessary either to overcome obsolescence or to rectify shortfalls in safety.

Manpower and Training

The existing equipment requires 2 semi skilled watchkeepers and one skilled maintainer. In a four watch system, this requires a total of 9 personnel. In addition, the unique aspects of the LOX plant put a heavy maintenance load onto the ships's staff. For serious defects, it is often necessary to involve the manufacturer. This is expensive and involves the use of a number of authorities leading to delays and operational penalties. There is no shore based trainer and personnel are taught the theoretical aspects at RAF *Cardington*'s Oxygen Training School. As a result LOX plant operators tend to carry out most of their training when on board. This is far from ideal. Running a LOX plant is very much an acquired skill and plant performance is operator dependent. This situation is far from satisfactory bearing in mind the potential hazard posed by the plant. An idea of the size of the plant can be gained by (FIG. 1).

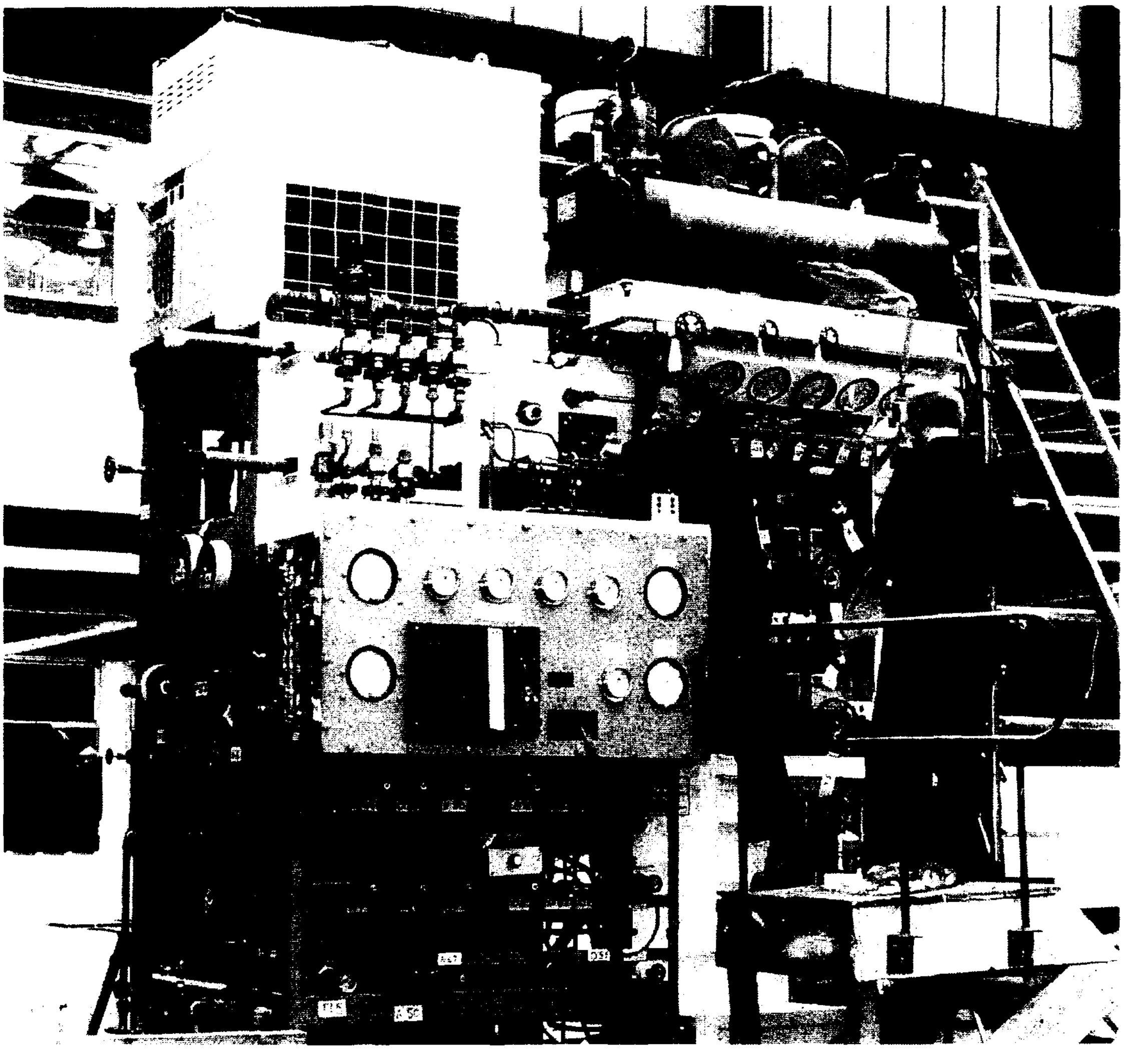


FIG. 1—MARK 2 RS500 LOX PLANT
HMS 'Illustrious' plant being modified at the manufacturer

Options for the future

DGFS(S) were concerned that the plant modifications to date, did not fully remove many of the plant's deficiencies previously discussed or make use of current technologies available for the production of oxygen. As a result a review of the options, for the future life of the CVSGs, was undertaken. This study identified a number of other techniques suitable for producing the small amount of gaseous oxygen required by Sea Harrier pilots; in particular electrolysers, as used in submarines, and Pressure Swing Molecular Absorbers (PSMAs). These options are discussed below:

Option 1—Continued Operation of the RS500 LOX Plant

Background and Technical Description

This option involves the modification of the existing plant as undertaken in HMS *Illustrious*' refit work package, described earlier in this article.

Advantages and Disadvantages

When comparing modern oxygen production technology there are a number of disadvantages in bringing *Invincible* and *Ark Royal* to the *Illustrious* standard (post A&A 306). RN LOX plants have a poor record for reliability and are manpower intensive, although recent work on the CVSGs has resulted in an increase in availability. In the event of battle damage it poses a significant hazard to the ship. In peace time, as well as being one of the largest hazards on board, it places a number of restrictions on the day to day operation of the ship. The work package for the Mk 2 plant is very large and involves the removal of the existing plant. Experience with the *Illustrious* refit shows that the coordination of the many parties involved in the LOX plant is time consuming, difficult and contractually complex. The LOX plant is such a specialist equipment that the prime contractor for the refit is forced to sub contract out to the LOX plant manufacturer. This problem is compounded by the large number of interfaces the LOX plant has with the ship.

Option 2—Fitting a Low Pressure Electrolyser (LPE) in place of the LOX Plant

Background

The LPE was developed in the 1980s to overcome the shortfalls of the High Pressure Electrolyser (option 4). The LPE has proven to be a highly successful equipment. It is currently being fitted to all nuclear submarines at build and refit.

Technical Description

The LPE uses a solid polymer electrolyte instead of a caustic liquid and operates at near ambient pressures. It produces hydrogen at 7 bar and in a submarine this is then fed to a hydrogen compressor. If it was fitted in a CVSG then the hydrogen compressor would be adapted to compress oxygen. The hydrogen would be disposed of by passing it over a low temperature catalyst which would oxidise it to water. A small amount of development work would be necessary to dry the oxygen, modify the control system and test an electrolyser in this mode. The LPE comes as a twin pack unit which means that it is in effect 2 completely separate units. Therefore fitting this equipment to the CVSG would provide 100% redundancy as only 1 unit is run at a time. The LPE is a far smaller equipment than the LOX plant and requires only electrical power, chilled water and demineralised water as services. It was designed to be backfitted to submarines and can be broken down to fit though a standard 32" submarine hatch. The small size of the plant can be seen in (FIG. 2), which shows a twin pack unit.

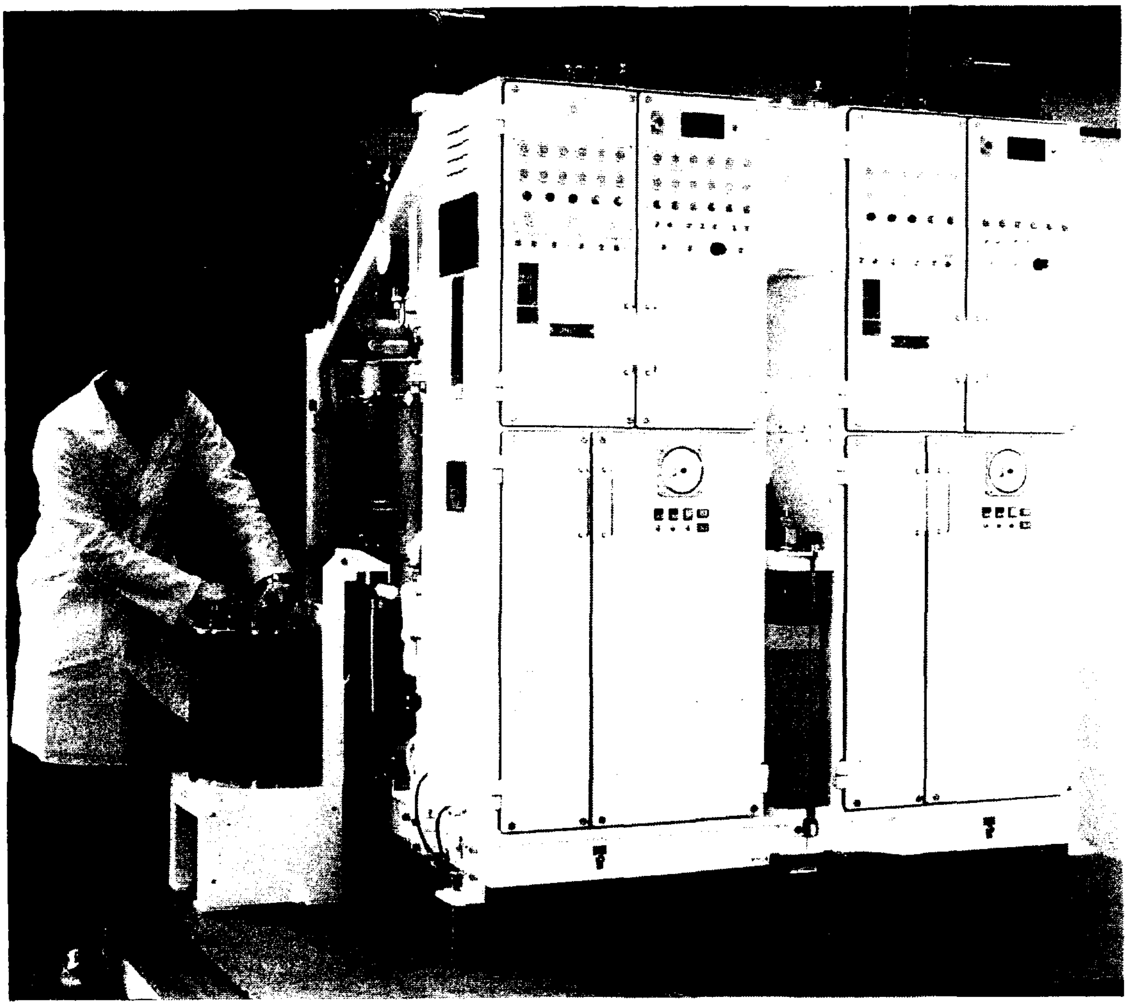


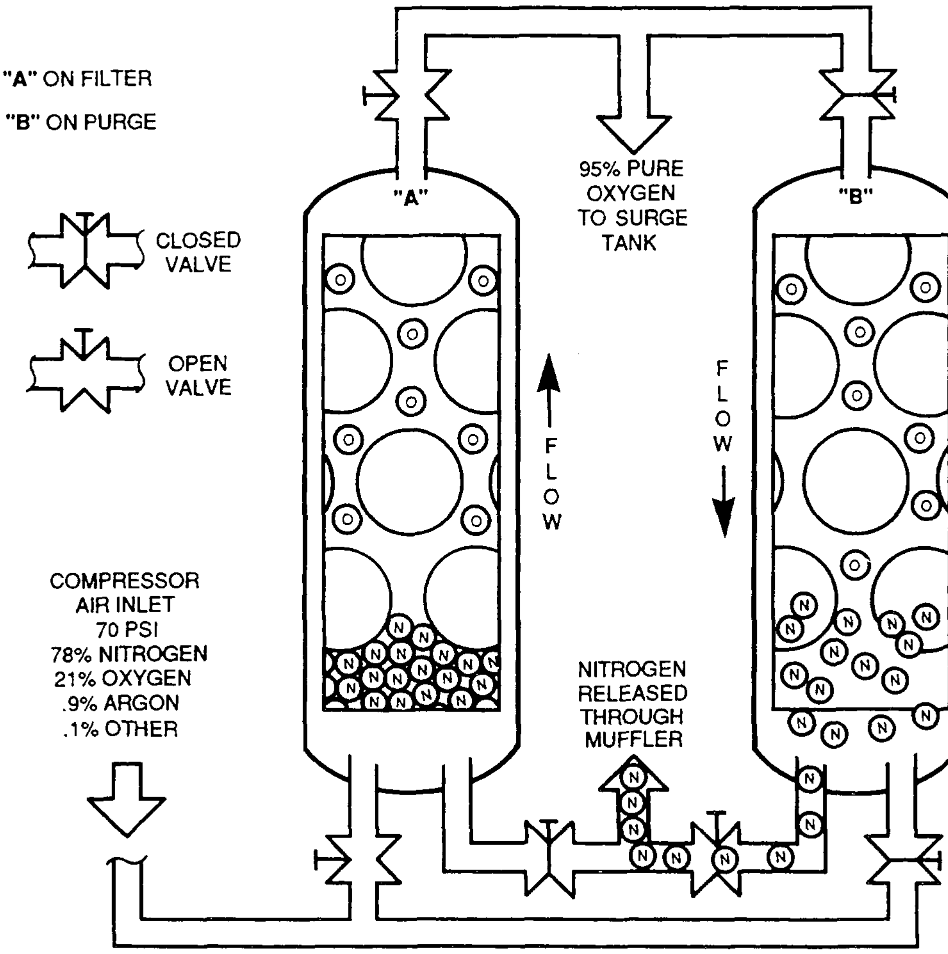
FIG. 2—TWIN PACK LOW PRESSURE ELECTROLYSER
The small object to the left of the plant is the cellstack within which electrolysis takes place

Manpower and Training

The LPE is fully automated and does not require a dedicated watchkeeper. It fails safe in all failure modes. The Submarine School at HMS *Dolphin* runs operator and maintainer courses. As the electrolyser provides a constant supply of oxygen for 160 submariners, 24 hours a day, it is envisaged that it would only need to be run for a few hours a day to meet the CVSG requirement. Therefore the ship would only require 4 semi skilled operators and 1 maintainer (part time). The LPE is fully supported and has technical support in place in Plymouth and Faslane. In addition the manufacturers are situated in Portsmouth and are fully conversant with NESs.

Advantages

The LPE is a mature, successful equipment which will be in service for many years to come. It is fully supported and the navy has a high level of expertise with this equipment. In addition the manufacturer provides an excellent back up service. A shore training facility complete with trainer is already in place. The LPE has proven to be very popular with the submarine flotilla and has a well earned reputation for reliability. In this application the electrolyser would have a vast over capacity. However it would be cheaper to use a production unit rather than developing a down rated one. The LPE is far smaller than the existing LOX plant and the LPE has been successfully type tested for service in submarines. The LOX plant has never been shock tested



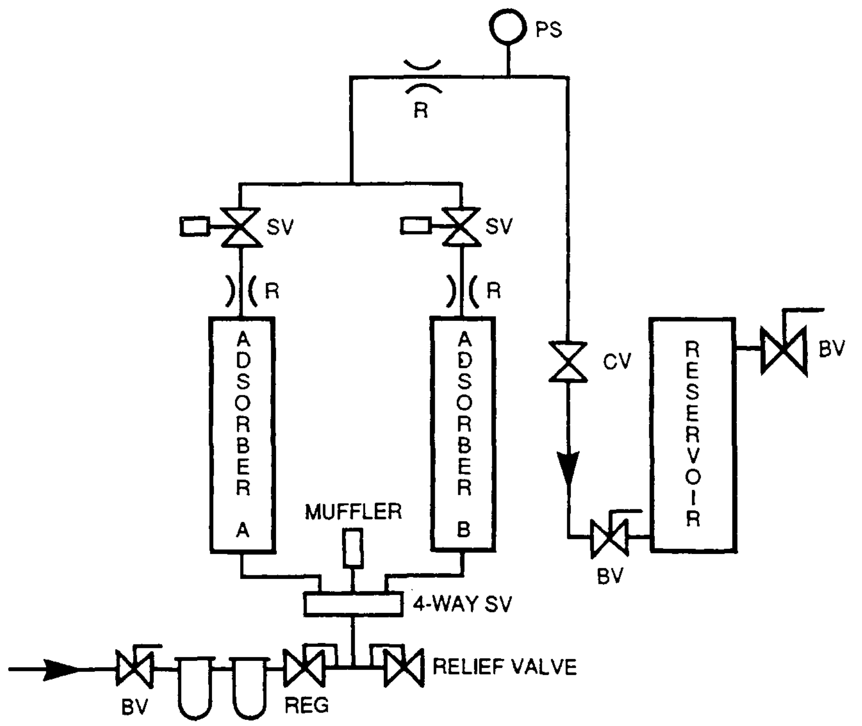


FIG. 3—OXYGEN PRESSURE SWING ADSORPTION—FLOW DIAGRAM
BV: BALL VALVE CV: CHECK VALVE PS: PRESSURE SWITCH
R: RESTRICTOR SV: SOLENOID VALVE

and in the case of action damage it is unlikely to remain operable, whereas the LPE is a much more rugged equipment. The consequences of a direct hit to the LOX plant would have severe implications to the ship as a large amount of LOX would be released. Fitting the LPE in place of the present LOX plant would offer a significant increase in both ship and personnel safety as large quantities of LOX and GOX will not be stored. Fitting the LPE is of low technical risk.

Disadvantages

The main disadvantage is the large unit production cost (UPC) of an electrolyser. The cost for this option may be reduced by fitting refurbished LPEs that will become available from decommissioning submarines. If the electrolyser is sited in the LOX compartment then services such as chilled water, demineralised water and 440V will need to be run to the compartment.

Option 3—Replace LOX Plant with Pressure Swing Molecular Absorber (PSMA)

Background

PSMAs are widely used in industry for supplying small quantities of oxygen. Small PSMAs have been fitted into aircraft including the Harrier GR7. The army procured a number of containerised PSMAs for the Gulf conflict, which were used to supply field hospitals with oxygen.

Technical Description

Most PSMAs produce only about 94% pure oxygen, the remaining 6% being mainly argon and other noble gases. The standard for pilots's breathing oxygen[3], requires that the oxygen has a purity of 99.5%. Recent advances in technology have resulted in the development of a 2 stage PSMA process, capable of producing oxygen of greater than 99% purity. PSMAs are simple equipments. They work by cycling low pressure air through a number of Zeolite resin beds. One bed is on line and nitrogen molecules are sieved out leaving just oxygen and a small amount of argon. Meanwhile the other bed is regenerated,(FIG. 3) shows this diagrammatically. The PSMA would be mounted on a skid containing integral LP air compressor, filters, resin beds and watchkeeping panel. The only services required are a supply of fresh air and a 440V AC supply. Two units could be incorporated into the existing LOX compartment thus providing 100% redundancy. (FIG. 4) shows a sketch of the envisaged installation.

Manpower and Training

The pre-production prototype unit could be used as a trainer. It is believed that the trainer should be sited at HMS *Sultan*. This would enable the RN to accumulate a level of expertise with the unit and in particular with high pressure oxygen. The plant is automatic in operation and it is envisaged that the ship would require 4 semi skilled operators and 1 maintainer (part time).

Advantages

The PSMA offers a low cost method of providing oxygen to Sea Harrier aircrew. The plant is inherently simple, uses current technology and it is hoped to use a number of components already in naval service. A training package can be put together for the operators and maintainers. As the plant only requires 440V and a supply of fresh air, the number of interfaces to the ship systems have been minimised. If the PSMA is successful, then it is expected that the RAF and medical services may be interested in procuring some of these units. Many RN ships use large quantities of bottled oxygen both for medical and engineering needs. Having a machine capable of producing oxygen would offer a significant enhancement, particularly for casevac/disaster relief roles.

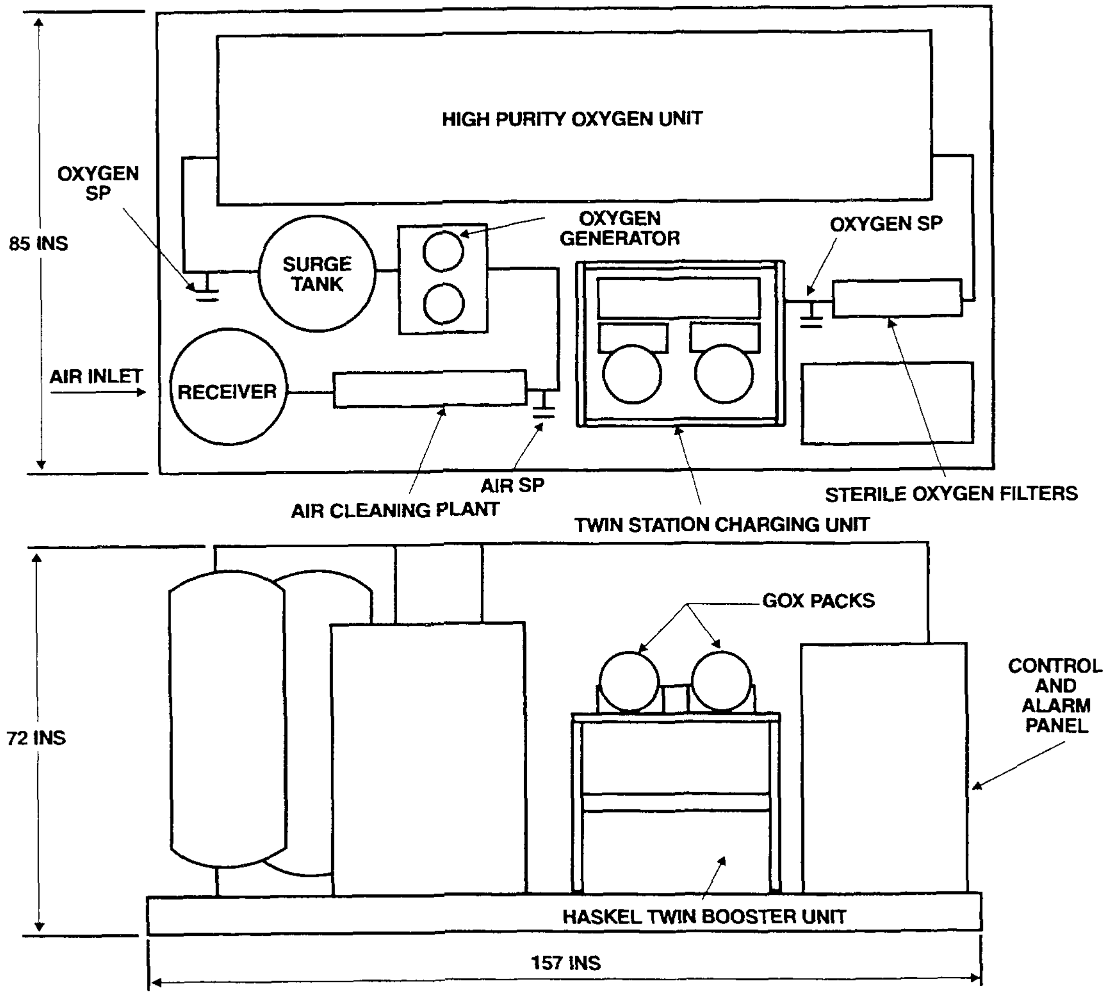


FIG. 4—PSMA—PROPOSED INSTALLATION
SP: Sampling Point

Disadvantages

PSMA technology, although used widely in industry, is novel to the RN. In addition the 2 stage process is relatively new. With regard to the question of oxygen purity, ES235 are currently investigating with the Institute of Aviation Medicine whether the purity standard can be reduced to 99%. Therefore, there is a level of technical risk that the unit may not produce oxygen to the quality demanded by DefStan 16–1. This element of risk can be addressed at the pre-production prototype stage, when trials are carried out on the equipment. Even if the unit can not provide 99.5% pure oxygen, it may be possible to negotiate a relaxed purity standard for PSMA derived 'aircrew breathing oxygen'.

Option 4—Refurbished High Pressure Electrolyser (HPE)

Background

The HPE is fitted to a number of submarines and is being removed at refit. It would be possible to refurbish some of these and fit them to the CVSGs. The HPE was developed during the 1960s, uses a caustic electrolyte and operates at high pressure. Although the process is simple, safety considerations mean that the HPE is very complex. This complexity leads to the plant becoming maintenance intensive and often unreliable, so in the 1980s the LPE was developed. This was further spurred on by obsolescence of a key component, the cell stack.

Technical Description

HPEs would be removed from decommissioned submarines and refurbished by the manufacturer. The HP oxygen produced by the HPE would be boosted to the pressure needed by the GOX pack by a booster unit.

Advantages and Disadvantages

The main advantage of this proposal is that the capital equipment is readily available. In addition training courses and stores support is already in place. However there are a number of fundamental disadvantages. Firstly, the equipment is rapidly approaching obsolescence. The HPE was designed in the 1960s and recent advances in material science indicate that if a new HPE was to be designed, then many of the materials would have to be changed for safer and more expensive ones. In addition the HPE is potentially hazardous and does not necessarily fail safe. Although it does not require a dedicated operator it does require the attention of a skilled maintainer in an emergency. In a submarine this is not a problem but in a CVSG, the large size of the vessel could delay the maintainer from reaching the plant. This could result in the plant exploding with possible loss of life of those in the vicinity. For these reasons ES235 believe that this option is unacceptable and therefore is discounted.

Option 5—Fitting On Board Oxygen Generating System(OBOGS)/ Molecular Sieve Oxygen Concentrating System (MSOCS) into the Sea Harrier

Background

Traditionally aircraft have carried packs of LOX or GOX which are refilled prior to a sortie. LOX is held at low pressures, but at cryogenic temperatures. GOX is stored at up to 6000 psi. Damage to either system could result in a fire or explosion. The systems in the aircraft have to be kept to oxygen clean standards and there has to be strict control on materials used in the system. The RAF generally buy LOX from commercial sources although they do have a handful of 'portable' LOX plants for use in the field. Small pressure swing absorber units were developed for aircraft installation in order to remove the need for a logistic chain for supplying oxygen. This is of particular benefit to aircraft operating from temporary airfields, which may not have LOX storage facilities.

Technical Description

MSOCS units use bleed air from the gas turbine and pass it through small zeolite resin beds. An automatic control system switches the beds between absorption and regeneration cycles. The system works at low pressures which eases the material compatibility problems and produces oxygen at purities of up to 94%. A small emergency bottle of oxygen is provided in case of system failure. The system is in service in the Harrier GR7. It is of note that 94% pure oxygen is acceptable for breathing on line, whereas 99.5% pure oxygen is currently required for bottled oxygen.

Advantages

From a marine engineering point of view this system is ideal as it gives oxygen generation to the air engineers and encourages the operator/ maintainer concept. It also considerably enhances the availability of aircraft as they are no longer dependent upon a single ship mounted equipment. Furthermore there is a considerable saving in space as the LOX compartment becomes free for other uses. Total manpower can also be reduced, as the squadron would only need one maintainer for this equipment. On safety grounds, MSOCS has a number of major advantages; as the oxygen is produced whilst flying, MSOCS removes the requirement for storing oxygen both onboard the ship and aircraft. This removes a significant hazard, particularly during conflict.

Disadvantages

There has been vigorous debate between DGFS(S) and DGA(N) on the practicality of fitting such units to the Sea Harrier. Although the MSOCS unit will fit in the space occupied by the existing LOX/GOX pack, there are considerable engineering issues that would need to be resolved as the Sea Harrier is very different from the GR7. In addition this modification could only take place at major overhaul and is not part of the Sea harrier FRS2 programme. Therefore, the conversion of the Sea Harrier to use MSOCS has been ruled out by DGA(N). However, the Sea Harrier replacement will have this type of equipment.

Preferred Options

Replacing the LOX plant with shipmounted PSMAs offers the most cost effective solution to providing Sea Harrier aircrew with breathable oxygen. However there is a degree of technical risk that a timely solution will not be achieved. Replacing the LOX plant with a LPE is a lower technical risk but more expensive option than using a PSMA but still cheaper than continuing with the LOX plant.

Procurement Strategy

DGFS will be presenting Directorate of Operational Requirements (Sea) with an investment appraisal during the summer of 1993, which presents the advantages to be gained from moving away from the existing cryogenic plant for the production of oxygen in the CVSGs. If the recommendations of the appraisal are approved, then this should clear the way for a development programme to be undertaken.

Conclusions

This article has shown why the provision of oxygen to the Sea Harrier aircrew is difficult and expensive. It has demonstrated how changing the NSR from the provision of LOX to GOX has enabled other technologies to be considered. Consideration of the options available for the production of oxygen to support Sea Harrier operations in the CVSGs has identified PSMA technology or LPE as the way forward. Replacing the LOX plant with either an LPE or PSMA will result in a more cost effective, safer and more reliable supply of oxygen to the Sea Harrier. Additionally, both options will give 100% redundancy as well as significantly reducing the amount of stored oxygen held on board along with its associated hazards.

References

1. MOD PE Specification 0.4081 Guide to the Compatibility of Materials with Oxygen, Issue 4, May 1991.
2. D/SSC/ME235/361/01/03, 1986
3. Defence Standard 16–1.