DOE/MC/28055-96/C0600

CONF-950886--11

Pressurized Solid Oxide Fuel Cell Testing

Authors:

Emerson R. Ray
R.A. Basel
J.F. Pierre

Contractor:

Westinghouse Electric Corporation
1310 Beulah Road
Pittsburgh, Pennsylvania 15235-5098

Contract Number:

DE-FC21-91MC28055

Conference Title:

Fuel Cells '95 Review Meeting

Conference Location:

Morgantown, West Virginia

Conference Dates:

August 9-10, 1995

Conference Sponsor:

U.S. Department of Energy, Morgantown Energy Technology Center (METC)

2.4 Pressurized Solid Oxide Fuel Cell Testing

CONTRACT INFORMATION

Contract Number DE-FC21-91MC28055

Contractor Westinghouse Electric Corporation
1310 Beulah Road
Pittsburgh, PA 15235-5098
(412)256-5313 (telephone)
(412)256-2002 (telefax)

Contractor Project Manager Mr. Emerson R. Ray

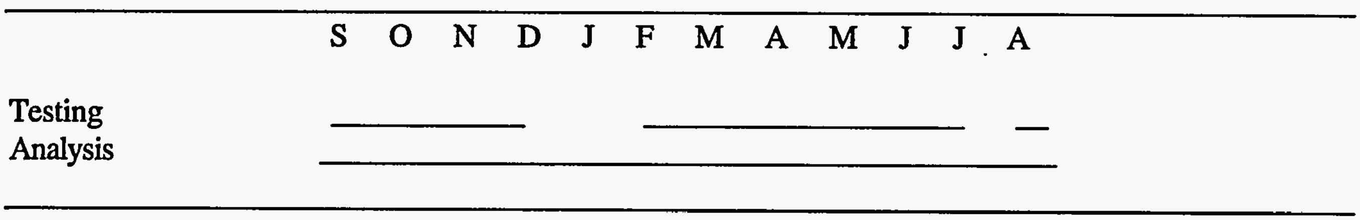
Principal Investigators R. A. Basel and J. F. Pierre

METC Project Manager Mr. Bruce Harrington

Period of Performance April 1, 1991
Nov. 30, 1995

Schedule and Milestones

FY1995 Program Schedule



CONTRACT INFORMATION

A cooperative test program between the United States Department of Energy (DOE), Westinghouse, and two customer consortiums is focused on the testing of the tubular solid oxide fuel cell (SOFC) at elevated pressures. The design of a pressurized test facility (PTF) was funded by DOE and Westinghouse. Construction and operation of the PTF, which is located at Ontario Hydro Technologies, Toronto, Canada was funded by a consortium of Canadian utilities and agencies. DOE provides SOFC's and test articles. Operational consultation and data analysis is provided by Westinghouse with financial support from Westinghouse, DOE and a consortium of Japanese electric power companies and NEDO.

The cells and test articles are returned to Westinghouse at the completion of testing.

The Pressurized SOFC Test Program is an integral part of the Cooperative Agreement between Westinghouse and DOE and was put into place to evaluate the effects of pressurization on SOFC performance.

OBJECTIVES

The goals of the SOFC pressurized test program are to obtain cell voltage versus current (VI) performance data as a function of pressure; to evaluate the effects of operating parameters such as temperature, air stoichiometry, and fuel utilization on cell performance, and to demonstrate long term stability of the SOFC materials at elevated pressures.

BACKGROUND INFORMATION

The high temperature Westinghouse tubular SOFC is an electric power generation technology that electrochemically generates electricity at high efficiencies in a clean, environmentally benign process. The technology has progressed to the stage where atmospheric pressure SOFCs have demonstrated operating efficiencies above 50% and the potential for direct utilization of pipeline natural gas (PNG), naphtha, and coal derived fuel gas. In parallel with the technology development work being performed by Westinghouse under the sponsorship of DOE, Westinghouse has completed a number of system studies for DOE and foreign and domestic utilities. These studies indicate that atmospheric pressure SOFC systems have the potential to be economically competitive with and environmentally superior to gas turbines and combined cycles. However, the pressurized technology provides additional performance/ economic advantages which will expand the economically competitive market range and increases the likelihood of investment by utilities in a new technology.

The benefits of pressurization include improved cell performance, (increased power output, efficiency > 60%), smaller equipment sizes, and reduced heat losses and pressure drops. In combination these benefits will yield a lower cost of electricity for SOFC systems. Ongoing system studies indicate that relative to an atmospheric pressure SOFC system, performance should increase by approximately ten percent and the cost-of-electricity may decrease by ten percent for a pressurized SOFC system. These studies are based on predictions of the cell voltage increase that may be realized via pressurizing the SOFC technology.

PROJECT DESCRIPTION

In 1992 Westinghouse and Ontario Hydro Technologies (OHT) entered into a joint program to design, construct, and operate a pressurized SOFC test facility (PTF). The PTF, located at OHT's Kipling Avenue Facility in Toronto, Canada, consists of two independent test stands as shown in Figure 1. Each stand can hold an array of one to four cells with active lengths up to 200 cm. The stands are fully instrumented, have multi-fuel capability, and are capable of operating at pressures up to 15 atm.

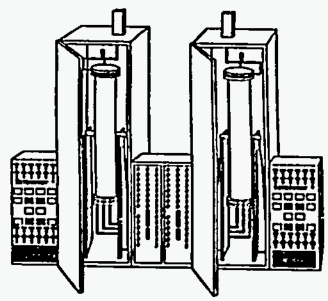


Fig. 1. SOFC Pressurized Test Facility

Figure 2 depicts the pressurized test article (PTA). The SOFCs are located within an alumina muffle tube which in turn is surrounded by a five zone electric heater assembly. The heater and muffle assembly is covered with alumina insulation and alumina sheath. A natural gas reformer inside the muffle tube permits operation on pipeline natural gas. The fully assembled PTA is delivered to OHT and installed into the pressure vessel. Flanges at both the top and bottom of the pressure vessel are fitted with penetrations for fuel, air, and exhaust flows, electrical power, and instrumentation leads.

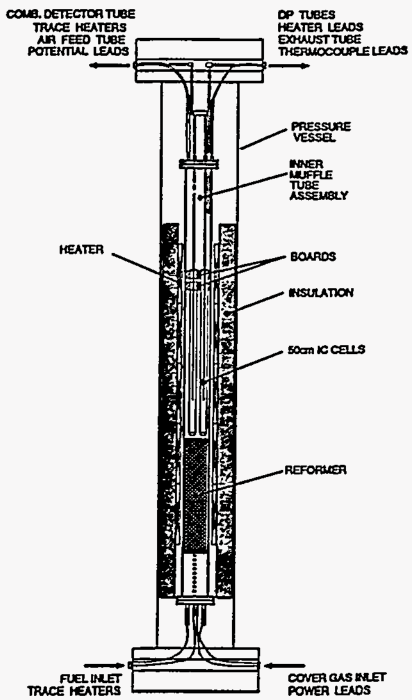


Fig. 2. Pressurized SOFC Test Article

Table 1 delineates the areas of responsibility for Westinghouse and OHT and its funding partners. Title to the SOFCs remains vested with DOE/Westinghouse.

Table 1. Westinghouse/OHT Pressurized SOFC Program

Scope of Supply

• Westinghouse	• Ontario Hydro
- Facility Specifications	- Facility to House Test Stand
- Test Stand Design	- Test Stand Equipment Design
- Test Envelope Design	- Fabrication and Construction
- Operating Procedures	- Shakedown
- Training	- Data Acquisition System
- Test Plans	- Control System
- Consultation	- Operation
- SOFC Test Articles	- Consumables
- Data Analysis	

RESULTS

Three PTAs have been tested in the PTF since March 1994. The first two, PTA-400 and PTA-405, served to shakedown the facility. The results discussed herein were obtained using the third test article PTA-443.

PTA-443 contains four 50 cm active length, air electrode supported (AES) cells. These cells are typical of those employed in the present SOFC field units. After an initial test period at Westinghouse, PTA-443 was installed in the PTF in September 1994. The test parameters for the pre-test were replicated at the PTF to verify instrumentation and to ensure that the PTA was not damaged during transport and installation.

Open circuit voltage (OCV) measurements at pressures up to 15 atm were taken and found to be consistent with theoretical predictions (Figures 3 and 4).

In Figure 3, the measured open circuit voltages are slightly less than the theoretical value. Figure 4 shows the open circuit voltage increase in going from 1 atm operating pressure up to 15 atm operating pressure. It can be seen that the measured voltage increases are in good agreement with the theoretical values.

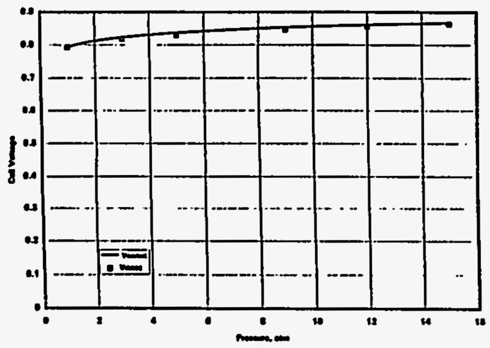


Fig. 3. Open Circuit Voltage for PTA-443

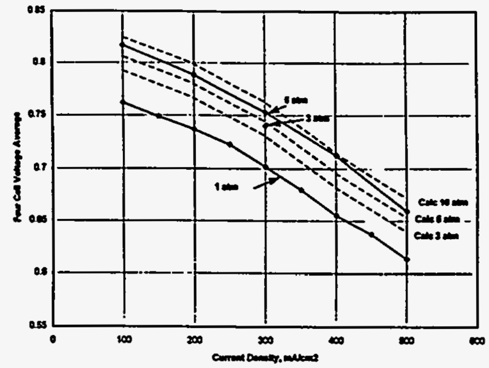


Fig. 5. Four Cell Average Voltage vs Current Density With H_2O Fuel, 85% Fuel Consumption and 6 Air Stoichs

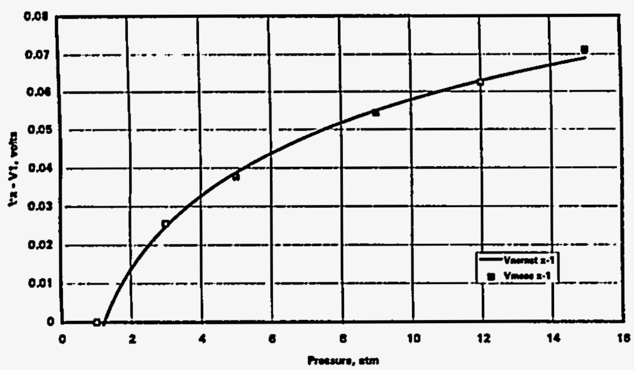


Fig. 4. Comparison of Measure vs Predicted Open Circuit Voltage

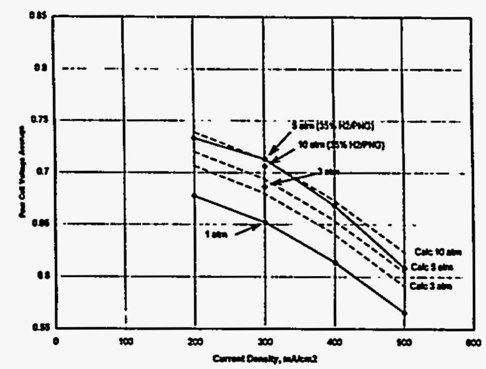


Fig. 6. Four Cell Average Voltage vs Current Density With PNG Fuel, O:C = 4.0 85% Fuel Consumption and 6 Air Stoichs

Voltage versus current density (V-J) curves were obtained at 1 and 5 atm on H2 fuel and PNG fuel as shown in Figures 5 and 6. The calculated values for 3, 5, and 10 atm were obtained by adding the expected increase in the Nernst potential due to increased pressure to the measured voltage at 1 atm. The measured results are in good agreement up to 5 atm. V-J curves at pressures above 5 atm will be obtained in future testing.

The test article was operated for a total of 5000 hours and 5 start/stop thermal cycles. Of the 5000 hours, 1515 hours were spent at 10 atm operating on PNG. The 1515 hours were divided into two portions of 265 hours and 1250 hours due to a scheduled site power outage. Prior to each shutdown the 1 atm V-J curve and the 300 mA/cm2 point at 5 atm were repeated with H2 fuel to assess the condition of the cells. The results are shown in Figures 7 through 10. It can be seen that after 265 hours there was virtually no change in the voltage of all four cells. After 1000 hours one half of the top guard heater zone failed making it impossible to maintain all four cells at a uniform 1000 C, thus making assessment of the cell condition difficult. Figures 7 through 10 show that after 1515 hours at 10 atm cells 3 and 4 show no change in voltage, but cells 1 and 2 show reduced voltage as current increases. The shape of the 7/12/95 V-J curve for cells 1 and 2 is typical of what would be expected if the cell temperatures were lower than for the previous curves. The fact that cells 3 and 4 show the same V-J behavior as before suggests that cells 3 and 4 are still at 1000 C and that the failed heater (each zone consists of two half clam shell cylindrical heaters) is on the cell 1 and 2 side. A post test V-J to assess the condition of the cells will be performed when the test article is returned to Westinghouse.

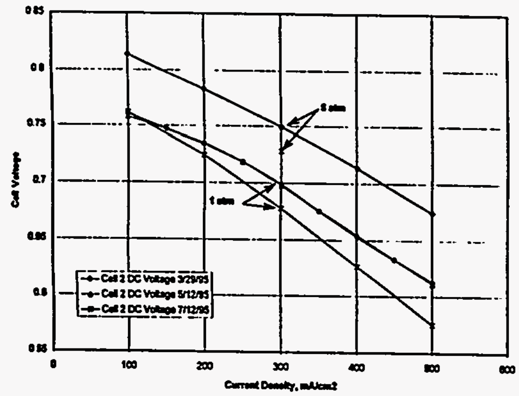


Fig. 8. Cell 2 Voltage vs Current Density With H_2 Fuel, 85% Fuel Consumption And 6 Air Stoichs

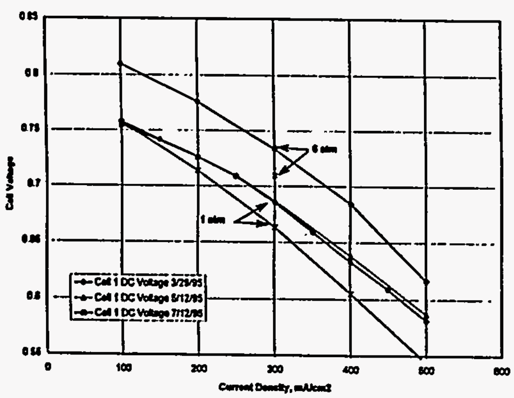


Fig. 7. Cell 1 Voltage vs Current Density With H_2 Fuel, 85% Fuel Consumption And 6 Air Stoichs

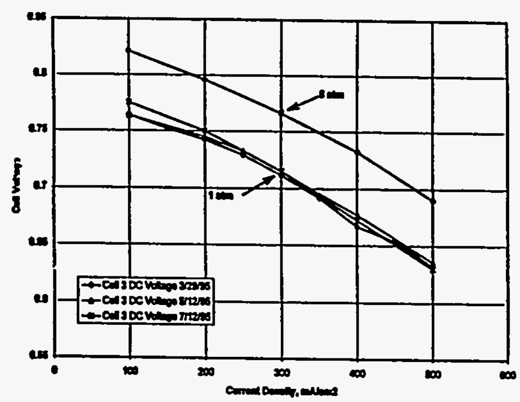


Fig. 9. Cell 3 Voltage vs Current Density With H_2 Fuel, 85% Fuel Consumption And 6 Air Stoichs

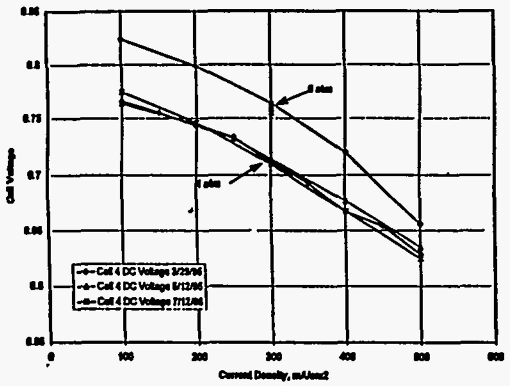


Fig. 10. Cell 4 Voltage vs Current Density With H_2 Fuel , 85% Fuel Consumption And 6 Air Stoichs

Test Article exhaust gas NO_x levels were obtained before the heater failure. Measurements were made using a hand pump/detector tube system. The results are listed in Table 2.

Table 2. Pressurized SOFC Exhaust Gas NO_x Measurements 6 Air Stoichs

	0.80 F.C.	0.75 F.C.
10 atm	1.0 ppm	2 ppm
5 atm	0.5 ppm	--
1 atm	Trace (~0.02 ppm)	--

CONCLUSIONS

Tubular solid oxide fuel cells have successfully operated on reformed natural gas for up to 1500 hours at 10 atm. V-J performance is as expected up to 5 atm. NO_x emissions are 2 ppm or less up to 10 atm. Further test articles are planned.

ACKNOWLEDGMENT

Westinghouse gratefully acknowledges the support of The United States Department of Energy - Morgantown Energy Technical Center for the continued development of the tubular SOFC. Westinghouse also acknowledges the support of the New Energy and Industrial Development Organization; The Hokkaido Electric Power Company; the Tokyo Electric Power Company; Chubu Electric Power Company; Chugoku Electric Power Company; Kyushu Electric Power Company, and the Electric Power Development Company for their financial and programmatic support of the Pressurized SOFC Test Program. The support of Ontario Hydro Technologies, the Canadian Electrical Association, Natural Resources Canada, Gas Technology Canada, Consumers Gas, Union Gas, British Gas, and the Ontario Ministry of Environment and Energy is gratefully acknowledged. A particular acknowledgment and note of gratitude is due to the personnel of Ontario Hydro Technologies for their competent and dedicated efforts in the installation and operation of the Pressurized Test Facility.