ELECTRICALLY REGENERATIVE HYDROGEN-OXYGEN FUEL CELLS

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Abstract

This paper describes the status of Electro-Optical Systems in the development of an electrically regenerative hydrogen-oxygen fuel cell for space application. The system performs the same function as a secondary battery in spacecraft and shows potential advantages over batteries from standpoints of energy-to-weight ratio, cycle life, and operating temperature range.

Description and Operation of Cell

The components of the experimental cell are shown in Fig. 1. The hydrogen and oxygen electrodes are identical and consist of platinized porous nickel. The electrolyte is a solution of potassium hydroxide impregnated in asbestos. The cell frames are made of stainless steel and contain a silicon rubber "O" ring to seal the gases. Miniature gas cylinders, also of stainless steel, are employed to receive and store the generated gases. The volume ratio of the cylinders is 2:1 for hydrogen and oxygen, respectively.

The first multicell assembly was completed in December 1961. Figure 2 shows the unit under test. As indicated, the unit contains nine series connected cells. The hydrogen and oxygen gas cylinders are located on either end and form an integral part of the unit. Insulated tie bolts are employed to fasten the assembly. Small passages within each cell spacer serve to conduct the gases from the electrodes to their respective gas cylinders. The cell spacers are made of nickel-plated plastic.

Both the single cell and the multicell assembly are operated in the same manner as a secondary battery. The

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distinguishing feature is that the half cells are gas electrodes, i.e., H_2 and O_2 in contrast with the conventional metal electrodes such as zinc, cadmium, silver oxide, etc. The overall reactions during charge are given below:

Anode	$4\ H_2O + 4\ e^- \rightarrow 4\ OH^- + 2\ H_2$
Cathode	$4\ OH^- \rightarrow 2\ H_2O + O_2 + 4\ e^-$
Cell	$2\ H_2O \rightarrow 2\ H_2 + O_2$

The overall reaction is thus seen to be the electrolysis of water. During discharge the reverse reactions take place, i.e., the formation of water and electrical energy from the two gases. No mechanically moving parts are used for any portion of cell operation.

Performance

Voltage-Current Characteristics

The voltage-current characteristics of this cell are shown in Fig. 3. The dashed horizontal line at 1.23 v corresponds to the theoretical open-circuit voltage for the hydrogen-oxygen reaction. The difference between the operating and theoretical voltage is appreciably reduced by an increase in operating temperature for both charge and discharge. The discharge polarization is reduced and charge polarization increased by an increase in pressure.

Discharge Characteristics

A typical discharge curve for this cell is shown in Fig. 4. As indicated, the voltage remains relatively constant throughout the entire discharge period. The slight decrease in voltage with time may be attributed to the lower gas pressures, which decrease linearly with time at constant current.

Charge Retention

The self-discharge characteristics of this cell are given as a function of temperature in Fig. 5. Inspection of this figure reveals that at temperatures in excess of 200^{o}F the self-discharge rate is extremely high, i.e., up to several percent loss per hour, whereas below this temperature the rate is very low. The self-discharge rate also is found to be independent or at least a very weak function of pressure to 500 psig.

All results shown in Fig. 5 were based on a 72 hr stand test. In a 30-day stand test the cell was found to retain and then deliver 91% of its initial charge input of 2 amp-hr after the 30-day stand at 100 psig and 70^{o}F.

Cycle Life

Automatic cycling equipment has been employed to determine the cycle life characteristics of this cell. One cell has been cycling continuously since November 1961. The particular cycle consists of 65-min charge at 108 ma and 35-min discharge at 200 ma. The voltage has remained relatively constant from cycle to cycle (see Fig. 6), indicating no measurable effect of cycling on performance. Altogether, the cell has completed over 3000 cycles for a total of over 5000 hr.

Environmental Testing

A series of environmental tests was conducted in order to determine the effect of vibration, acceleration, and shock on the electrical characteristics of the cell. The tests that were conducted at the Jet Propulsion Laboratory, Pasadena, Calif., simulated those of the boost and space flight phases of the Mariner spacecraft.

The cell performance was measured both before, during, and after each environmental test. The results shown in Figs. 7 and 8 indicate relatively little effect of the environment on performance. The maximum acceleration was 14 g for 5 min. The most severe vibration test was 15 g-rms noise for 6 sec. The maximum shock was 200 g, 0.5-1.5 msec.

Multicell Performance

The voltage-current characteristics of the 9 cell series-connected unit are shown in Fig. 9. The current output at 6 v is approximately 2.5 amps at room temperature and 4 amps at 150°F. These results, when expressed in terms of volts per cell vs current density, correspond very closely with those of the small single cells. Hence there appears to be no effect of scaling to this size.

Future Efforts

Future efforts will include scaling up the forementioned multicell unit in both size and number of cells. Specific goals call for the development of a 28-v unit with a capacity of 35 amp-hr and weight of less than 50 lb. The power and energy-to-weight ratios are expected to be 4 w/lb and 20 w-hr/lb, respectively.

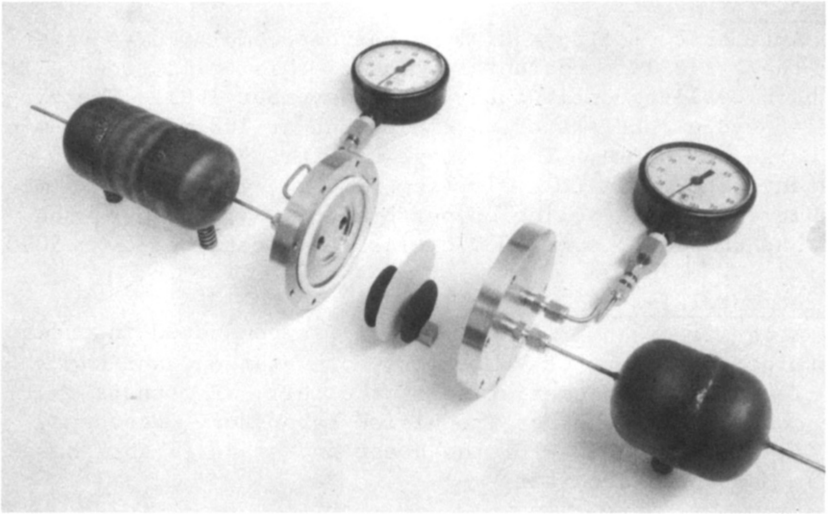

Fig. 1   Components of cell

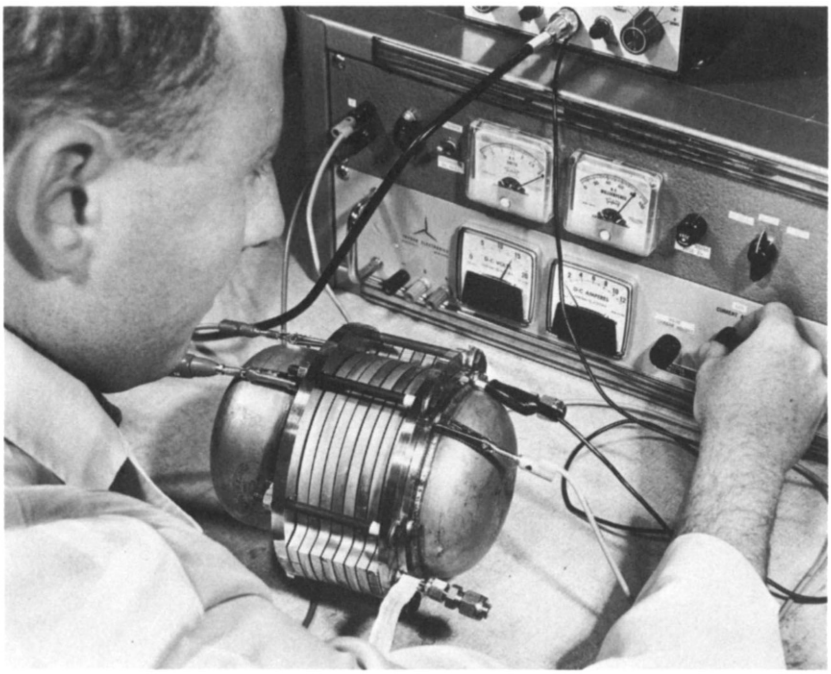

Fig. 2   Nine-element fuel cell

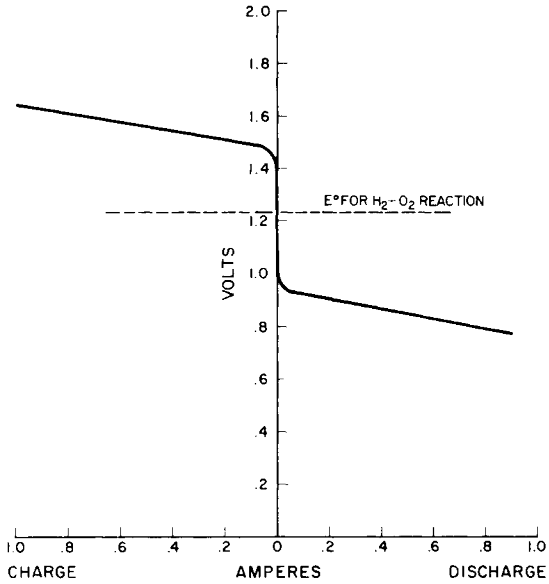

Fig. 3 Voltage current characteristics of single cell

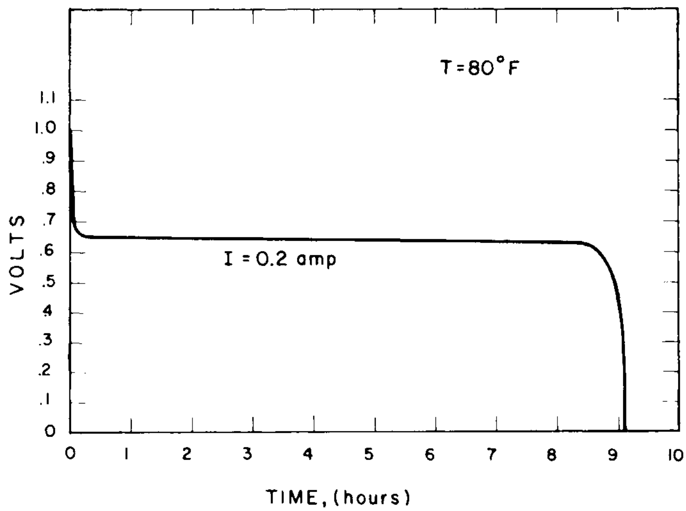

Fig. 4 Discharge characteristics

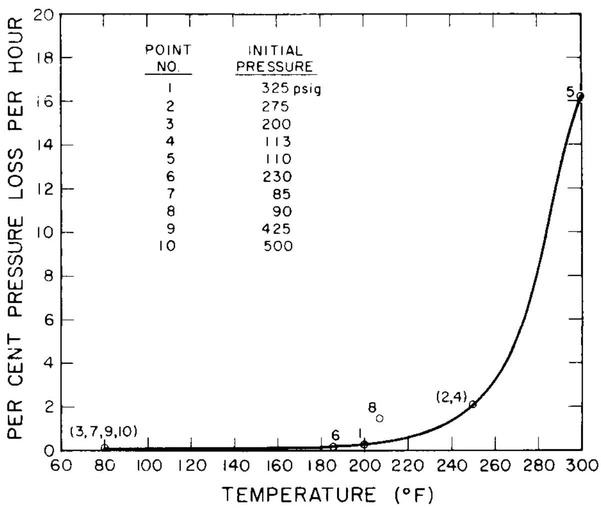

Fig. 5 Self-discharge characteristics

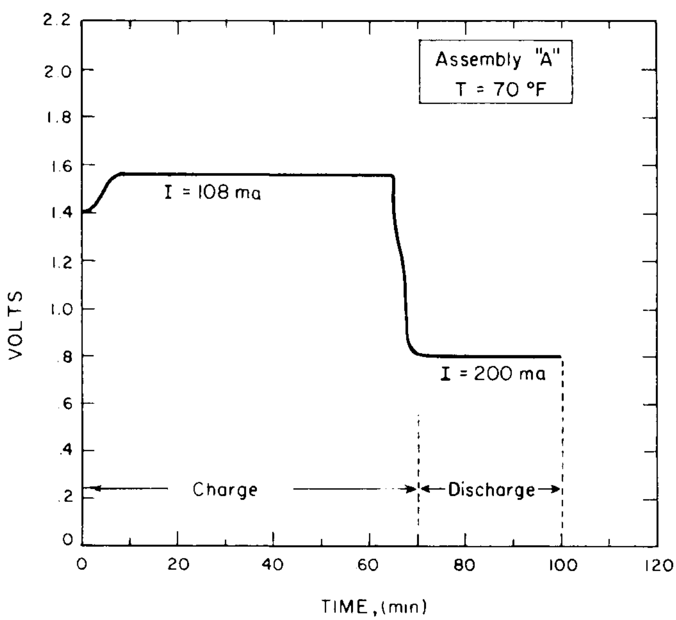

Fig. 6 65/35 cycle

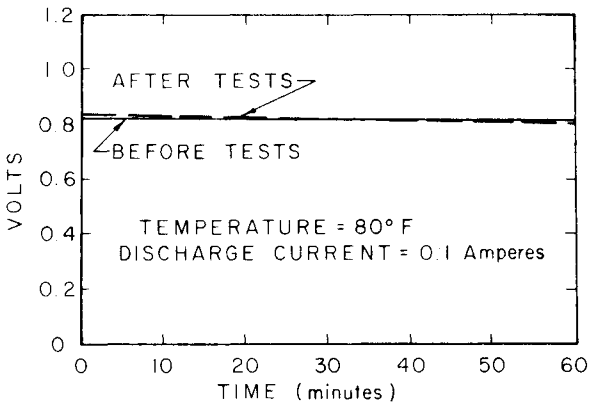

Fig. 7 Effect of environmental tests on discharge characteristics

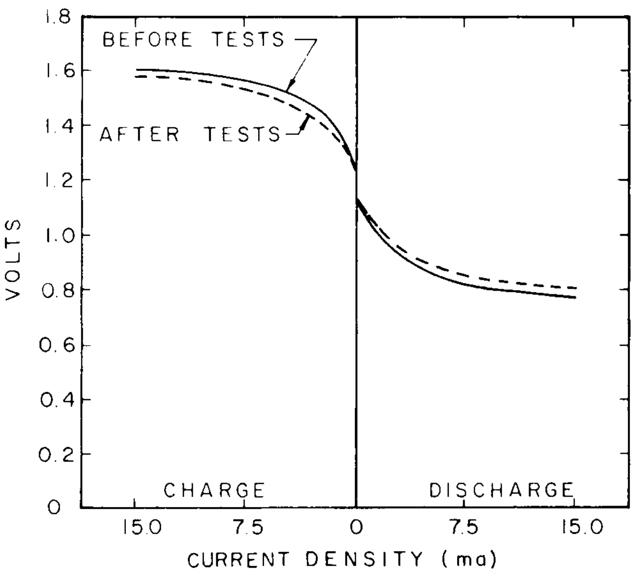

Fig. 8 Effect of environmental tests on V/I characteristics

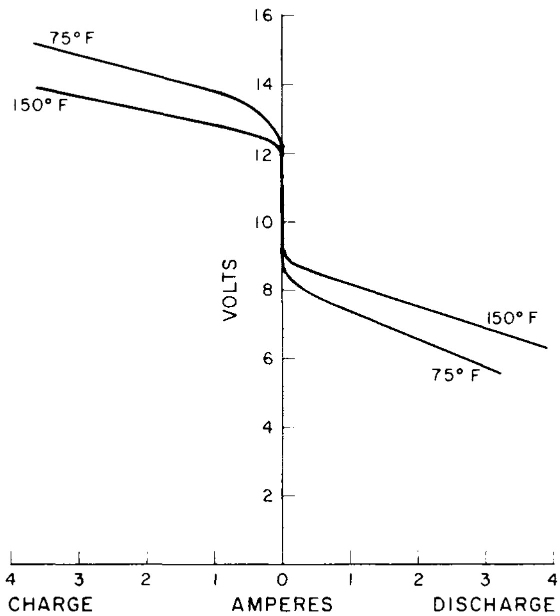

Fig. 9 Voltage current characteristics of nine-cell unit