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ADVANCED SPACECRAFT FUEL CELL SYSTEMS

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INTRODUCTION

Lightweight, long-lived, reliable, versatile fuel cell systems are the goal of everyone in the fuel cell area. The Lewis Research Center's Advanced Technology Fuel Cell System Program with Pratt & Whitney Aircraft's South Windsor Engineering Facility is an evolutionary advanced technology program aimed at meeting the requirements of the next generation of fuel cell systems as well as providing technology fallout to ongoing mission oriented programs. In programs that are specific mission oriented, very often scheduling constraints require that the shortcomings of fuel cell systems be designed around rather than addressed directly. An advanced technology program on the other hand does permit more effort to be applied towards solving these basic problems. The potential benefits of such a program are two-fold. First, a superior system can emerge at a technology level where potential users can compare it to the existing inventory of systems. Second, and of equal importance, technology generated during the course of such a program (superior catalysts, materials of construction, etc.) could be utilized by ongoing mission oriented programs. For this reason, the LeRC program has tasks in the area of advanced materials for cell frames, matrices, catalysts, electrolyte reservoirs, etc. The goal in the materials area is towards lightweight cell components that will withstand higher temperatures at high current densities for longer periods of time.

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THE SYSTEM

The schematic of the system selected for development is shown in Figure 1. The specific goals for it are 10,000 hours of operation with refurbishment, 20 lb/KW at a sustained power of 7 KW, and 21 KW peaking capability for durations of two hours. The system is designed to operate on low pressure, propulsion grade hydrogen and oxygen. The system rejects waste heat to the spacecraft cooling system at power levels up to 7 KW. At higher power, or if the spacecraft heat sink is temporarily not available, the system automatically transfers to open cycle operation with cooling provided by venting steam overboard. The design point of the alkaline electrolyte matrix fuel cells is 180°F and a reactant pressure of 16 psia. The goals for this system and other operating details are listed in Table I. Although this overall system concept is new, it contains features that have appeared in previous system concepts. The system requires no parasitic power except for the electronics. There are no rotating pieces of equipment. The one pump used is a reciprocating device operated by the gas pressure of the incoming hydrogen.

Product water is removed by a passive water removal method (Figure 2) that employs a porous hydrophobic membrane as a part of the water transport plate. Heat is removed using intercell evaporative coolers. These devices (Figure 3) permit water to be evaporated through a porous hydrophobic membrane into the low pressure steam cavity. This cooling concept reduces the temperature variations across the face of the cells to a minimum.

As in other fuel cell powerplants, the waste heat and product water removal controls maintain the cells' temperature and water balance within the desired ranges. In this system, the controls are pressure regulator valves in the steam/water loop. This loop collects the water vapor from the intercell evaporative coolers as well as from the product water removal cavities. After these vapors are condensed, the water is pumped either into the intercell coolers or stored onboard the spacecraft. During the 21 KW peaking operations this stored water is returned for use in the evaporative coolers as the condenser is sized only to handle 7 KW water vapor loads. This open cycle operation commences when the condenser can no longer handle the heat load and the pressure in the loop builds up to where the overboard vent valve opens.

The life goal of 10,000 hours of operation in combination with the weight goal of 20 lb/KW led the contractor to stress weight improvements rather than increases in current densities. A cell current density of 133 amp/ft^2 corresponds to 7 KW. The requirement for high voltage operation (117 volts) was met by adopting the concept of a multicell plaque (Figure 4) where the manifolded services are shared by a number of single cells edge connected in series. This figure depicts the present concept of six cells per plaque. The cathode screen from one cell passes through the gas-tight intercell seal and becomes the anode screen for the adjacent cell. Thus, all the anodes are on one side of the plaque, and all the cathodes on the other. In the complete stack these plaques can be connected electrically in series and parallel arrangements to provide the required 117 volts or lower voltages as mission requirements dictate.

At the time of this writing about eight months of the first phase of this program have passed. No complete system build will take place until successfully completing an evolutionary technology program in which all of the integral parts and components have been verified and undergone endurance testing. At appropriate times during the course of this program, results of testing to date as well as inputs from spacecraft prime contractors will be used in performing trade-off studies which could effect the final design of the complete system.

SYSTEM COMPONENT TESTING

At the present time single cells, multi-cell plaques, intercell evaporative coolers and a breadboard condenser are undergoing what is termed research and technology testing. A major effort is devoted to exploring alternate materials and fabrication techniques for producing single cells and multi-cell plaques which provide the required corrosion resistance, dimensional stability and practical production characteristics. Figure 5 is a detailed drawing of the single cell showing the dimensions of the components. The stress on weight reductions for the overall system is reflected in the cell in terms of the widespread use of plastics as well as the thinness of all the components. The small electrolyte inventories resulting from this approach requires that the plastic cell structures and sealing materials be almost totally resistant to oxidation. Oxidation products result in a conversion of a portion of the electrolyte to carbonate. Carbonated solutions not only possess poorer ionic conductivities, but their vapor pressure characteristics are such (Ref. 1) that loss of electrolyte volume ensues both of which result in a reduction in cell performance. Special materials compatibility testing techniques have been developed and are being used to identify the oxidation characteristics of candidate cell materials.

Intercell evaporative coolers have been tested at twice the maximum anticipated heat load over a range of water pressures. There appears to be no difficulties in this area.

A plate-fin condenser is being used to verify that this type of construction can be used in a variable gravitational environment and maintain proper liquid/vapor location over a variety of heat loads. The sub-atmospheric pressure condenser has shown it can perform satisfactorily.

ADVANCED MATERIALS

To achieve the weight goals set for this program requires the use of non-metallic structural components for cells and evaporative coolers. Achieving the life goal requires that such components be highly resistant to degradation from the potassium hydroxide electrolyte, steam, and reactant environments. Particular attention is being given to cell framing materials. Previous experience (Ref. 2) has shown that fiberglass-epoxy materials used in state-of-the-art fuel cells are not suitable for long term operation with low electrolyte inventory cells. Multi-thousand hour duration corrosion tests are being performed on candidate materials to identify the best combinations of plastics, filler materials and bonding agents.

Reconstituted asbestos has already replaced the Johns-Manville produced material for cell matrices. It is felt that matrices made from DuPont's Fybex$^{(R)}$ potassium titanate normally used as a filler material for plastics could result in even better matrices. At the Lewis Research Center it was found to be more stable in 150°C, 42 w/o KOH, 500 hour soak tests than asbestos or other forms of potassium titanate. Since KOH attack on the silicate part of the asbestos structure limits the upper temperature for asbestos matrix cells, potassium titanate matrices will allow higher temperature operation.

Improved oxygen catalysts are also being pursued to extend life and allow higher temperature operation. The solution rate of platinum presently used as an oxygen catalyst is such that although single cells have been run for over ten thousand hours with acceptable performance losses, the platinum cathode catalyst migration has been significant. This rate of migration increases with temperature and could lead to electrical shorts across the cells or to undesirable alterations in the physical properties of the matrix and/or electrodes. Gold, on the other hand, has long been known to be more noble than platinum, but tends to be subject to grain growth and thus loss of active area. A cathode catalyst alloy of 97 w/o gold and 3 w/o platinum has shown very encouraging results. Figure 6 shows that the initial performance of a cell with a gold catalyzed cathode is superior to a cell with platinum catalyst. A 5,000 hour endurance run on a cell with the gold-platinum alloy catalyst was recently completed. Post test examination showed the cathode to have experienced almost no loss of catalytic activity and no gold migration. The slow drop-off in performance (about 6 microvolts/hr @ 100 ASF) was most likely due to electrolyte carbonation or improper electrode structuring. The problem of improper electrode structures, that is, inability to maintain the desired gas-electrolyte-catalyst interface, is the main source of difficulty with the gold-based catalysts. The efforts in this area are now being directed to electrode fabrication techniques to achieve reproducible, superior cathode structures.

SUMMARY

The initial phase of an advanced technology fuel cell system has been described. The program philosophy is an evolutionary technology advancement in the area of materials of construction and system components. Design tradeoff studies based on inputs from the technology advancement tasks as well as from potential users of advanced systems will be performed in a timely manner in order that the resulting system will find wide application. At the present time, materials studies, single cell, and multi-cell plaque work is the main effort.

REFERENCES

1. NASA TM X-52812 "Effects of Carbon Dioxide on Trapped Electrolyte Hydrogen-Oxygen, Alkaline Fuel Cells," L. H. Thaller, R. E. Post and R. W. Easter (1970).
2. K. O. Wood and W. F. Bell, "The Effect of Design and Operating Factors on Life and Performance of Matrix Fuel Cells". Final Reports on Contract NAS3-13229.

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TABLE 1

SYSTEM GOALS

OPERATING LIFE, HOURS	10,000
SPECIFIC WEIGHT	
LB. PER KW SUSTAINED POWER	20
LB. PER KW MAXIMUM POWER	6.7
SPECIFIC VOLUME	
FT^3 PER KW SUSTAINED POWER	.50
FT^3 PER KW MAXIMUM POWER	.17

SYSTEM PARAMETERS

VOLTAGE LEVEL	117
POWER RANGE, CLOSED CYCLE, KW	1.4–7
POWER RANGE, OPEN CYCLE , KW	1.4–21
TOTAL CELL AREA, FT^2	60
CELL TEMPERATURE , °F	180
CELL PRESSURE, PSIA	16
REACTANT SUPPLY PRESSURE, PSIA	35–1,000
SPECIFIC REACTANT CONSUMPTION LB/KWH	.87

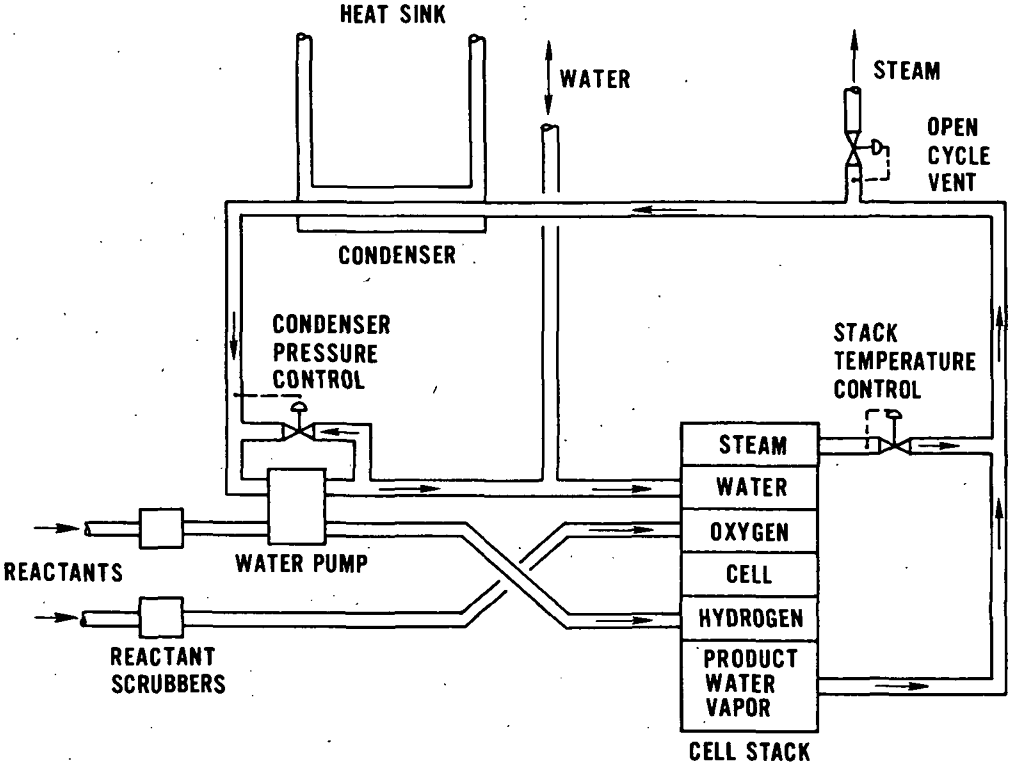

Fig. 1. - Advanced fuel cell system schematic.

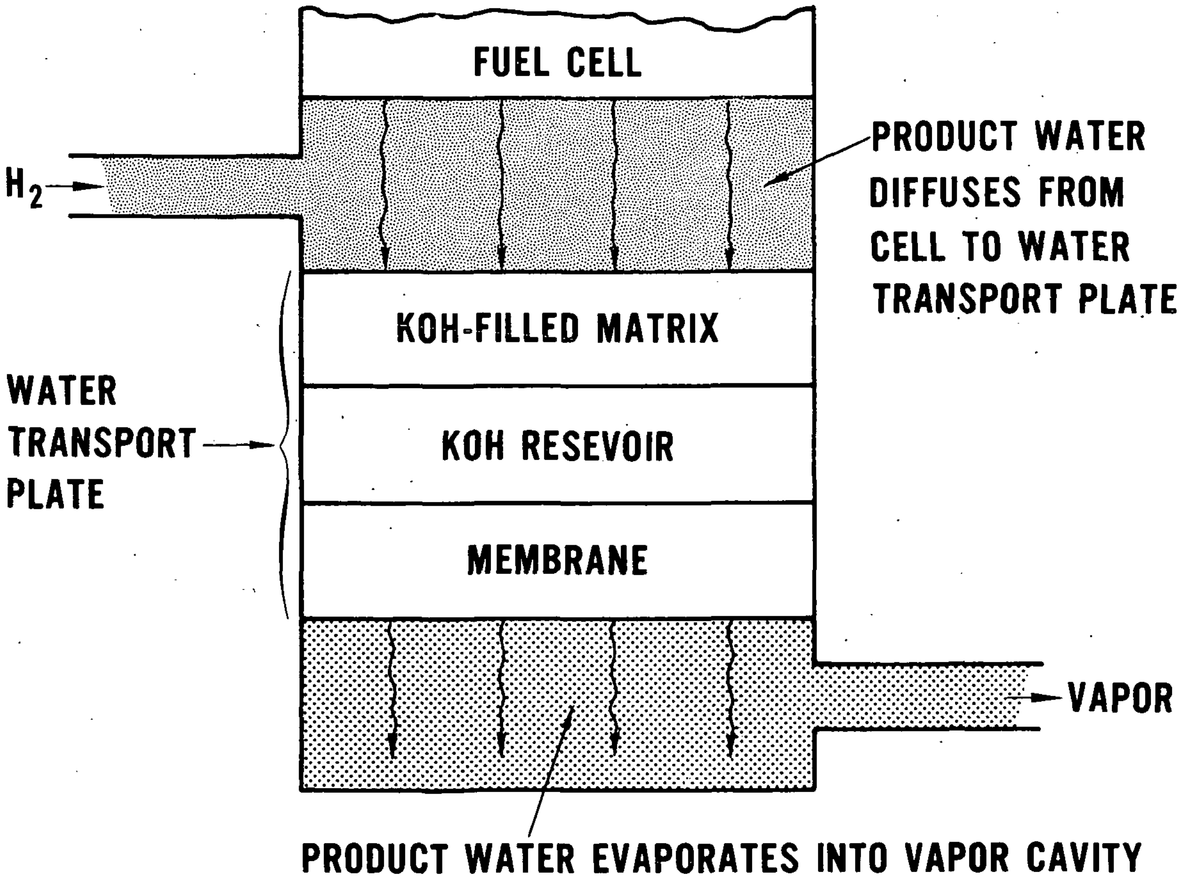

Fig. 2. - Passive water removal schematic.

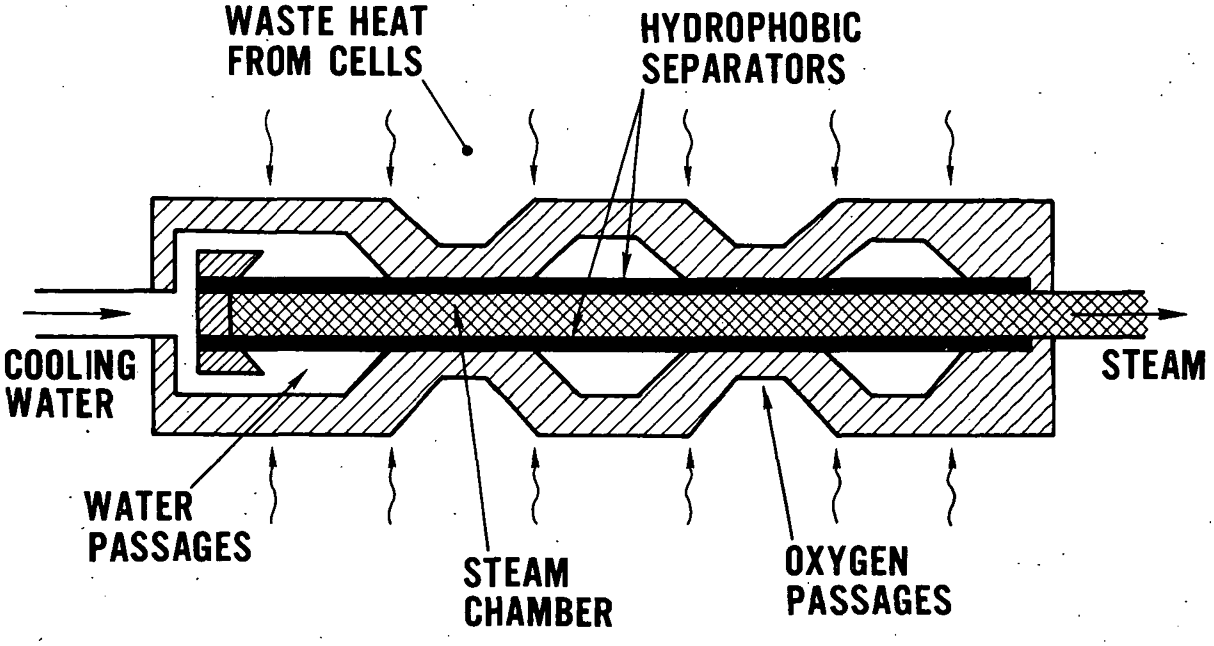

Fig. 3. - Evaporative cooler schematic.

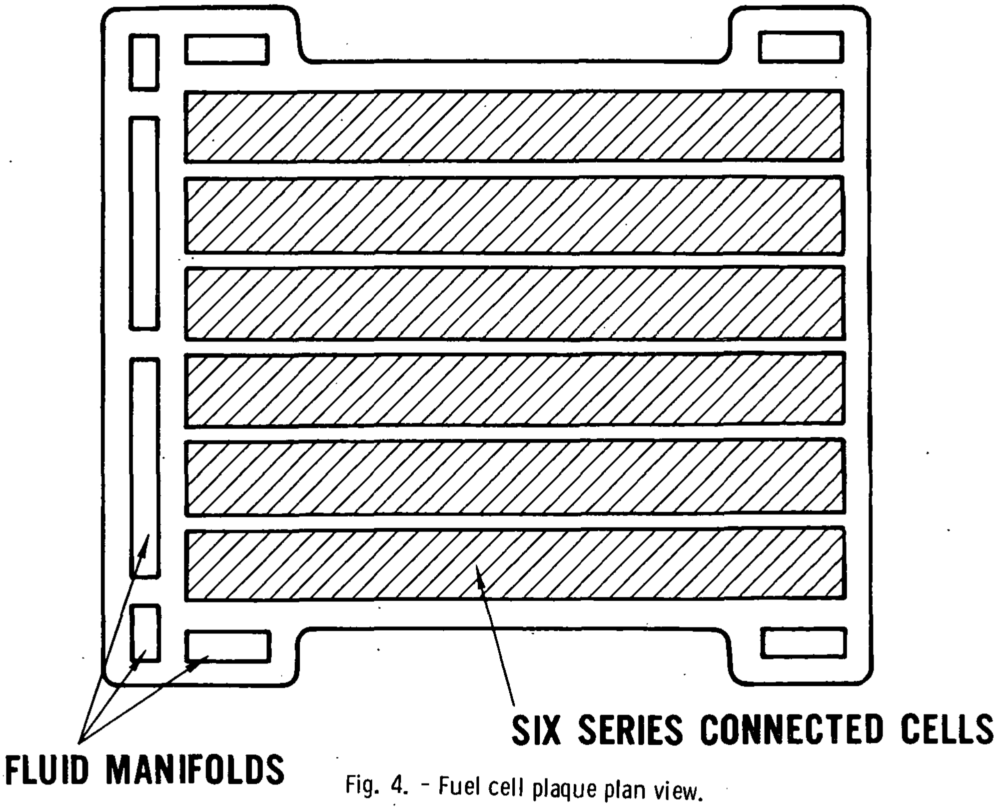

Fig. 4. - Fuel cell plaque plan view.

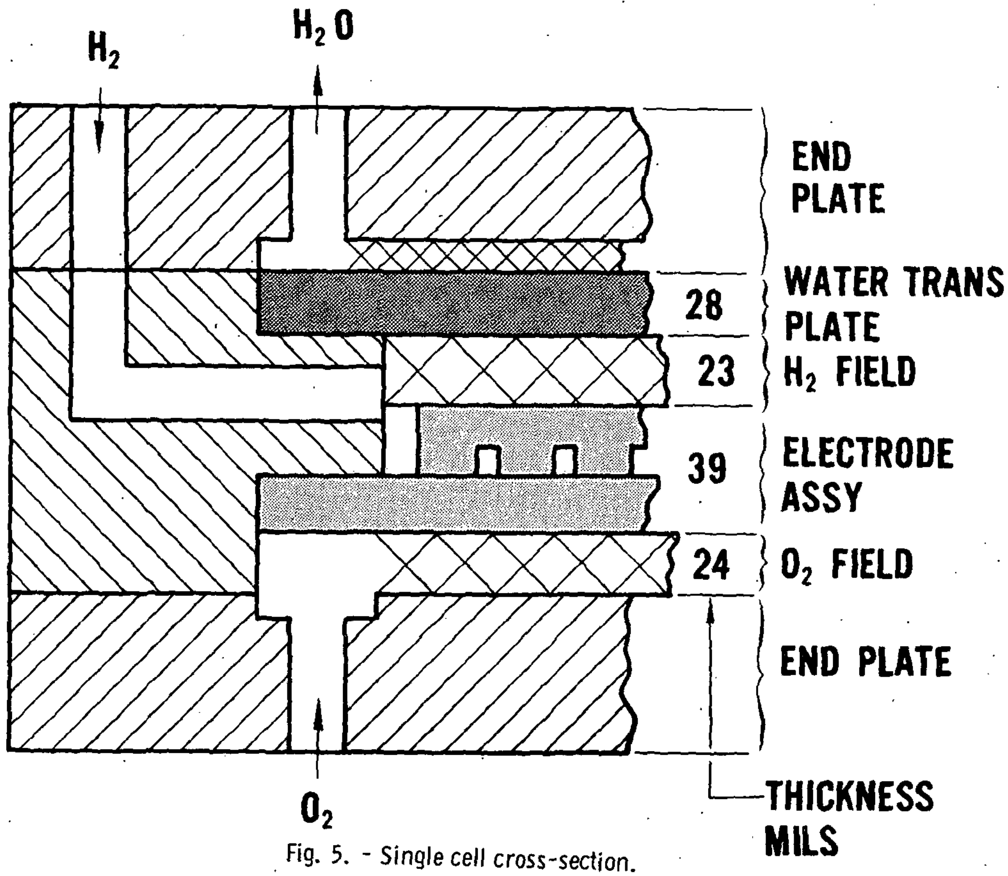

Fig. 5. - Single cell cross-section.

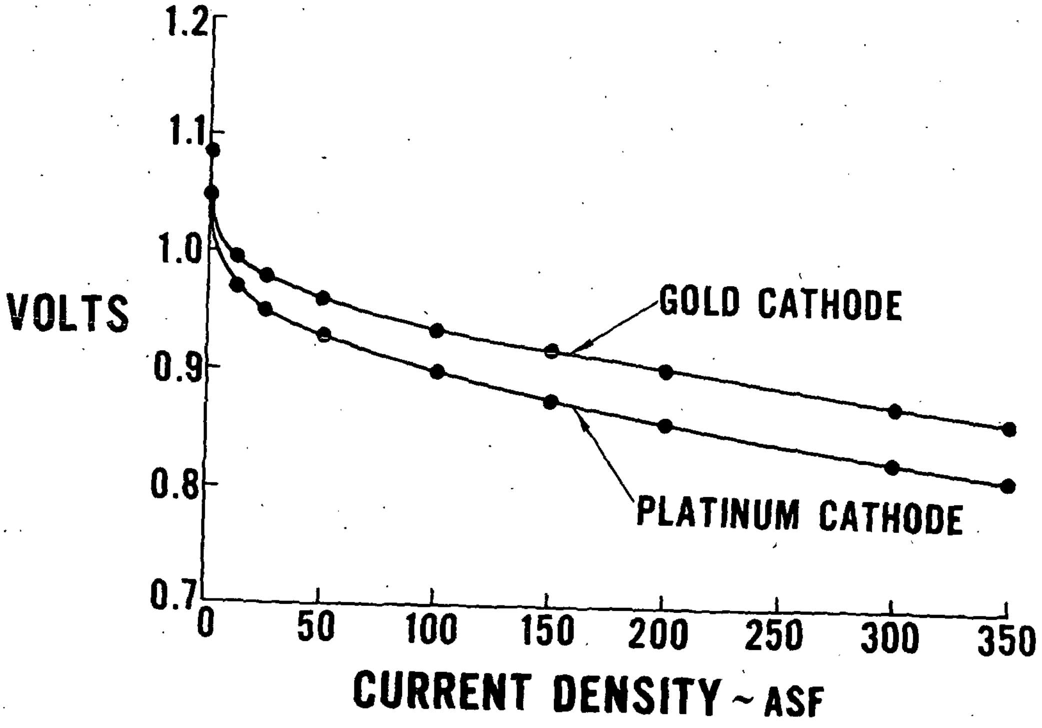

Figure 6. - Comparative cell performance at 16 psia, 190° F.