FACTORS INVOLVED IN THE USE OF A HIGH-TEMPERATURE FUEL CELL AS A SPACE POWER SOURCE

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Abstract

Potential advantages of using a high-temperature, molten-electrolyte fuel cell as a space power source are discussed. Problem areas requiring development work before the cell can meet all space needs also are considered. These discussions are based on the performance characteristics of the molten-electrolyte fuel cell developed by Texas Instruments. Advantages of this cell for space power use are 1) high operating temperature (600°-650°C) permits use of small radiator and materially reduces chances of finding a nonsolar planetary surface temperature higher than that of the radiator; 2) product water leaves the cell as steam, does not dilute the cell electrolyte, and can be condensed for human use; 3) average power density in excess of 25 w/ft^2 at 0.7 v is achieved; 4) 30-day reliability at constant load is assured; 5) the capillary-immobilized electrolyte probably will meet all zero-g requirements; and 6) the cell can be operated on a variety of fuels. Problem areas requiring development work are 1) increase in power density by increasing current density and decreasing weight of cell materials; and 2) developing a satisfactory system for feeding carbon dioxide from fuel-electrode effluent to air-electrode influent. Solutions for these problems are evident and lie within relatively short time frames.

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Introduction

The use of a fuel cell as an auxiliary power supply in space has received considerable attention.[1-4] To date, such consideration has been confined to cells operating in the 25°-60°C and 200°-260°C ranges. It is the purpose of this paper to show that a fused-salt-electrolyte fuel cell, operating at 600°-650°C, has performance characteristics that recommend its serious consideration as a space power source.

Details of this fuel cell recently have been presented.[5] Figure 1 shows part of a typical development cell. The basic part of the cell consists of a rigid, porous MgO disk to either side of which porous, metal electrodes are mounted. The disk then is impregnated with $LiNaCO_3$ electrolyte (mp, 520°C) and sealed into a mild steel cell body. Caps with the necessary electrical and gas leads are welded to each side of the body, and the development cell is ready for operation.

As can be seen from Table 1, this cell system offers reproducible and reasonably high power at 0.7 v at 600°C. Using pure O_2 instead of air as oxidant will give an increase in power. This power can be increased further 1.5 to 2 times by raising the operating temperature to 650°C. Still further power increases can be obtained by pressurizing both the H_2 and air fed to the cell. For example, with both H_2 and air at 10 psig, power was increased to 1.4 times that obtained by using H_2 and air just above atmospheric pressure.

One attractive feature of this high-temperature cell is that it can operate well on impure H_2. This is seen in Fig. 2, which shows the voltage-current curve given by a cell after 21 hr of continuous operation on the fuel obtained by feeding propane to a small reformer mounted on the cell body. Using the previous slide as reference, it is seen that 80-85% of the power obtained with pure H_2 was obtained with the reformer product.

Another useful property of the cell is its ability to withstand thermal cycling. This characteristic is shown in Fig. 3 by the failure of daily cycling from 600°-25°-600°C to affect cell performance adversely. It is important to note that, except for fuel and air, no additions of any kind have been made to the cell throughout this cycling program.

Obtaining data like these requires long and careful monitoring of cell performance. A view of part of the cell reliability laboratory in which this work is done is shown in Fig. 4.

Results of this work now are being applied to assembly of fuel cell batteries. The first of these, comprising six cells and putting out 22 w at 0.7 v on H_2 and air at 600°C is shown in Fig. 5. This first battery was over-engineered as first products often are, with the result that the power-to-weight ratio was 1 w/lb. However, replacement of several steel parts by high-purity alumina is now underway. This step will increase the power-to-weight ratio to 3 w/lb at 0.7 v. By raising the current density from 100 to 200 amp/ft^2, an acceptable 6 w/lb can be achieved. This latter goal is a realistic one, as is shown by Fig. 6, which presents the gain in current density achieved in nine months by making relatively simple changes in the physical structure of the electrodes. With the fundamental information now coming from basic studies of electrode-electrolyte interaction, the authors are confident of achieving a current density of 200 amp/ft^2 at 0.7 v on H_2 and air at 600°C. With this fuel cell system for a source of auxiliary power in space, the following advantages can be realized:

1) The 600°-650°C operating temperature permits achieving a significant gain over 50°- and 200°C-cells in the net rate of heat rejection per unit radiator area. The actual gain factors can be as much as 30-40 times. Table 2 shows this. In Table 2, the radiator temperature has been taken to be 3/4 the cell temperature. At this condition, the required radiator area is minimized.[4] From Table 2, it is seen that, for fuel cells having the same electrical power and efficiency, a 600°C cell will permit using a radiator 18 times smaller than that required by a 100°C cell, 29 times smaller than that needed by a 50°C cell, and 38 times smaller than that used by a 25°C cell. Direct benefits to be gained from use of the 600°C cell and its small radiator include 1) reduced degradation of and damage to the radiating surfaces by radiation effects and meteorites, 2) decreased amount of working fluids used to supply heat to the radiating surface, and 3) freedom from decrease in radiator capacity when the sun's radiations strike the radiator surface, an effect that is significant for radiator temperatures below about 282°C (540°F,

1000°R).[4] In connection with this last advantage, the 450°C radiator temperature also will reduce materially the chances of finding a planetary surface temperature higher than that of the radiator. The sunlit side of Mercury, which radiometric measurements shows to be 410°C, is one of the few planetary surfaces which would present a problem for a 450°C radiator. The best solution, if the radiator had to face the 410°C surface, would be to increase both the cell operating temperature and the radiator surface temperature. This can be done.

2) Another advantage of the molten-electrolyte fuel cell for space use is that the cell products, H_2O and CO_2, leave the cell without diluting the electrolyte. In space operation, these products, formed at the fuel electrode, would be pumped to the oxygen electrode, where CO_2 is needed to replenish that consumed in the fuel electrode reaction. The water would be removed enroute by one of several techniques that are now available. The water, produced at the rate of about 1 lb/kw-hr, would be potable.

3) The molten $LiNaCO_3$ electrolyte, held in the MgO matrix by capillary forces, probably can meet all zero-g requirements. A similar arrangement, in which an ion-exchange membrane, saturated with 30% potassium hydroxide, is used as an electrolyte matrix, has been proposed for a fuel cell designed to operate in a space power system.[1]

4) Finally, the reliability of this fuel cell assures obtaining the length of operation required of space power units in which fuel cells are used. The authors have run five cells for 75 days or more, 11 cells for 50 days or more, and 24 cells for 30 days or more, this latter group including one that was cycled daily from 600° to 25° and back to 600°C. In all cases, power level was at 25 w/ft^2 or higher at 0.7 v.

Two major problem areas require development work before this molten-electrolyte fuel cell system can become a practical reality for space power use. One problem area is scientific, and the second is engineering. The scientific problem is to increase the current density to 200 amp/ft^2 at 0.7 v. This achievement, coupled with substitution of ceramic materials, such as high-purity alumina, for steel components, will increase the energy-density of the cell system significantly. The authors' experience shows that this dual accomplishment is feasible. The major engineering problem is to develop a satisfactory system for feeding CO_2 in the effluent from the fuel electrode to the air electrode and to remove the water enroute in such a way as to make it available for drinking. There is nothing in principle blocking solution of this problem, and results of preliminary experiments are promising.

It was anticipated that another major engineering problem existed. This was the rapid heating of the cell to operating temperature in the interval from liftoff to the start of orbital flight. The excellent thermal cycling results that were shown in Fig. 3 removed much of the uncertainty here. For instance, it is standard procedure in this cycling program to bring the cell from 25°C to operating temperature in 35 min. No attempt has been made to shorten this bring-up time but only because the necessary equipment is not readily available. As a result, the authors now are confident of being able successfully to bring the cell system to operating temperature even in a time-frame of as short a duration as minutes. Three approaches to this high-rate heating problem are 1) pyrophoric techniques, such as those used with thermal batteries; 2) catalytic heaters that operate on the oxidation of H_2; and 3) use of the exhaust heat from the vehicle itself, the heat being transmitted to the cell system through the radiator.

In conclusion, then, the advantages to be gained by use of a molten-electrolyte fuel cell system as a space power source are real and significant. There remain some few scientific and engineering problems to be solved before a working space power source is realized. However, the solutions for these problem areas are evident and lie within relatively short time-frames.

References

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Table 1 Demonstration of cell reproducibility[a]

Cell number	Power output at 0.7 v, w/ft^2	Point in cell life at which data were taken
275	51.6	7 days
276	43.8	7 "
278	46.3	8 "
279	38.5	7 "
296	54.5	7 "
297	46.0	7 "
298	42.0	7 "
302	45.5	7 "
303	47.3	7 "
308	48.5	7 "

[a] Operating temperature, 600°C; fuel, H_2; oxidant, air.

Table 2 Relative values of net rates of heat rejection by fuel cell radiator to space

Fuel cell temperature, °C	Radiator temperature °C	Radiator temperature °K	Relative values of net rates of heat rejection by radiator to space (x 10^3)
25	19	292	26
50	38	311	34
100	75	348	54
200	150	423	117
300	225	498	225
600	450	723	1000

Fig. 1 View of typical TI development cell

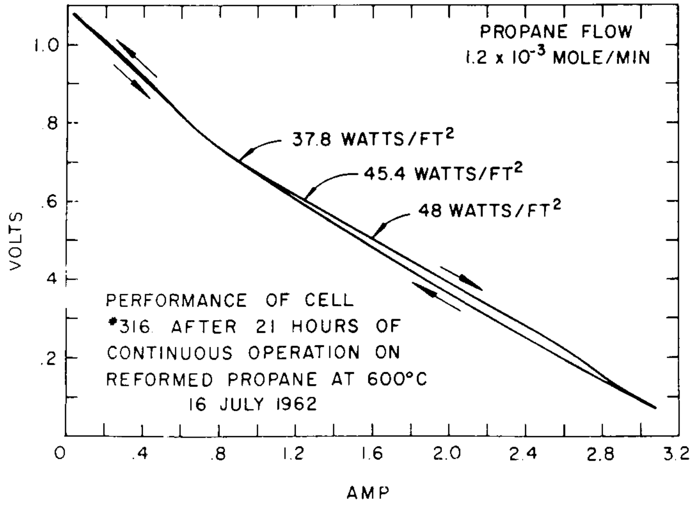

Fig. 2 Voltage-current curve for cell running on reformed propane (21st hr of continuous operation at 600°C)

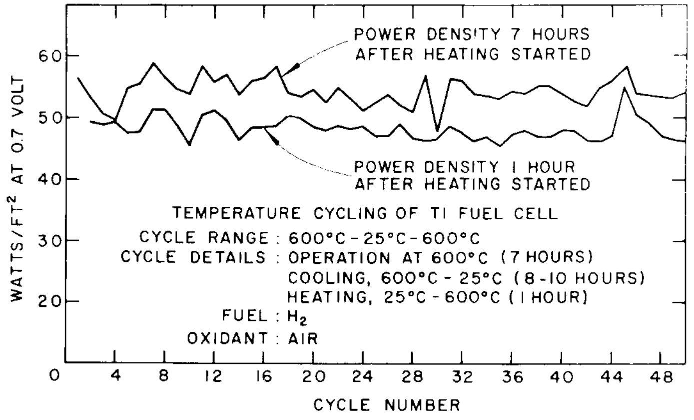

Fig. 3 Performance of a cell submitted to a daily thermal cycle from 600° to 25°C, then back to 600°C

Fig. 4 A view of part of the cell reliability laboratory

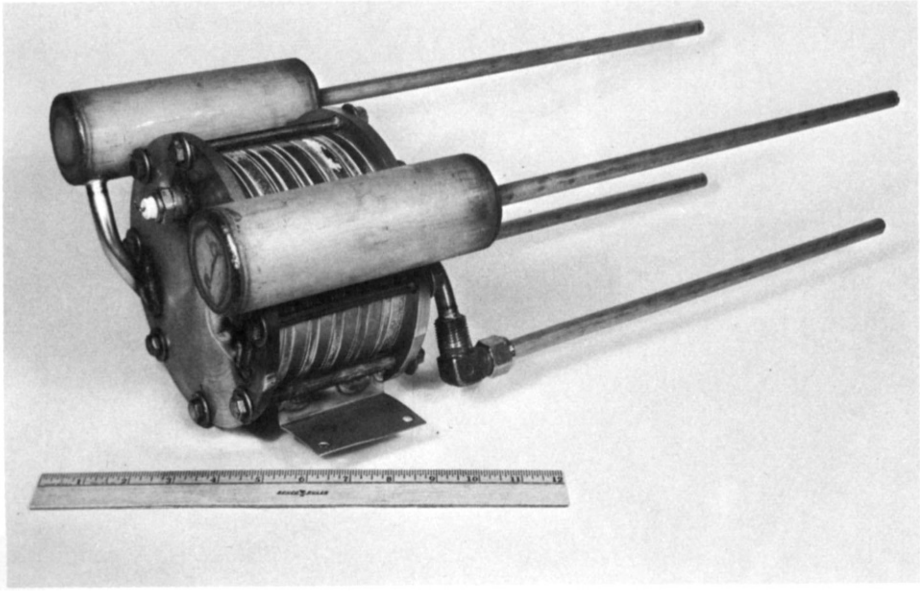

Fig. 5 First six-cell battery

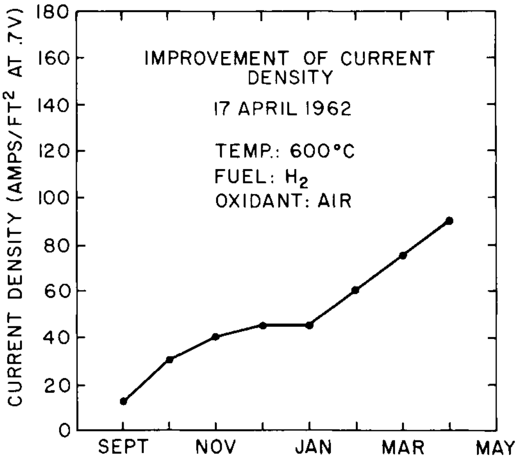

Fig. 6 Improvement in current density over a nine-month period