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FUEL CELL TECHNOLOGY FOR LUNAR SURFACE OPERATIONS

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Abstract

Hydrogen-oxygen fuel cells have been shown, in several NASA and contractor studies, to be an enabling technology for providing electrical power for lunar bases, outposts, and vehicles. The fuel cell, in conjunction with similar electrolysis cells, comprises a closed regenerative energy storage system, commonly referred to as a regenerative fuel cell (RFC). For stationary applications, energy densities of 1,000 watt-hours per kilogram, an order of magnitude over the best rechargeable batteries, have been projected. In this RFC, the coupled fuel cell and electrolyzer act as an ultra-light "battery." Electrical energy from solar arrays "charges" the system by electrolyzing water into hydrogen and oxygen. When an electrical load is applied, the fuel cell reacts the hydrogen and oxygen to "discharge" usable power.

Several concepts for utilizing RFCs, with varying degrees of integration, have been proposed, including both primary and backup roles. For mobile power needs, such as rovers, an effective configuration may be to have only the fuel cell located on the vehicle, and to use a central electrolysis "gas station."

Two fuel cell technologies are prime candidates for lunar power system concepts: alkaline electrolyte and proton exchange membrane. Alkaline fuel cells have been developed to a mature production power unit in NASA's Space Shuttle Orbiter. Recent advances in materials offer to significantly improve durability to the level needed for extended lunar operations. Proton Exchange membrane fuel cells are receiving considerable support for hydrospace and terrestrial transportation applications. This technology promises durability, simplicity and flexibility.

FUEL CELL TECHNOLOGY FOR LUNAR SURFACE OPERATIONS

The fuel cell is an electrochemical device in which hydrogen and oxygen react directly to produce electricity without combustion or mechanical conversion. The products of this reaction, besides electricity, are potable water and heat. The fuel cell is highly efficient; aerospace fuel cells operate at over 70% efficiency at rated power. Unlike most power sources, fuel cell efficiency increases at part power.

Fuel cells have been utilized in the U.S. manned space programs because their high efficiency and high energy density provide the lowest-mass means of generating electrical power. Other beneficial characteristics of the fuel cell include: freedom from noise, vibration, and torques; the capability for instantaneous power transients (both up and down); and the absence of any effluents other than potable water. Three IFC fuel cell power plants provide all on-board electrical power for the NASA Space Shuttle Orbiter, and were previously utilized on the Apollo Command and Service Module.

Another beneficial characteristic of fuel cells is the relationship between power and energy. A fuel cell powerplant is sized based on the system power requirements; this results in a fixed powerplant mass independent of energy. Energy needs are met by providing the hydrogen and oxygen reactants (and storage tanks), which are extremely light compared to other forms of energy storage. In the case of the Orbiter, this results in a power system energy density of over 500 watt-hours per pound.

While there are several types of fuel cell technologies (differentiated by the cell electrolyte), only two are relevant to space applications: alkaline and proton exchange membrane (PEM). The alkaline cell utilizes an aqueous potassium hydroxide (KOH) solution as the electrolyte, while the PEM cell employs a perfluorosulfonic acid polymer membrane. Each technology offers certain advantages for particular applications, as is discussed following. The alkaline technology is more mature, as evidenced by its use on the Orbiter. However, PEM is receiving considerable support for terrestrial and hydrospace applications and is approaching operational powerplant status.

Alkaline cells intrinsically have the highest efficiency. However, the concentration of the aqueous electrolyte must be controlled with relative precision, which necessitates a sophisticated control system. The alkaline technology is particularly well-suited to longer-duration missions, where its high efficiency results in pronounced reactant mass savings. Also, the alkaline cell is capable of large-magnitude power pulses (ten or more times nominal). The current state of the art in alkaline fuel cells is the 12-kw Orbiter powerplant, which has accumulated over 27,000 hours of operation in 45 missions. In SEI, alkaline fuel cells are envisioned primarily for efficiency-critical baseload or power sharing applications, where they will operate continuously for long periods with few start/stop cycles.

The PEM fuel cell, with its solid electrolyte, requires a simpler control system, affording ease of start/stop. Because the electrolyte is a non-corrosive solid, PEM cells can utilize less sophisticated materials than are required for alkaline cells. The simplified controls and materials result in a powerplant which is projected to be lower in cost. Further, the absence of a corrosive electrolyte enables extended durability. The PEM cell does, however, have somewhat lower efficiency than the alkaline cell at comparable conditions. These characteristics make PEM most suited to missions where repeated start/stop and durability are the prime factors. In SEI, PEM cells are envisioned for use in rovers or other installations where frequent start/stop and relatively short operating periods are necessary.

Numerous studies have indicated that regenerative fuel cells (RFCs) are a key element in a lunar surface power system. An RFC is created by coupling a fuel cell with an electrolyzer and tankage to act as an ultra-light battery. The electrolyzer is also an electrochemical device, which acts as the reverse of a fuel cell: the application of electric power to the cell causes the dissociation of water into its hydrogen and oxygen constituents. In the RFC, the electrical power available from a solar photovoltaic array during the lunar day is used to electrolyze water. The resulting H_2 and O_2 are stored as high-pressure gasses. Then, in lunar night, the reactants are supplied to the fuel cell to produce electric power. The product water is collected and stored, to be electrolyzed during the next lunar day. Thus the RFC is a totally closed system, requiring only an initial charge of either water or reactants.

RFCs are considered for use in several modes. In a photovoltaic system, the RFC would be the sole source of power during lunar night. However, if a nuclear-based system is eventually established, the RFC would be used to provide peak load shaving and emergency backup power. For stationary equipment, such as a habitat or outpost, the fuel cell and electrolyzer would be integrated as a single unit. However, when it is desired to have mobile power, such as a rover, the fuel cell and electrolyzer can be decoupled. The electrolyzer would be located at the base, where it would deliver reactants to storage tanks. The fuel cell would be on the rover, which would return to the base "gas station" to refuel and return its product water for electrolysis.

RFCs have a significant mass advantage over batteries. In a study[1] for NASA, Los Alamos National Laboratory sized an RFC systems for a 25-kW 14-day lunar night mission; this resulted in a system mass of 8300 kilograms. By comparison, a battery system, using 50 watt-hour per kilogram batteries, would have a mass of 84,000 kilograms. Thus the RFC provides a mass saving of 75,000 kilograms.

The choice of fuel cell technologies (between alkaline and PEM) is still undecided. The alkaline system is space qualified and more efficient, but at present, its durability is limited due to corrosion of the cell materials by the electrolyte. The PEM system, while potentially simpler and less costly, is not operational and has not demonstrated space/lunar compatibility. The choice (if in fact it is necessary to make a single choice) will depend on mission/application requirement and on the state of the art at that time. It is possible , however, that both technologies will be used in different applications to take advantage of their unique capabilities.

The major issue in the alkaline cell is durability due to corrosion. Recent work in high power density fuel cells for SDI applications has identified and demonstrated new materials which significantly extend cell life. Incorporation of these materials into the Orbiter (or an Orbiter-derivative) powerplant would allow projection of a 20,000 - 40,000 hour service life. In addition, the compatibility of the alkaline fuel cell with PEM electrolyzers (the probable choice for SEI) has been demonstrated. An Orbiter powerplant was operated with a PEM electrolysis unit, as a breadboard RFC, for extended periods by NASA-JSC.[2]

In PEM, the key issue is to adapt the soon-to-be-operational terrestrial/hydrospace cell and powerplant to the space/lunar environment. While nothing in this call and system design is inherently incompatible, the efficacy in a 0g or low-g vacuum environment has yet to be demonstrated. Further, the terrestrial PEM applications are not mass-critical, so the cell may require engineering to reduce mass. Additional effort to improve efficiency may also be necessary.

Despite the key role assigned to RFCs in the space exploration scenario, there is at present no ongoing government-sponsored activity to test or develop the RFC. Nor is there any activity to improve the Orbiter fuel cell or adapt the PEM cell to space. Thus, although RFC concepts are well-defined, and have been tested as a breadboard, there is little depth of knowledge regarding integration issues. While the existing state of the art may be adequate for early lunar missions, a strong, focused development effort will be necessary to insure readiness for a permanent lunar presence.

REFERENCES

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[2]Saucier, D., "Hybrid Regenerative Fuel Cell Systems for Space Applications." Proceedings of the 23rd Intersociety Energy Conversion Engineering Conference, Denver, CO (July 31 - August 5, 1988).