Advanced Ejector and Water Separator Development for Human Spaceflight Proton Exchange Membrane Fuel Cell Applications

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Fuel cell reactant pumps that can be integrated with passive water and gas separation devices will be needed for future Proton Exchange Membrane Fuel Cell (PEMFC) power systems to enhance reliable and safe operation in multiple gravity environments for future crewed (and crewless) space exploration activities. This project is pursuing the development and evaluation of an advanced ejector reactant pump that will be integrated with a reactant pressure regulator and multistage water separator. The final developed product is intended for product water removal and gas separation in future PEMFC power plant reactant circulation systems.

The Energy Systems Division's (ESDs) Energy Conversion Systems Branch and Energy Systems Test Branch are tasked, under the Exploration Technology Development Program's Energy Storage Project, to support Glenn Research Center (GRC) in increasing the technology-readiness levels of fuel cell space power systems. Working in collaboration with GRC, other NASA centers, universities, and commercial vendors, the approach was to develop, to the greatest extent possible, passive components with no or few moving parts, or in the case of active components, to reduce hazards associated with high-speed components relative to compatibility with the operating fluids of the PEMFC, especially oxygen and hydrogen. Concepts and devices were obtained from both within NASA (in-house) and from outside entities (via contracts and grants), and knowledge gained from earlier work was used to direct the overall planning for this project.

Fuel Cell Background

A fuel cell is an electrochemical device that can produce electricity from a catalyzed, low-temperature reaction between hydrogen (fuel) and oxygen (oxidant). Unlike a battery, the fuel cell operates as long as fuel and oxidant are supplied. The by-product is water, which can be used for human consumption, vehicle cooling, or other purposes. Fuel cells are characterized primarily by the chemistry of the electrolyte through which the fuel and oxidant react. The perfluorosulfonic acid copolymer of the PEMFC is one such electrolyte. Fuel cells are highly efficient power sources, converting between 50 and 70% of the energy of the reaction to electric power. Fuel cells can be built in almost any size and capacity, enabling a wide range of applications and capabilities. Clean, quiet, and with high specific energy and power, fuel cells are attractive for environmentally sensitive applications including electric cars, buses, hospital power supplies, residential and utility power generation, and spacecraft power systems.

The PEMFC uses a thin, tough sheet of polymer plastic – an ion-exchange membrane (which, when hydrated, produces the perfluorosulfonic acid electrolyte) – as the electrolyte. Platinum catalyst electrodes bond to each side of the polymer membrane and form a rugged and simple structure. Hydrogen reacts at the anode to give up electrons to an external circuit while simultaneously releasing hydrogen ions into the electrolyte. The hydrogen ions conduct through the membrane to the cathode. At the cathode, the hydrogen ions from the anode combine with oxygen and the electrons from the external circuit to produce water. Water is removed from the cell cathode either by a wicking material or by being swept out by circulating extra-oxidant gas. Waste heat must also be removed to maintain stable performance. These fuel cells can be connected in series and parallel in a stack to produce the required voltage and power level. To sustain continuous power production, a fuel cell system typically requires a reactant supply subsystem, a fuel cell stack, water and heat removal subsystems, and an electrical control subsystem.

Advanced Ejector and Regulator

NASA has recognized gas ejectors as a viable alternative to mechanical pumps to provide reactant circulation for product water removal and reactant pre-humidification in spacecraft fuel cell power systems. The ejector motive force is provided by a high-pressure supply gas that travels through the ejector's jet nozzle, whereby the pressure energy of the fluid stream is converted to kinetic energy in the gas jet. In this advanced ejector concept, ejector flow is controlled by an external-sense regulator.

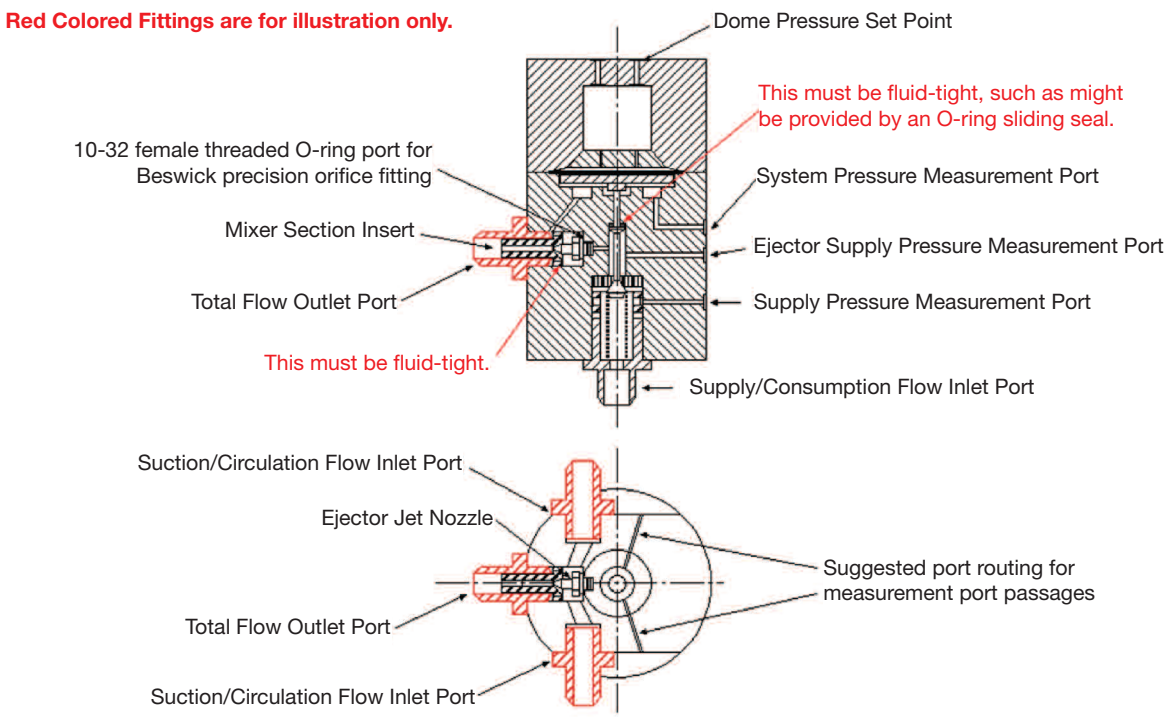

Fig. 1. *Integrated ejector and regulator schematic.*

The external-sense regulator senses the system pressure downstream of the ejector total flow outlet and uses that signal (system pressure) as the feedback to its internal control valve. As changes in system pressure occur as a result of consumption of gases in the fuel cell stack, the external-sense regulator quickly responds with the variable supply of high-pressure gas to the inlet of the ejector jet nozzle. Two characteristics of the ejector that are used for fuel cell reactant pump design are: 1) the ejector-developed delta-pressure is directly proportional to the supply flow through the ejector jet (with only a slight offset at low jet supply conditions); and 2) the circulation flow produced by the ejector is directly proportional to the supply/consumption flow through the ejector jet. The ejector can produce circulation to consumption flow ratios that are relatively high (2-3 times) and this can be used to provide completely for passive, self-regulating reactant pre-humidification in a PEMFC.

Taking advantage of the capabilities of commercially available products that could be used in the prototype phases of development, procurements were completed for reactant pressure regulators that can be configured with ejector jet nozzles and mixer sections. Tescom (Elk River, Minn.) developed a custom regulator design that allows Beswick (Greenland, N.H.) precision-orifice jet nozzles to be used to provide motive gas flow with varying inlet jet supply pressure using a particular internal fluid routing scheme in the regulator, as shown in figure 1.

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Water Separator

We are developing a two-stage water separator concept with inter-stage fluid pumps using membrane contactors from Liqui-Cel (Charlotte, N.C.) and diaphragm pumps from KNF-Neuberger (Trenton, N.J.). The first stage is a bulk liquid and gas separator, receiving two-phase flow from the fuel cell stack and passing only steam and reactant gas to the reactant pump suction flow inlet port; liquid water will accumulate in the first stage. Inter-stage pumps will be used to transfer fluid accumulating in the first stage to the second stage de-bubbling membrane contactor, and gas removed from the de-bubbled water stream will recycle to the first stage. The first stage of the water separator is also intended to be compatible with the reactant pumping characteristics of our advanced ejector. We are working in collaboration with Texas A&M University (TAMU) to provide a vortex separation section to augment the inter-stage pumping in multi-g acceleration environments. TAMU's Center for Space Power (funded through a grant) has specific expertise in the area of two-phase vortex separation systems.

Forward Work

Once component-level models of the ejector, regulator, and two-stage water separator are validated, these components will be integrated together for system performance evaluation using one or more of the following: 1) multi-orientation ground tests; 2) zero-g aircraft flight tests; and 3) installation and operation in a fuel cell operational verification test bed.