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SMALL SPE FUEL CELLS FOR ARCTIC APPLICATIONS

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Introduction

Small solid polymer electrolyte (SPE) fuel cells ranging in size up to a few hundred watts (1,2) could, with development, supply power for remote relay networks, power for equipment and for navigational aids in the Arctic. There, ambient temperatures can range from +30° C in the summer sun to cold winter nights that dip to −55° C. Because SPE fuel cells and their product water freeze up at 0° C, a suitable thermal enclosure is required if they are to provide one year of operation in the Arctic.

We proposed that the fuel cell be located in an insulated container and use waste heat to keep itself warm. We looked at the electrical efficiencies, the waste heat available and changes due to variations in temperature of 12 and 30W fuel cells. Various storage vessels for hydrogen and oxygen and the damage of insulated containers by hydrogen/oxygen and by hydrogen/air explosions will also be described.

Insulated Containers

Insulated containers were designed to maintain a temperature 50° C above the ambient using 30W of heat. For simplicity it was assumed that hydrogen and oxygen would be supplied to the stack and that ambient air was not required.

The first container was made from a convenient 61 cm by 94 cm (45 gal) drum lined with 7.5 cm of white styrofoam as shown in Figure 1; the ends were insulated with 10 cm of styrofoam and resistive heaters were mounted at the top. A fuel cell producing 30W would fill two thirds of this cavity with water in about 6 months.

Tests conducted in our cold room at temperatures from 20° C down to −50° C showed that a 30W heater would maintain an acceptable temperature in the barrel. However, when the drum was placed in the summer sun the temperature of its black exterior rose to 49° C and operation of 20W heaters increased this value to 70°–80° C inside which was above the stability limits of the styrofoam. The resulting shrinkage of the styrofoam (Figure 1) decreased the insulation value below an acceptable level. Painting the barrel white lowered the cavity temperature by 15° C.

A rectangular plywood box with 10 cm of white styrofoam insulation inside and a heat-activated vent door seen in Figure 2 was built to have a cavity with a volume similar to our drum. In addition to the heaters, a 5 liter bottle of water and valve were added that delivered 300 ml of water to a siphon-sump nine times in 48 hr; the 1/4 in. I. D. Tygon siphon drained the sump (when it was full) to a −30° C cold-room ambient without being blocked by ice.

In a −30° C cold room test, this box cavity, warmed by 20W of heat, was 52° warmer at the top and 30° C warmer at the bottom than the ambient. Without door gaskets, when the ambient dipped below −45° C, the sump froze. At room temperature the vent door seen in Figure 2 opens to reduce the top-of-cavity temperature; with ambient temperatures of 23° C the top reached 40° C.

From these initial tests we learned that insulation, free volume and siphoned sumps can be engineered in unlimited combinations to contain or expel the heat and water produced by a fuel cell. Also, greenhouse type vents can be used to dissipate excess heat from insulated cavities if insects, rodents, and idle fingers do not jam the system. Auxiliary heaters may be desirable to prevent freezing during extremely cold periods or when fuel cell loads are reduced.

Fuel Cells Tested

Three hydrogen/air SPE fuel cell systems were evaluated for remote application. The first, a 12W, 4-cell stack, used hydrogen at 12.4 cm water column (W.C.) and ambient air. Its electrical output and fuel consumption are shown in Figure 3. At 5A, the hydrogen consumed corresponds to 25W, but the stack yielded only 10.5W electrical. The voltage efficiency was also lower than expected (2) but was independent of temperature from 10° to 60° C. These results were obtained by operating the stack inside a temperature controlled metal box (with a Saran cover for explosion venting and for viewing). Consumed oxygen was replenished with pure oxygen using the Saran cover as a pressure indicator and ballast volume.

Unfortunately this stack failed at the end of 455 hr operation when water penetrated the corrosion protection layer on its aluminum cooling fins and the hydrogen ports plugged with the products of corrosion. Similar fuel cell stack designs have exceeded 48,000 hr of operation (2).

The other two were 30W, 34-cell stacks from a second supplier. They used hydrogen at 10 cm W.C. and ambient air. One of these failed after just 86 hr of operation because hydrogen leaked from the cells. The other has now operated for more than 4400 hr. Its performance after 33 hr of operation is shown in Figure 4. At 0.75A the hydrogen consumed corresponds to 32.4W, but the stack produced only 17.6W electrical.

Thus, according to our data, both systems convert all of the hydrogen to current and, in addition, both of these hydrogen/air fuel cells needed to have 10% of their hydrogen purged or stack voltages failed.

Consumables

In any practical system the fuel cell must be supplied with hydrogen and oxygen. The weights and volumes of some choices (including tanks, mounts, valves and consumables) are listed in Table I. For these calculations we assumed that a nominal 30W SPE system would be operated below capacity (at say 24W and perhaps 0.7V per cell) at current efficiencies of 80% and with purge losses of 5–10%. Such a system will consume

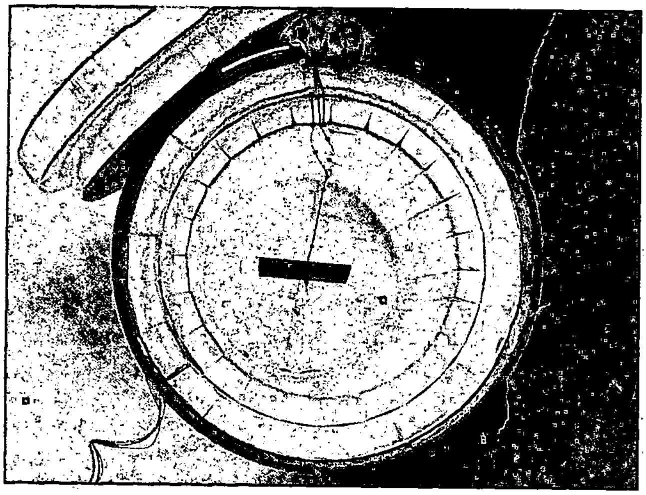

Figure 1. Deterioration of styrofoam lining at temperatures above 70° C.

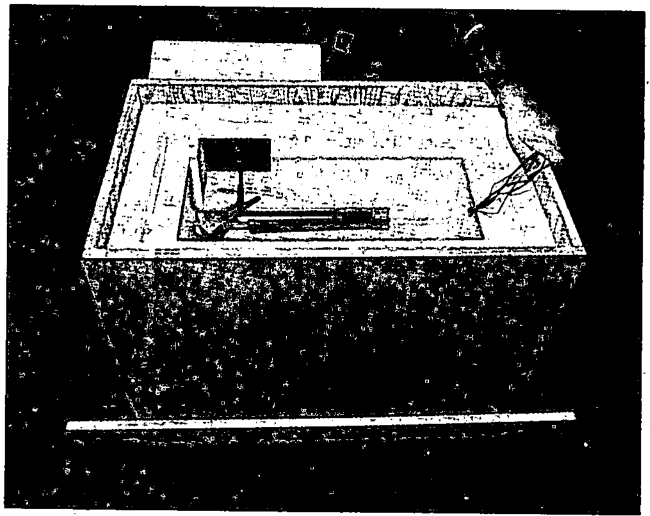

Figure 2. Insulated box 79 × 46 × 100 cm outside with 15 × 15 cm vent.

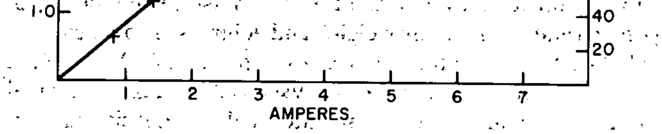

Figure 3. Performance of a 12W, 4-cell SPE fuel cell at 10° and 60° C.

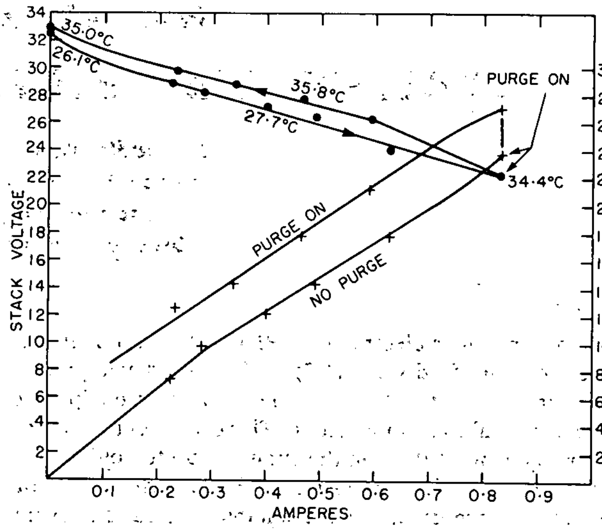

Figure 4. Performance of a 30W, 34-cell SPE fuel cell at 30° C.

about 14 kg of hydrogen and an equivalent amount of oxygen per year.

Where the storage system listed provides hydrogen only, oxygen is considered to be available from air that must be warmed and humidified before it reaches the cell stack.

The Kevlar and fiberglass reinforced pressure tanks listed are calculated to hold their gases at 34.5 MPa (5000 psi). Titanium alloy hydrides (3) were not considered because they are inoperative at −55° C and heating them would demand much more fuel than heating the fuel cell. Kipp generators suffer from similar problems.

The recommended design of cryogenic tandem vessels houses liquid oxygen and liquid hydrogen containers in the same outer vessel and uses a vapor-cooled heat shield around both to keep the heat leak rate below the demand. No boil off losses need be incurred in one year of use or during shipments lasting up to 3 months prior to operation. Within this tank, 14 kg of hydrogen would occupy about twice the volume needed to store 114 kg of liquid oxygen.

For comparison, the air depolarized batteries (4) that are used now weigh 1900 kg and occupy 1.44 cubic meters for this one year mission. They have been shown (5) to operate down to −55° C if the current drain is not excessive and they are relatively inexpensive if transportation costs are low. For Arctic applications, where transportation to remote sites can

TABLE I
CONSUMABLE STORAGE SYSTEM

Vessel	Full weight (kg)	Volume (m³)
Tandem (liquid $H_2 + O_2$)	273	0.534
Kevlar (H_2 at 34.5 MPa)	273	3.76
Kevlar ($H_2 + O_2$ at 34.5 MPa)	394	5.61
Fiberglass (H_2 at 34.5 MPa)	410	3.76
Fiberglass ($H_2 + O_2$ at 34.5 MPa)	592	5.61

cost up to $22 per kilogram, a heavier system looks much less attractive.

Explosions in Containers

Fuel cells, gaskets, lines and valves fed with hydrogen will probably leak at some time and incidents are likely (6). To understand the impact of combusting hydrogen with air and/or oxygen inside insulated containers, several were built with walls of various materials to enclose about 28 dm^3 (1 ft^3). Various mixtures of hydrogen/air and hydrogen/oxygen were spark ignited inside the structures to observe the explosive violence.

Our results can be summarized by stating that (*i*) hydrogen/air mixtures reacted quietly without overpressure (7) while hydrogen/oxygen mixtures detonated with associated noise and damage; (*ii*) insulating the walls of a 28 dm^3 container or filling it with fiberglass had little effect on either.

Summary and Conclusions

Small SPE fuel cells could, with some development, use hydrogen and oxygen from a tandem cryogenic container to supply power as low as 30W for unattended equipment that operates for one year in the extremes of an Arctic environment from +30° to −55° C. The system would cost more but weigh less and be easier to transport than conventional air depolarized batteries. Suitable thermal enclosures for the fuel cell and its product water can be kept warm by the waste heat of the fuel cell alone although the addition of protective heaters could provide a further margin of safety against environmental extremes and equipment failures.

The hazards of hydrogen/oxygen explosions are undiminished by the walls of an insulated container so safety precautions such as catalytic combustor protection against the formation of explosive mixtures must be taken. A hydrogen/air system would not explode violently. Further efforts will be needed to engineer a practical purge control system and to evaluate the problems of frozen valves, frosted lines and intruding pests.

ACKNOWLEDGMENT

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