

Development Testing of a High Differential Pressure (HDP) Water Electrolysis Cell Stack for the High Pressure Oxygen Generating Assembly (HPOGA)

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ABSTRACT

The International Space Station (ISS) requires advanced life support to continue its mission as a permanently-manned space laboratory and to reduce logistic resupply requirements as the Space Shuttle retires from service. Additionally, as humans reach to explore the moon and Mars, advanced vehicles and extraterrestrial bases will rely on life support systems that feature in-situ resource utilization to minimize launch weight and enhance mission capability. An obvious goal is the development of advanced systems that meet the requirements of both mission scenarios to reduce development costs by deploying common modules. A high pressure oxygen generating assembly (HPOGA) utilizing a high differential pressure (HDP) water electrolysis cell stack can provide a recharge capability for the high pressure oxygen storage tanks on-board the ISS independently of the Space Shuttle as well as offer a pathway for advanced life support equipment for future manned space exploration missions.

After completing a preliminary system study of the HPOGA, two areas for concentrated development to mitigate program risk were identified: increasing the oxygen output level of the HDP cell from 2000 psig to 3000 psig, and evaluating the system safety and reliability requirements for high pressure oxygen, particularly as they pertain to the design of the electrolysis cell stack. Hamilton Sundstrand is working with NASA to advance the design of the HDP cell hardware to achieve the goal of higher oxygen output pressures and to develop cell stack mock-up assemblies and test protocol to investigate oxygen safety of the HDP cell stack.

INTRODUCTION

Water electrolyzers based on proton exchange membrane (PEM) technology are a key element in air revitalization systems on-board nuclear submarines and the International Space Station (ISS). Oxygen is provided at ambient pressure for crew respiration while the hydrogen is provided at a pressure sufficient for disposal. Continued advancement of the cell hardware

has resulted in water electrolyzers that can safely provide either or both of the product gases at elevated pressures without the need of a pressure vessel or mechanical compressor, making PEM water electrolyzers attractive for advanced life support and energy storage applications.

The ISS features two high pressure oxygen tanks located on the outside of the airlock module Quest. These tanks replenish the metabolic oxygen consumed during extravehicular activity (EVA); provide oxygen for the emergency breathing masks and for medical purposes; and act as a redundant source of oxygen in the event of a failure of the station oxygen generating system (OGS). Currently cryogenic oxygen on-board the Space Shuttle is evaporated and subsequently compressed by the Oxygen Recharge Compressor Assembly (ORCA) to 2700 psig and stored in the two high pressure oxygen tanks on the ISS. When plans for the retirement of the Space Shuttle were announced, NASA and Boeing began to examine alternate approaches for providing this valuable commodity on the ISS, including generating high pressure oxygen directly from the electrolysis of water utilizing electrolysis cell stack technology developed in the 1990s for an aircraft on-board oxygen generating system (OBOGS). NASA funded an engineering study in 2006-07 to examine electrolysis system options and develop a preliminary system fluid schematic for an HPOGA operating at 3000 psig oxygen pressure to recharge the ISS tanks. Specific task elements of the study effort included:

- conduct an initial hazards analysis to identify the most significant oxygen safety issues, and develop a plan for addressing these issues;
- assess system packaging options for installation into the existing ORCA footprint within the ISS airlock;
- trade cell stack size against power supply requirements and projected oxygen usage; and
- create a risk mitigation strategy that identifies areas for focused development.

Advancing the operating pressure of the OBOGS water electrolysis cell stack from 2000 psig to 3000 psig, and demonstrating the safe containment of cell hardware in the event of a catastrophic failure of the electrolysis cell stack were identified as two key areas to advance the design of an HPOGA for the ISS. A Phase II program was initiated whereby a two-cell prototype stack assembly (1/6th scale) would be built and tested to gather performance data of an HDP water electrolysis cell operating at 3000 psig oxygen, and two mock-up cell stack assemblies would be constructed for testing at the White Sands Test Facility. The results from the two-cell performance test program are presented in this paper along with an item description and test plans for the mock-up assemblies.

HISTORY

The oxygen delivery pressure from water electrolysis systems has changed over time. These changes reflect the necessary evolution of cell and cell stack technology to address changing system needs. The first water electrolysis systems used on submarines delivered oxygen at ambient pressure because the technology at the time was unable to deliver high pressure oxygen. When submarines were outfitted with the earliest water electrolysis systems, they also carried on board at least one other form of contingency oxygen in the event of a malfunction of the generator. Contingency oxygen was supplied either by chemical oxygen generators or by tanks that contained high pressure gaseous oxygen.

Depleted chemical oxygen generators can be replaced when the submarine is at port, but high pressure oxygen gas tanks could theoretically be filled and recharged by a water electrolysis system if the water electrolysis system were capable of delivering high pressure oxygen. The earliest high pressure water electrolysis systems were developed to meet this operational need. However, the cell stacks were not capable of sustaining large differential pressures either between the anode and cathode side of the cell membrane or between the cell stack and the outside environment. The solution to these problems was to place the cell stack inside a pressure vessel filled with high pressure nitrogen, and to maintain a relatively low pressure differential between the anode and the cathode side of the cell membrane by incorporating a pressure control system that referenced the pressures of all operating fluids in the system. This architecture kept the membranes protected from pressure stresses, kept the oxygen and hydrogen from leaking overboard into the external environment by managing the hoop stresses on the cell stack, and enabled the system to deliver high pressure oxygen. This method of producing high pressure oxygen works well when the system is operating continuously at a fixed pressure and delivery rate. But the system is difficult to operate and control during start-up and shut-down transients as three different pressure environments (the anode side of the cell, the cathode side of the cell, and the containment dome) need to be pressurized within design limits of the cell hardware.

The method of developing high pressure oxygen in the HPOGA is fundamentally different from the early high pressure water electrolysis systems used on submarines. The cell membranes are supported by a metal porous plate that is porous enough to permit the transfer of gas and water between the cell membrane and the bulk fluid stream, but is sufficiently rigid to withstand large pressure differentials without deforming. The oxygen and hydrogen/water cavities within a cell are fabricated by bonding together several circular, patterned metal foil layers, thereby also creating the cell structure to contain the fluids within the cell and providing an electrical pathway through the cell stack. Bonding of the foil layers is accomplished by using the

periphery of each part with a thin fluoroelastomeric material followed by a heated compression cycle. Around the periphery of each part, known as the seal area, details are formed into each layer to allow for the passage of working fluids to or from their respective cavity. The passages also allow the fluids to enter or exit the stack axially and connect to their respective system fluid lines. The seal area of the bonded metal laminate assembly forms the wall of a cylinder and acts as a pressure vessel capable of significantly higher hoop stress than cells designed with plastic frames and allows this metal laminate design to operate at high pressures without the need for containment in a secondary vessel [1].

DEVELOPMENT TEST PROGRAM

TWO-CELL PROTOTYPE STACK ASSEMBLY – During the previous trade study effort of potential system options for the HPOGA, the liquid cathode feed cell was selected since it provided oxygen gas without any liquid water and allowed the hydrogen/water system to operate at essentially ambient pressure. A schematic of a liquid cathode feed electrolysis cell and a simplified system schematic are presented in Figure 1 [2]. The

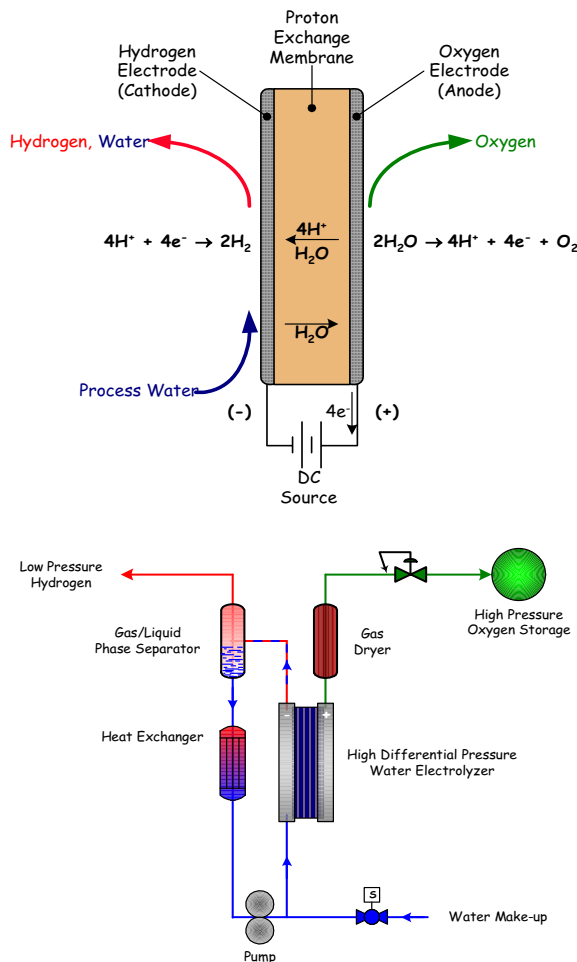


Figure 1- Liquid Cathode Feed Cell and Simplified System Schematic

active area of the HPOGA cell was established at 0.10 ft² based on the results of a previous cell stack and power supply weight study. Nafion 1110® was selected to manufacture the membrane and electrode assemblies to improve the probability of successfully sealing the HPOGA prototype cell stack in this initial attempt and gather baseline performance data of a cell operating at 3000 psid oxygen. A schematic of the two-cell prototype stack assembly is included as Figure 2.

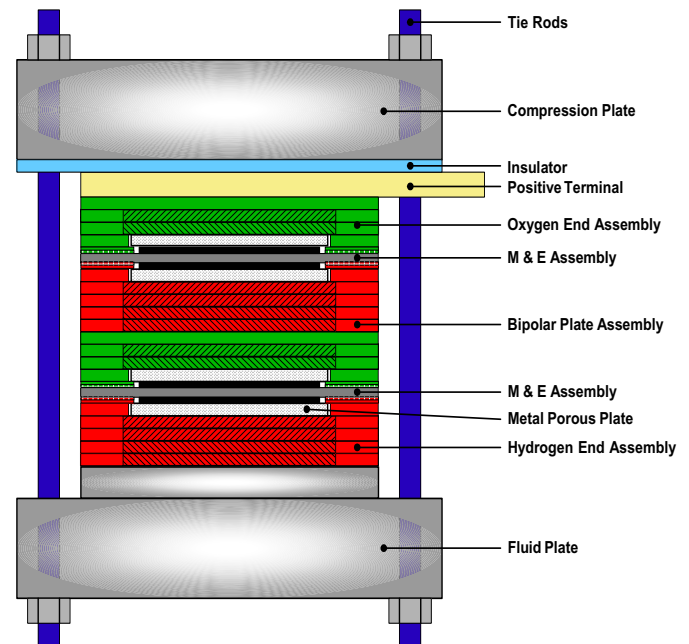


Figure 2 – Two-Cell Stack Assembly Schematic

The stack consists of a:

- Fluid plate for transporting fluids to/from the cell stack and the test system.
- Hydrogen end assembly which serves as the cathode cavity for the first cell in a stack.
- Membrane and electrode (M&E) assembly for cell #1.
- Bipolar plate assembly, which serves as the anode cavity for cell #1 and the cathode cavity for cell #2. The bipolar plate includes a separator sheet to isolate the fluids between adjacent cells. For a multi-cell assembly, the number of bipolar plates in a stack is equal to one less than the number of cells.
- Membrane and electrode (M&E) assembly for cell #2.
- Oxygen end assembly which serves as the anode cavity for the last cell in a stack.
- Positive terminal or anode plate which provides the positive connection point to the cell stack.