**Oxygen Storage Module with Physisorption Technology for Closed-Circuit Respirators**

**A M Swanger**, J E Fesmire1, R Fernando2

1 Cryogenics Test Laboratory, NASA Kennedy Space Center, FL 32899, USA
2 National Institute for Occupational Safety and Health, Pittsburgh, PA 15236 USA

---

### Introduction

- The new Cryogenic Flux Capacitor (CFC) technology employs nano-porous aerogel composites to store large quantities of fluid molecules in a physiosorbed solid-state condition at moderate pressures and cryogenic temperatures.
- By its design architecture, a CFC device can be "charged" and "discharged" quickly and on-demand according to standby/usage requirements. For example, a CFC device can be designed to store hydrogen for fuel systems, nitrogen for cryo储系统, or oxygen for life support systems.
- Test the feasibility of applying the CFC technology to closed-circuit escape respirators (CCERs)
- The CFC Oxygen Storage Module stores oxygen in solid-state form, according to physisorption processes at any cryogenic temperature, and deliver it as a gas upon demand.
- Gaseous oxygen (GO) is admitted into the breathing loop of the CCER by introducing heat into the module.
- Potentially replacing the gaseous or chemical based oxygen supply used in today’s closed-circuit respirators (CCRs), the new device is a high-capacity, conformal, small-size solution for future life support equipment. In particular, the CFC CCER must be capable of being carried on the person, ready to be quickly deployed and used for escape in an emergency.
- Test data for physiosorption of oxygen in aerogel materials and CFC core modules are presented and basic operational parameters for charging and discharging are summarized through prototype testing of the cryogenic oxygen storage module.

**KEY BENEFITS:**

1. Low-pressure storage at high density (approximately the same as liquid density) but without the problems of liquid storage.
2. Quick charging and quick discharging through application of heat to the modulator's thermally conductive structural design.
3. Inherently high thermal insulating properties due to use of aerogel composite materials.
4. Potential for high-capacity, small-size apparatus in a conformally-shaped wearer-able form.

### Cryo Flux Capacitor for Storage of O2

- The CFC device is an energy system for the storage (charging) and un-storage (discharging) of fluids in a practical way. The stored energy in this case is represented by fluid molecules accumulated in a solid-state manner. Solid-state in this context means that the fluid atoms or molecules are physically bonded within the pores of a meso-porous or nano-porous storage media.
- A CFC device, for an effective means of storing and un-storing O2 molecules, is being developed for new CEER. The O2 molecules can be liquid or gas coming in and will always be coming out. Problems with liquid behavior such as sloshing or liquid level management are avoided because the fluid is stored in a physiosorbed state that is not liquid, no matter the density or temperature.
- Three chief design problems for the module are summarised as follows: 1) stand-by (ambient heat leak), 2) capacity for one hour at a nominal withdrawal rate of 1.35 lpm oxygen, and 3) regulation of demand from 0.5 to 1.0 lpm oxygen.
- In the stand-by mode the module must be as thermally isolated as possible, but in the discharge mode the heat exchange with the ambient process is needed. As the GO scrubber material generates a list of heat, future module designs may be able to take advantage of this heat to drive the discharge flow rate.

### CFC Modules Test Results

**CFC Modules Test Results**

- **Requirements for emergency oxygen 1-hour rescue pack: 1.35 l/min at 57F (33.9°C) or a total mass of 1560 g (0.8 kg) with the module in 1,200 mm by 200 mm by 200 mm and 20 minutes to charge with the oxygen storage density slightly higher than that of the liquid phase**.

- **GO liquid volume equivalent for oxygen is approximately 100 l/kg (9.0 g/ml) and the solid-state oxygen is 116 g/kg (0.29 g/ml)**.

- To liberate (or “un-store”) the cryo-adsorbed molecules within the core of the CFC-based module, a heat source in required. Heating can be provided by a solid conductor path from the ambient environment, the heated breathing air, or the exhaled breath. The selection of the associated CFC scrubber material for oxygen balancing effect to meet demand cycles from steady-state to high flow.

**Prototype CFC module and charging station**

**Prototype O2 with flask (left); detail of cryo-adsorb counter flow heat exchanger (right)**

- **Net loaded mass burn-down profile: NO2, O2, and N2**

---

### Conclusions

- **The technology of using the phenomena of cryo-adsorption afforded by the Cryogenic Flux Capacitor (CFC) device appears feasible for the breathing oxygen application**.

- **For the core modules tested, the storage density shows the opportunity for compact, lightweight storage of oxygen**.
  - **The liquid volume equivalent for oxygen is approximately 100 l/kg (9.0 g/ml) and the solid-state oxygen is 116 g/kg (0.29 g/ml)**.
  - **The size and weight should be well within the current bounds**.
  - **Promise is shown for additional features and capabilities such as CO2 sequestration and longer endurance to provide comfort, with less envelope/weight**.

---

**Performance of three CFC core module test articles in 1-hour test (left)**

**Prototype CFC modules tested: Module I, Module II, and Module III (from left to right)**

- **Prototype O2 with flask (left); detail of cryo-adsorb counter flow heat exchanger (right)**

---

**Storage of O2 for Breathing Apparatus**

- Storage of oxygen for breathing apparatus is typically done as low pressure, cryogenic liquid O2 (gaseous oxygen (GO) is removed by an absorber and oxygen is added to the system according to the user’s metabolic needs. CCERs are smaller versions of CFCs used for escape purposes and usually carried by the person at all times, ready to be used in an emergency.
- Next Generation CCER are needed for comfort and continuous wear by persons during their daily work routines as well as for an escape breathing apparatus in the event of an emergency.

**Using physisorption technology combined with cryo-adsorption, an alternative method of fluid storage is being developed for oxygen storage. The net storage density is much higher pressure gas storage and can be had with liquid purity but without the limitations of these storage methods. The CFC technology includes a core module for oxygen charging at any cryogenic temperature and then discharging upon demand for GO supply.**

- **As part of the NASA-funded Liquid Oxygen Storage Module (LORS) project to develop new oxygen breathing equipment, prototypes of the CFC modules have been produced and tested by the Cryogenics Test Laboratory at NASA Kennedy Space Center.**

---

**Design Basis and Heat Exchange Process**

- **Requirements for emergency oxygen 1-hour rescue pack: 1.35 l/min at 15°F (33.9°C) or a total mass of 1560 g (0.8 kg) with the module in 1,200 mm by 200 mm by 200 mm and 20 minutes to charge with the oxygen storage density slightly higher than that of the liquid phase.**

- **The O2 molecules can be liquid or gas coming in and will always be coming out. Problems with liquid behavior such as sloshing or liquid level management are avoided because the fluid is stored in a physiosorbed state that is not liquid, no matter the density or temperature.**

- **Three chief design problems for the module are summarised as follows: 1) stand-by (ambient heat leak), 2) capacity for one hour at a nominal withdrawal rate of 1.35 lpm oxygen, and 3) regulation of demand from 0.5 to 1.0 lpm oxygen.**

- **In the stand-by mode the module must be as thermally isolated as possible, but in the discharge mode the heat exchange with the ambient process is needed. As the GO scrubber material generates a list of heat, future module designs may be able to take advantage of this heat to drive the discharge flow rate.**

---

**CFC Modules Test Results**

- **Prototype CFC modules tested: Module I, Module II, and Module III (from left to right)**

---

**Net loaded mass burn-down profile: NO2, O2, and N2**

---

**Performance of three CFC core module test articles in 1-hour test (left)**

**Prototype CFC modules tested: Module I, Module II, and Module III (from left to right)**

- **Prototype O2 with flask (left); detail of cryo-adsorb counter flow heat exchanger (right)**

---

**Conclusion**

- **The technology of using the phenomena of cryo-adsorption afforded by the Cryogenic Flux Capacitor (CFC) device appears feasible for the breathing oxygen application.**

- **For the core modules tested, the storage density shows the opportunity for compact, lightweight storage of oxygen.**
  - **The liquid volume equivalent for oxygen is approximately 100 l/kg (9.0 g/ml) and the solid-state oxygen is 116 g/kg (0.29 g/ml).**
  - **The size and weight should be well within the current bounds.**
  - **Promise is shown for additional features and capabilities such as CO2 sequestration and longer endurance to provide comfort, with less envelope/weight.**