Advanced Fuel Cells for Space Exploration Applications

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Scientists at NASA Glenn Research Center (GRC) are responsible for increasing technology readiness on fuel cell power systems. We are collaborating with them to develop passive components that have no or few moving parts, as high-speed components operating in pure oxygen (O_2) and hydrogen (H_2) environments are hazardous. Concepts and devices continue to be developed both within NASA (in-house) and at outside entities via contracts and grants.

NASA developed a proton exchange membrane fuel cell (PEMFC) test system under this effort. This test system – which incorporates an 8-kW, 72-cell PEMFC stack, two reactant pressure regulators with internal ejector reactant pumps, and a two-stage O_2/product water separator – provides a method to operationally verify these components while the components are used in an operating fuel cell power plant. All of these components were developed and evaluated at the component level in earlier phases of this effort. NASA envisions that fuel cell systems/subsystems such as these will enhance reliable and safe operation in the variable-gravity environments of future space exploration activities.

Fuel cell background

A fuel cell is an electrochemical device that can produce electricity from a catalyzed, low-temperature reaction between H_2 (a fuel) and O_2 (an oxidant). Unlike a battery, a fuel cell operates as long as fuel and oxidant are supplied to it. The by-product of this operation is water, which can be used for human consumption, vehicle cooling, or other purposes.

The PEMFC uses a thin, tough sheet of polymer plastic (an ion-exchange membrane) as the electrolyte. Platinum catalyst electrodes bonded to each side of the polymer membrane form a rugged and simple structure. Hydrogen reacts at the anode to give up electrons to an external circuit while simultaneously releasing H_2 ions into the electrolyte. The H_2 ions conduct through the electrolyte membrane to the cathode. At the cathode, H_2 ions from the anode combine with O_2 and electrons from the external circuit to produce water. Once this occurs, waste heat must be eliminated to maintain stable performance. Water can be removed from the cell cathode either by a wicking material (non-flow-through water removal) or by being entrained and swept out by a circulating extra-oxidant gas (flow-through water removal).

Integrated pressure regulator and ejector

The appreciable mass, volume, and complexity of the typical motor-driven compressor and its control and drive electronics can be eliminated in fuel cell water management through use of an ejector integrated into a pressure regulator. Such an ejector requires supply pressures ranging from 250 to 500 psig. However, these pressures are typically available with the use of supercritical cryogenic reactant storage systems, such as those currently used on the space shuttle. To provide an ejector-reactant-gas-circulation-pump internal to the regulator, TESCOM, Elk River, Minn., developed a custom regulator designed to accommodate a precision-orifice jet nozzle and a custom ejector mixer section. We completed a series of inert gas test runs with this component – covering a range of purposefully selected geometries (ejector jet nozzle and mixer diameters), pressures, and flows – to provide useful performance data for ejector configurations that could provide beneficial flow characteristics for reactant circulation pumping in spacecraft fuel cell systems with a power range of 0.7 to 20 kW. In the geometry, pressure, and flow ranges tested, approximately 10-to-1 mixer-to-jet diameter ratios for ejectors matched the presumed closed fuel cell circulation requirements of total-to-motive-flow flow ratios of 2.5 to 4.5 at the higher consumption flow ranges while providing maximum pressure differences in the range of 1.5 to 2.5 psid.

Water separator

NASA is also developing a two-stage water separator concept with inter-stage fluid pumps that use Liqui-Cel® membrane contractors (Charlotte, N.C.). The first stage is a bulk liquid and gas separator that receives two-phase flow from the fuel cell stack and passes only steam and reactant gas to the reactant pump suction flow inlet port; liquid product water accumulates in the first stage. An inter-stage pump will be used to transfer fluid accumulating in the first stage to the second stage de-bubbling membrane-contactor, and O_2 gas removed from the de-bubbled water stream will recycle to the first stage. Discussions, beginning in April 2007, took place with Liqui-Cel® representatives concerning the long-term compatibility of

Fig. 1. Polypropylene (left) and PVDF (right) membrane contactors.

the polypropylene used in their commercially available membrane contactor with high-temperature O_2 gas in a fuel cell system. These discussions led to the suggestion made by Liqui-Cel® representatives that polyvinylidene-fluoride (PVDF) could provide an alternative material to offer increased O_2 compatibility. One noncommercial PVDF membrane contactor and one noncommercial PVDF de-bubbler were procured from Liqui-Cel® in 2008. Both the polypropylene and the PVDF membrane contactors are shown in figure 1.

In NASA's advanced flow-through fuel cell system design, the first stage of the water separator must be compatible with the reactant pumping characteristics of the integrated pressure regulator and ejector. We worked in collaboration with Texas A&M University (TAMU) on a vortex/centrifugal separation section to augment inventory management of product water in the first stage and the subsequent transfer of product water to the second stage (which, again, is currently planned to be a membrane contactor de-bubbler) in multi-acceleration environments. The TAMU Center for Space Power, funded through a NASA grant, has specific expertise in the area of two-phase vortex separation systems, and has delivered both a gas-driven separator to GRC and a liquid-driven vortex separator to the Johnson Space Center (JSC) for evaluation; several technical reports, including a doctoral dissertation, also resulted from this effort.

Fuel cell operational verification testbed

Fuel cell systems incorporating ejector reactant pumps warrant investigation of operability at the low-power, low-flow operating range. (Note that the ejector circulation flow rates are lowest at the low-power operating range.) We developed a fuel cell operational verification testbed (FCOVTB) using two of the integrated reactant pressure regulator and ejector packages as well as a basic set of component housings for the multistage water separator design concept. This FCOVTB also incorporates a 72-cell PEMFC stack procured from Teledyne Energy Systems, Inc. (Hunt Valley, Md.) as the electric-power-producing component of the testbed as well as coolant, instrumentation, and control subsystems. The testbed is shown in figure 2.

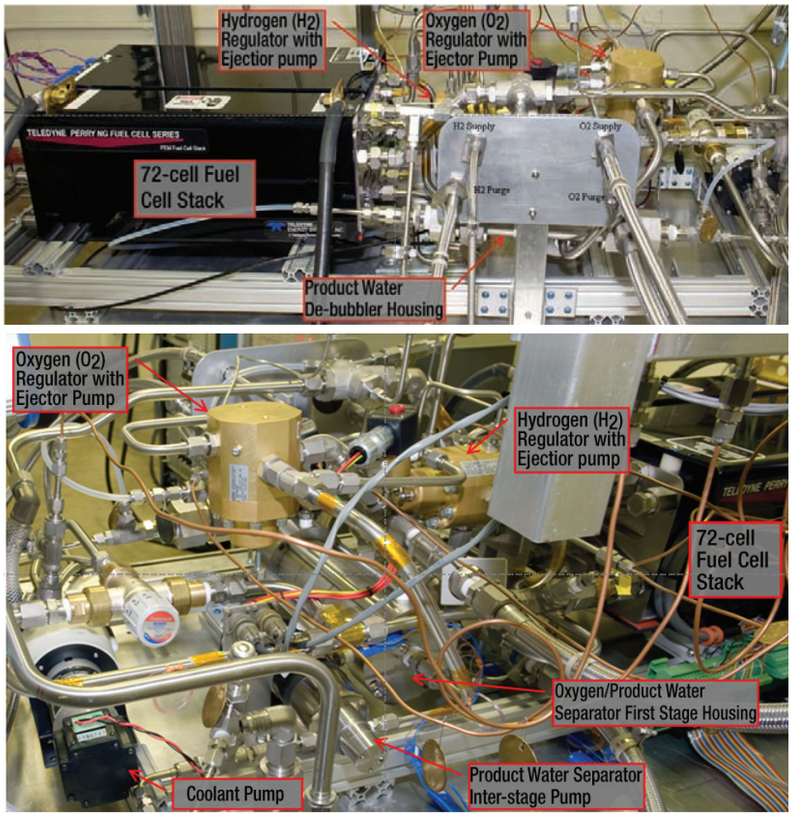

Fig. 2. Fuel cell operational verification testbed overall side view (top) and detail back view (bottom).

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continued

Scientists completed a major upgrade of the electrical control system of the Reactant Supply System at the JSC Energy Systems Test Area to support fuel cell testing in general. This upgrade provided an electrical control system with: (1) the potential for greater overall reliability; (2) significant improvements in remote control capability and user interface; and (3) maintenance of required safety controls.

Forward work

At least three configurations of multistage water separators are currently planned for investigation. The first configuration, which employs a gravity-dependent first stage, is intended to verify basic operation of the overall testbed and to acquire baseline performance data from the fuel cell power plant. The second configuration will incorporate the PVDF membrane contactor in the first stage of the water separator. Finally, the third configuration will add a liquid-driven centrifugal separator section to the first-stage housing.

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