

NASA LEWIS EVALUATION OF  
REGENERATIVE FUEL CELL (RFC) SYSTEMS

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INTRODUCTION

At the present time, the primary focus of the Energy Storage Branch at LeRC is the nickel-hydrogen battery, both IPV and bipolar configurations. However, relatively low-level efforts have been initiated recently on two regenerative fuel cell (RFC) systems. The first of these is the "passive" hydrogen-oxygen RFC, indicating a system capable of operating with no rotating components, such as pumps or compressors. The rationale for considering the development of such a system rests upon the high energy densities projected for hydrogen-oxygen RFC's in GEO orbits, the long life requirements for such orbits, the assumption that components such as pumps and motors would be the life-limiting elements in a conventional hydrogen-oxygen RFC, and the unlikelihood of servicing satellites in GEO orbit. The second RFC being considered is the hydrogen-bromine system. The most promising characteristic of this RFC is that the electrode reactions apparently are reversible, which could result in round-trip energy efficiencies of 75% or more. This would be very significant for LEO missions, since the smaller PV arrays required for the more efficient storage system would cause less atmospheric drag and thus require less reboost fuel over the mission life.

In addition to the advantages which are specific to the respective systems, there are also advantages which are generic to flow batteries. Perhaps the most significant of these is, that since all reactants and products are either liquids or gases, the difficulties associated with solid electrode reactants are avoided. These are related to morphology changes, and include swelling, shedding and dendrite growth. Flow battery systems also are amenable to efficient adaptation to changing mission requirements and growth, because the power-related portions of the system (cell stacks, pumps, etc.) and the energy-related portions (reactants and tanks) can be independently varied. Another characteristic of flow batteries is that they are generally constructed in the bipolar configuration, which results in the cells being electrically in series, but hydraulically in parallel. The effect of this is, that with respect to the concentrations of reactants entering the cells, all cells are always electrochemically in balance with respect to one another. It thus becomes possible to discharge different cells at different rates, or even to charge some cells while discharging others. This allows a great degree of operational flexibility with virtually no attendant penalty. Finally, because the reactants are liquids or gases, they tend to have quite high energy densities.

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This paper presents a brief discussion of the significant characteristics of each of the RFC systems under consideration, and indicates what presently is being done to evaluate them.

### THE PASSIVE HYDROGEN-OXYGEN RFC

The use of pumps and motors in a conventional hydrogen-oxygen RFC is associated with the removal of waste heat and the storage of product water. Elimination of these dynamic devices will require a system design that provides for an efficient static method of thermal control, and a cell design that can accommodate internal storage of product water. A block diagram of one possible passive RFC configuration is given in figure 1. In this concept, intercell heat pipes would transfer heat to a cold plate for radiation to space. The rate of heat rejection could be controlled by louvers positioned by bimetallic actuators. During the relatively long periods of low-rate charging, conservation of heat would probably be required. The system would therefore be well insulated, and provision probably would be made for parasitic heating of the reactant tanks to prevent condensation of water vapor on the tank walls.

Several options are available with regard to cell and stack configurations for the passive hydrogen-oxygen RFC. The first involves the choice between acid and alkaline electrolytes. Alkaline cells have been used on the Apollo and space shuttle missions. They represent a well-developed technology, and are generally more efficient than the acid electrolyte (SPE) cells. However, acid cells were used on the Gemini mission, and are now considered by some to offer the possibility of invariant performance over very long periods of time. Low power level SPE electrolyzers have been used in space in life-support systems, e.g., for carbon dioxide concentration. Therefore, both the acid and the alkaline technologies have been used in space, both have advantages and disadvantages, and both have their own advocates.

Another configuration issue is whether to incorporate separate cells for the charge (electrolyzer) and discharge (fuel cell) functions, or to use cells which can perform both functions. The latter option, of course, would be lighter and simpler, all things being equal. However, because of the well-known irreversibility of the oxygen electrode, better round-trip efficiencies can be achieved when optimized electrode catalysts are used for the charge and discharge modes, respectively, i.e., when separate cells are incorporated in the system. Such a configuration, though, would require some sort of edge current collection, which well might nullify any potential efficiency advantages.

It can be seen that a careful trade-off analysis must be carried out for the competing cell and stack configuration options for the passive hydrogen-oxygen RFC. Only after this is accomplished can a judgement be made concerning the possible development of the system for GEO missions. International Fuel Cells, Inc. (IFC) is presently starting work on this system analysis. At the same time, considerable effort continues to be expended on the development of oxygen electrode catalysts for fuel cells, electrolyzers

and dual-mode cells. This includes current contracts and grants, supported by LeRC, with Giner, Inc., the Polytechnic Institute of New York and ElTech, Inc. Results of this work naturally will be factored into the trade studies being carried out both at LeRC and at IFC.

## THE HYDROGEN-BROMINE RFC

This system has been evaluated in some detail in recent years, for several potential terrestrial applications. In all cases, the cell configuration has been based on the acid, solid polymer electrolyte (SPE) technology. The most attractive characteristic of the hydrogen-bromine cell is the apparent reversibility of the electrodes in both the fuel cell and the electrolyzer modes of operation. As mentioned earlier, this characteristic should be reflected in a stack and system design that is simple, lightweight and quite efficient. A block diagram of a hydrogen-bromine RFC is presented in figure 2, indicating a static hydrogen storage/supply system and a circulating aqueous bromine/HBr positive reactant. The use of such a system in space presents some unique constraints that did not need consideration for terrestrial applications. One of these is the absence of a sufficient gravity field for the separation of multi-phase fluids: Any gas passing through the SPE into the aqueous bromine system, or any liquid passing into the gaseous hydrogen system will tend to remain there and probably interfere with normal system performance. The evaluation of the membrane transport properties with respect to the various operating conditions and the various transportable species is thus of significance. Adding to this is the fact that the hydrogen electrode catalyst, typically platinum, is susceptible to poisoning or dissolution, depending on the electrode potential, in the presence of bromide ions which pass through the membrane.

Another multi-phase fluid situation can arise when the hydrogen-bromine system approaches full charge. As the HBr concentration is depleted, the solubility of bromine in the existing aqueous solution can be exceeded, resulting in a separate, pure bromine phase. The presence of bromine, whether in solution or not, creates a highly corrosive environment for the various cell components. This includes the bromine electrode itself, which may comprise a carbon or graphite structure and therefore be susceptible to intercalation and possible attendant damage.

Membrane transport properties and material compatibilities in the hydrogen-bromine cell environment have been studied by quite a few investigators. At LeRC we are undertaking an experimental program that initially will cover much the same ground as that covered by those investigators. One reason for this repetition is, that because of our interest in orbital missions and their unique characteristics, we bring a different perspective to the studies. Presently, we are carrying out static and electrochemical corrosion tests on candidate materials for cell construction, we are using electrochemical analytical techniques such as cyclic voltammetry for the evaluation of catalysts for the hydrogen and bromine electrodes, and we are evaluating single cells based on membrane and electrode (M&E) assembly technology developed by General Electric (Now Hamilton

Standard Electro-Chem, Inc.). We are also evaluating the transport properties of SPE membranes as functions of reactant concentrations, temperature, electric field intensity and membrane characteristics. In addition, we hope to continue a program with Giner, Inc., for the development of unique electrode catalysts for this system. Under a grant to the University of Akron, a system model is being developed and evaluated against single cell experimental data.

#### SUMMARY

LeRC has begun the evaluation, both in-house and under contracts and grants, of two regenerative fuel cell (RFC) systems. The passive hydrogen-oxygen RFC offers the possibility of a high-energy density, long-life storage system for GEO missions. The hydrogen-bromine RFC offers the combination of high efficiency and moderate energy density that could ideally suit LEO missions. If successfully developed, either or both of these systems would be attractive additions to the storage options available to designers of future missions.

PASSIVE H<sub>2</sub>-O<sub>2</sub> RFC

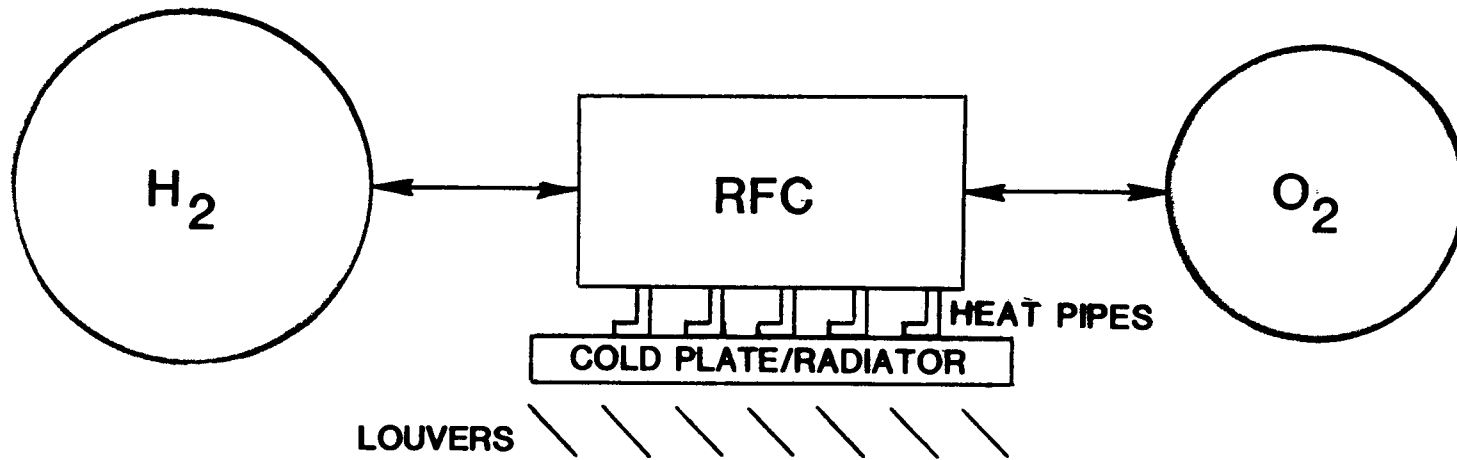


Figure 1. SCHEMATIC OF THE PASSIVE HYDROGEN-OXYGEN RFC

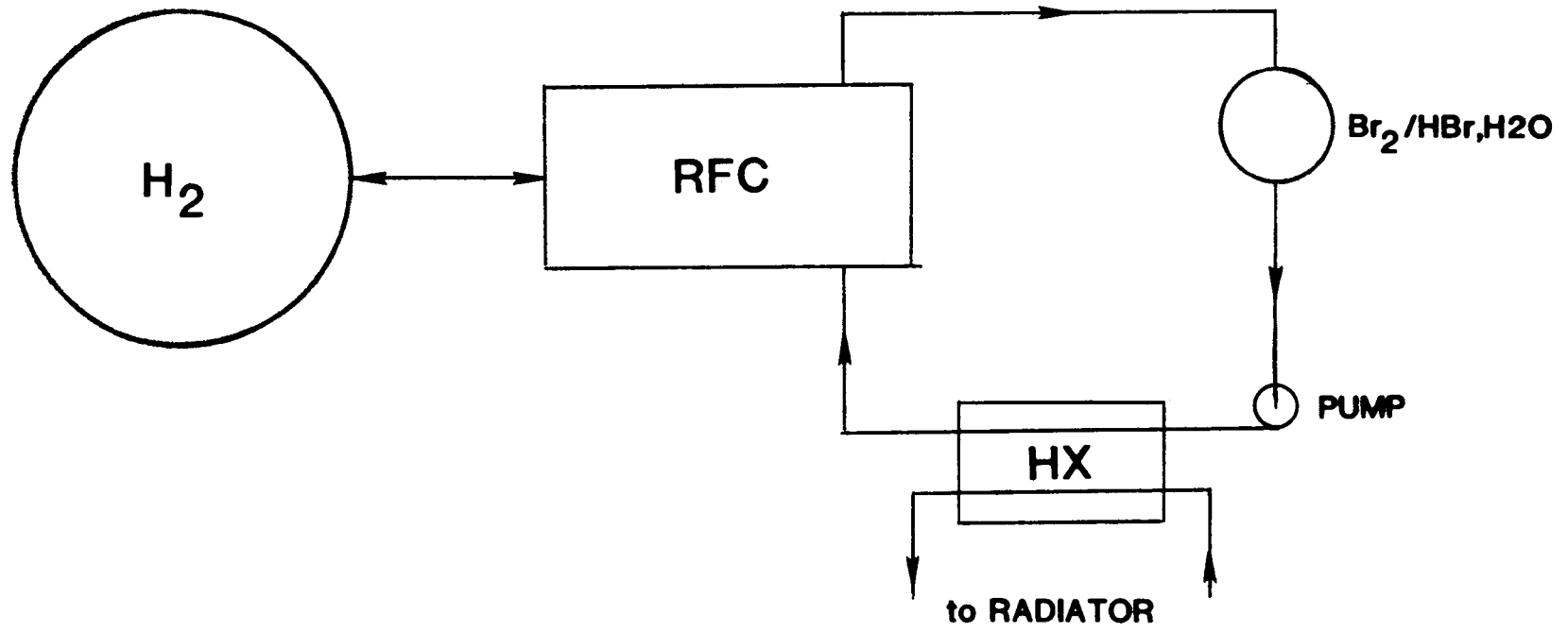


Figure 2. SCHEMATIC OF THE HYDROGEN-BROMINE RFC