PERFORMANCE ANALYSIS OF IMHEX FULL-AREA STACKS

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ABSTRACT

M-C Power Corporation is actively engaged in the commercialization of molten carbonate Fuel Cell Technology based on the IMHEX® stack configuration conceived by the Institute of Gas Technology (IGT). The active cell area has been successfully scaled up from 1 ft^2 of subscale stack to 1 m^2 of full-area commercial stack. Two 20 kW full-area stack tests have been completed. Both stacks operated successfully for about 2000 hours. Both stacks demonstrated the capability of producing maximum power exceeding the design capacity of 20 kW. Pressure drop characteristics were also within the range for designing larger commercial stacks. Both stacks demonstrated many of the operational modes expected for commercial applications. This paper presents the performance analysis of the data generated from these two full-area stack tests.

INTRODUCTION Since its inception in 1987, M-C Power has successfully demonstrated that the internally manifolded heat exchanger concept (IMHEX®) developed by IGT is a commercially viable molten carbonate fuel cell technology for power generation. In April-June of 1991, M-C Power successfully built and operated a 70-cell stack with active area of 1 ft^2 for 1580 hours of power generation. Since then, M-C Power has successfully built and operated two full-area-commercial-size fuel cell stacks with active area of 1 m^2. The first full-area stack with 19 cells was tested in April-July of 1992 for a duration of 2200 hours. The second full-area stack with 20 cells was tested in November 1992-January 1993 for a duration of 1900 hours. The following sections discuss the results obtained from these two full-area stack tests.

FIRST FULL-AREA STACK Two types of gases were used in testing the first full-area stack. One type is referred to as "reference" gases which has been used at IGT for years as standard gases for evaluating the cell performance. At the anode, the "reference" gas is a 3:1 H_2:CO_2 gas mixture by volume, humidified to about 20% of water. After this gas mixture reacts through the water shift reaction in the anodic chamber, it is similar to the product of a naphtha reformer. At the cathode, the "reference" gas is a 70:30 Air:CO_2 gas mixture by volume.

The other type of gases, used for a short duration during the test, is referred to as "system" gases. At the anode, it is a 4:1 H_2:CO_2 gas mixture by volume, humidified to about 25% water. After this gas mixture shifts in the anodic chamber, it is similar to a product of natural gas reformer. At the cathode, the "system" gas is a mixture containing about 7-10% O_2, 8-10% CO_2, and balanced by N_2. This "system" gas simulates the concentrations of O_2 and CO_2 that would be expected in the cathodic chamber during operation of a total molten carbonate fuel cell system with cathode gas recycled for controlling the stack temperature.

This stack demonstrated uniform cell voltages while maintaining an average stack temperature of 650 °C as shown in Figure 1. A uniform profile was obtained at OCV condition and at high current density of 150 mA/cm^2, indicating that good gas flow distribution was achieved. Shown in Figure 2 is the history of power generation during the test. The stack was capable of producing steady-state power for both the "reference" and "system" gases at about 18 and 13 kW, respectively. For a brief period, the stack was operated at power output exceeding the 20 kW design capacity. The fuel utilization during this test was between 60 to 75%.

For commercial power generation, sometimes it may be necessary to stop the hot stack from producing power and cool it down to room temperature for maintenance operations and then re-start the stack for power generation. This procedure is commonly referred to as thermal cycling. During this test, after about 1300 test hours, the stack was cooled from 650 °C operating temperature and then successfully re-started to generate power at operating temperature. The duration of this thermal cycle (TC #1) was about 470 hours with about 180 hours at room temperature. After about another 150 hours of operation, the stack went through another thermal cycle (TC #2). This time the stack was only cooled down to 300 °C to allow a faster re-start. The duration for this thermal cycle was about 100 hours.

To see if thermal cycling would affect stack performance, a polarization run was made shortly after TC #1, at about 1850 hours. This polarization run was compared to the polarization run made around 500 test hours. As shown in Figure 3, there was no significant degradation in stack performance after TC #1. The history of stack performance of this first-full area stack is also summarized in Figure 4. As indicated by OCV, load, polarization loss, and internal resistance loss data, this stack appeared to have operated without significant loss of performance for the entire 2200 hours of testing.

SECOND FULL-AREA STACK TEST For this second full-area stack, the test was also conducted with "reference" and "system" gases. The definitions for these gases as used in the second full-area stack test are the same as those used in the first full-area stack test, except that in the second stack test, the composition of the anode "reference" gas was now defined to have the same composition as the anode "system" gas, a 4:1 H_2:CO_2 mixture, humidified to about 25% of H_2O.

The history of power generation for this stack test is shown in Figure 5. The stack produced maximum power of 23 kW on "reference" gases and 21 kW on "system" gases. During this test, another commercial mode of operation was simulated. This mode is referred to as "hot standby". During the "hot standby" period, the feed gases were switched from "system" gases to "inactive" gases to protect the stack while the stack was maintained at operating temperature in open circuit condition for about 140 hours. The stack quickly produced power as soon as the "system" gases were re-introduced.

The performance characteristics for the second full-area stack can be seen from a polarization run as shown in Figure 6. At high current density of 160 mA/cm^2, the average cell voltage was at 687 mV. This is equivalent to producing 23 kW power which exceeds the 20 kW design capacity for this stack.

FIRST AND SECOND FULL-AREA STACKS COMPARISONS Shown in Figure 7 is the comparison of polarization run data obtained from the first and the second full-area stack tests. Both polarization runs were obtained at the average stack temperature of 650 °C and using "reference" gases. As indicated earlier, the anode "reference" gas mixture used in the first stack was a 3:1 H_2:CO_2 mixture and in the second stack was a 4:1 H_2:CO_2 gas mixture. Calculations show that due to the difference in composition, the OCV for the second stack should be higher than the OCV of the first stack by about only 12 mV. As shown in Figure 7, the polarization curve for the second stack is higher the polarization curve of the first stack by about 7 to 10 mv. The corresponding power curves also show no significant difference between these two stacks. Thus, we can conclude that the performance characteristics of the full-area stack has been successfully duplicated using the manufacturing technology developed at M-C Power Corporation.

M-C Power is now designing and manufacturing active components needed for a commercial 250 kW stack to be demonstrated at a UNOCAL facility. One of the many factors need to be considered in design is the pressure drop characteristics for cathodic chamber. An empirical pressure drop correlation shown in Figure 8 was developed based on the pressure drop and flow data obtained from these two full-area stack tests. The data show that the pressure drop correlation gives good prediction. In other words, the pressure drop characteristics for both stackd are the same. Additionally, pressure drop predictions based on cold-flow model also agree well with the empirical pressure drop correlation. This empirical correlation also shows that at the anticipated cathode flow rates for the 250 kW stack operation, the expected pressure drops are well within the design constraint for the wet seal.

CONCLUSIONS The test results from these two full-area stacks have shown that using the manufacturing technology developed at M-C Power Corporation, the IMHEX® configuration developed by IGT can be successfully implemented for commercial size stacks. During the test duration, both stacks were operated successfully and simulated "thermal cycling" and "hot standby" modes expected in commercial power generation. Within the experimental accuracy, the stack performance and cathode pressure drop characteristics have been successfully duplicated.

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FIGURE 1. First Full-Area Stack Cell Voltages
(75% Fuel Utilization @ 150 mA/cm2)

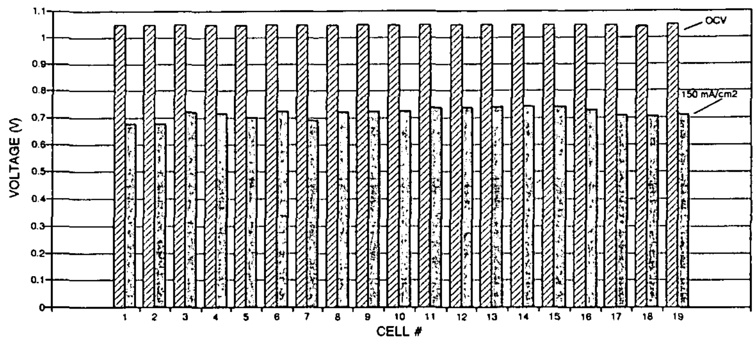

FIGURE 2. First Full-Area Stack Test
Stack Power vs. Time

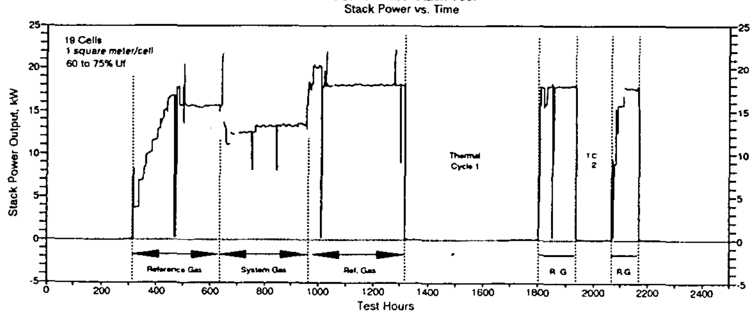

FIGURE 3. First Full-Area Stack Polarization
before and after Thermal Cycle

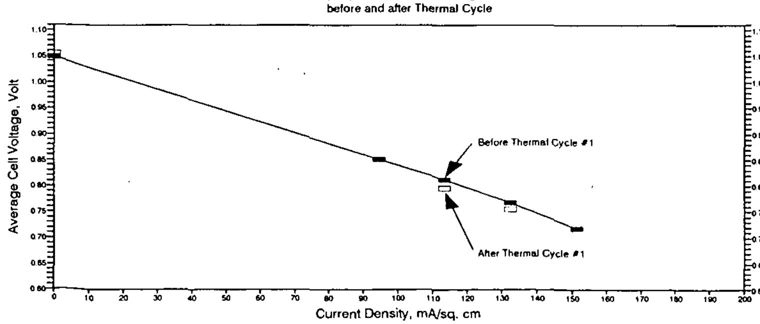

FIGURE 4. First Full-Area Stack
Performance History

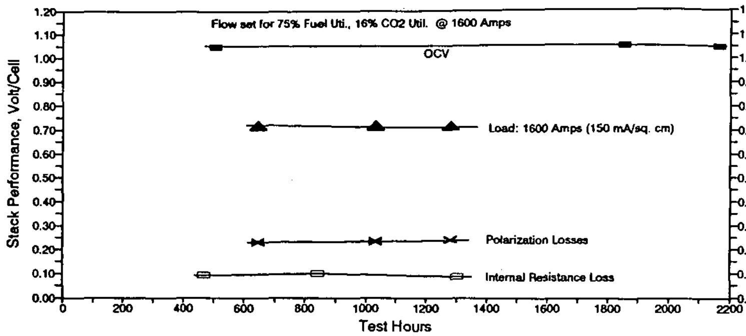

FIGURE 5. Second Full-Area Stack Test
Stack Power vs. Time

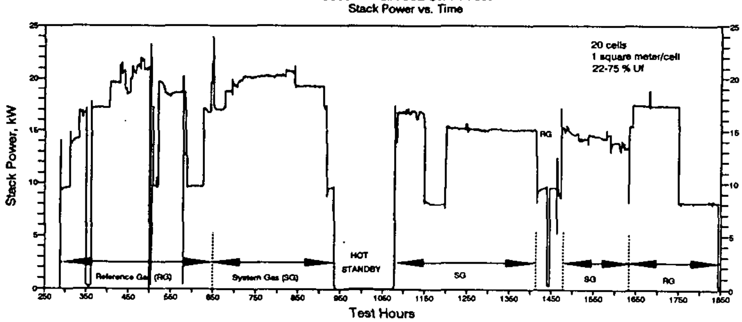

FIGURE 6. Second Full-Area Stack Polarization

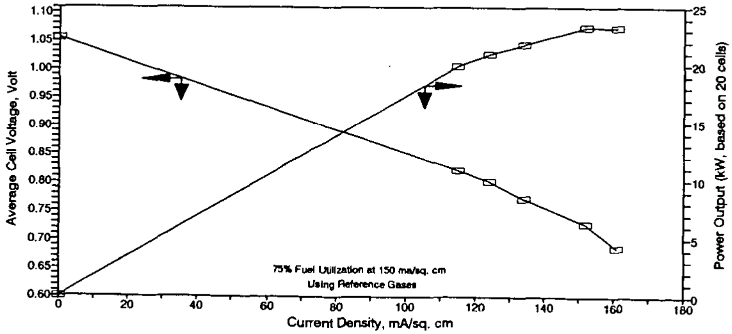

FIGURE 7. Comparision of Polarization Curves
First vs. Second Full-Area Stacks

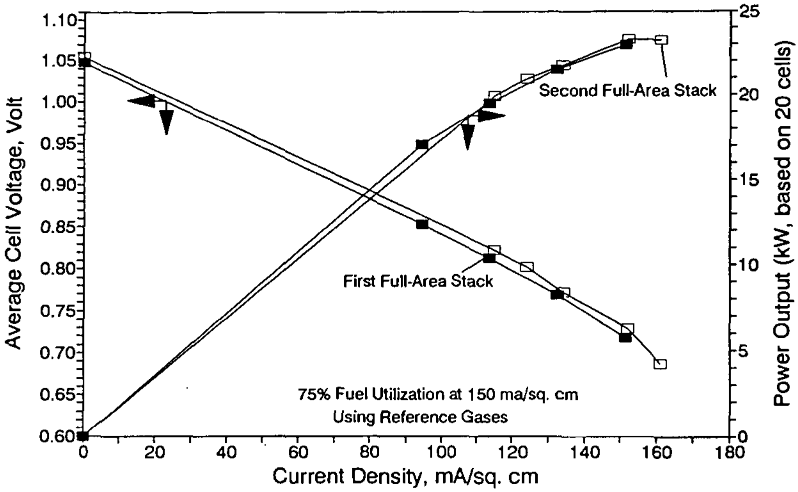

FIGURE 8

CATHODE PRESSURE DROP
Full-Area Tests