Solid Oxide Fuel Cell Hybrid System for Distributed Power Generation

Quarterly Technical Progress Report
July 2001 to September 2001

March 2002

Performed under DOE/NETL Cooperative Agreement
DE-FC26-01NT40779

Honeywell
Engines & Systems, Airframe Systems
2525 West 190th Street
Torrance, CA 90504

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DISCLAIMER

Abstract

This report summarizes the work performed by Honeywell during the July 2001 to September 2001 reporting period under Cooperative Agreement DE-FC26-01NT40779 for the U. S. Department of Energy, National Energy Technology Laboratory (DOE/NETL) entitled “Solid Oxide Fuel Cell Hybrid System for Distributed Power Generation”. The main objective of this project is to develop and demonstrate the feasibility of a highly efficient hybrid system integrating a planar Solid Oxide Fuel Cell (SOFC) and a turbogenerator.

An internal program kickoff was held at Honeywell in Torrance, CA. The program structure was outlined and the overall technical approach for the program was presented to the team members. Detail program schedules were developed and detailed objectives were defined. Initial work has begun on the system design and pressurized SOFC operation.

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Executive Summary

This report summarizes the work performed by Honeywell during the July 2001 to September 2001 reporting period under Cooperative Agreement DE-FC26-01NT40779 for the U. S. Department of Energy, National Energy Technology Laboratory (DOE/NETL) entitled “Solid Oxide Fuel Cell Hybrid System for Distributed Power Generation”. The main objective of this project is to develop and demonstrate the feasibility of a highly efficient hybrid system integrating a planar Solid Oxide Fuel Cell (SOFC) and a turbogenerator (microturbine).

The hybrid system is based on Honeywell planar SOFC and turbogenerator power technologies. The planar SOFC is based on thin-electrolyte cells and metallic foil interconnects. This technology leads to SOFC stacks that operate at reduced temperature (<800°C) and have high power density and reduced cost. The turbogenerator is based on a commercial microturbine such as Parallon™ 75. This work will culminate in a test of a small SOFC-based hybrid system that will incorporate all of the components/subsystems required for a full-fledged system.

The work consists of three phases and will focus on defining and optimizing a suitable system concept, conducting experiments to resolve identified technical barriers, performing cost analysis, and testing a small hybrid system to demonstrate concept feasibility.

The various phases and tasks to be performed under this program are attached in the Appendix. This cooperative agreement was awarded on July 5, 2001. Since the award, the following activities have been carried out:

- An internal program kickoff was held at Honeywell in Torrance, CA.
- The program structure was outlined and the overall technical approach for the program was presented to the team members.
- Detail program schedules were developed and detailed objectives were defined.
- Initial work has begun on the system design and pressurized SOFC operation.

Approach and Results

Task 1A.1 – System Design

Subtask 1A.1.1 – Design Concept Development.

The purpose of this task is to develop a system design concept for a hybrid system incorporating a planar SOFC with a commercial turbogenerator (e.g. Honeywell Parallon™ 75). Several system configurations based on pressurized fuel cell operation will be evaluated, and a configuration shall be selected as a baseline for reference design. The purpose of this task is to develop a set of criteria for the selection of the baseline design. Studies shall be performed to permit definition of all components/subsystems in term of type, performance, and input and output requirements. Focus shall be placed on the development of the fuel cell configuration including power level and control strategy including control structure. Significant activities during this reporting period are summarized below.

- Analysis efforts were concentrated during the first quarter on expanding Aspen Plus' compressor and turbine performance model capabilities. Aspen Plus is a process-modeling tool selected for the system analysis and design tasks of the SOFC Hybrid program. While it provides superior chemical and thermal process modeling capabilities, its compressor and expander models lack the level of detail necessary for the successful design of the hybrid system. The compressor and turbine performance routines developed for the program cover both the Parallon 75 and turbocharger types of performance maps. The availability of these routines is crucial to both the conceptual and demonstration system designs.
- In addition to the turbomachinery performance routines, Aspen flowsheets for modeling of the conceptual and demonstration systems were partially completed. The goal of the modeling efforts is to generate system component problem statements from the system heat and material balance. The completion of the first iteration designs of the conceptual and demonstration systems is expected in November 2001.

Task 1A.2 – Technical Barrier Resolution

Subtask 1A.2.2 – Pressurized SOFC

The purpose of this task is to fabricate and test planar SOFC's under pressurized conditions. The work will involve fabrication and testing of laboratory scale cells and stacks of increasing size to investigate their properties in pressurized environments. Electrochemical performance and structural integrity at pressures shall be evaluated. Analysis and modeling shall be carried out to identify performance degradation mechanisms under pressures, if any. Performance maps will be determined for various operating parameters. Thermal cyclability and lifetime under pressurized operation shall also be investigated. The purpose of this task is to modify cell and stack designs if required to improve cell performance and structure. Significant activities are summarized below.

- A test stand for testing small (< 8 cm diameter) cells and stacks was constructed using existing Honeywell equipment. The pressure vessel allows for testing of SOFC at pressures up to 300 kPa (3 atm) and stack temperatures of up to 800°C. Stack heating is provided by electrical heating elements contained within the pressure vessel. The test system is configured to allow for control of vessel pressure and temperature, fuel flow rate and composition, and air flow rate. The test system is instrumented to record stack current and voltage as well as the voltage of three groups of cells within the stack. The configuration of the test stand is shown in Figure 1.

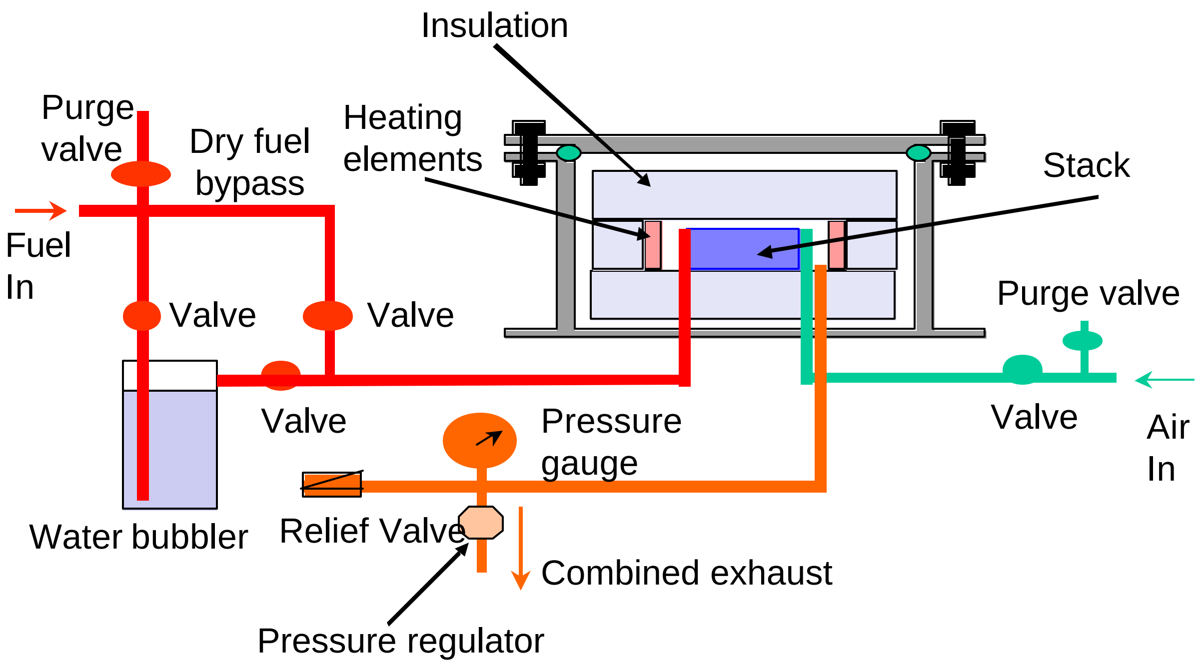

Figure 1. Schematic diagram of pressurized SOFC test stand.

- Small stacks and stack modules (a stack module is a one-cell stack that has all of the components of a mutli-cell stack, manifolds, endplates, flow distributors, and current collectors, and is fabricated in the same manner as multi-cell stack) and have been fabricated and tested under previous Honeywell internally funded work. Those test results will be used to form a baseline for stack testing under this program. A polarization and power density curve for a baseline stack module (one cell) is presented in Figure 2. The figure plots cell voltage, power density, and fuel utilization as a function of current density. The data is presented at two operating pressures, ambient (1 atm), and 200 kPa (2 atm). The fuel for this test was a mixture of 64% hydrogen, balance nitrogen. This composition, which is representative of a typical steam reforming fuel processor output, has been standardized for the fuel composition for stack testing for this program.

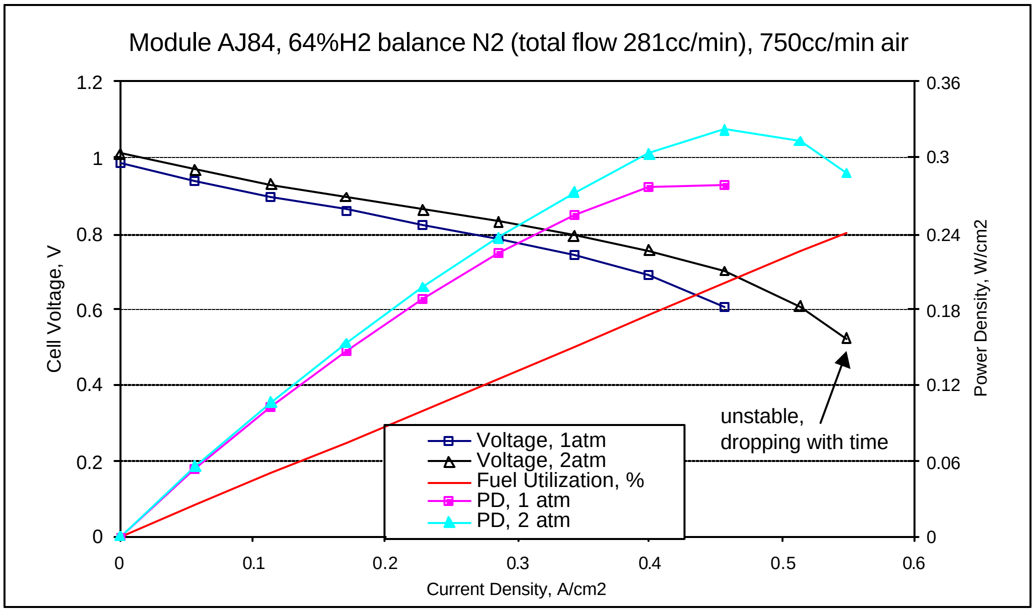

Figure 2. Performance curve for a baseline stack tested at 800°C and at ambiant and elevated pressures.

- Work during the initial period of the program has focused on the assembly of stacks and performance mapping. The data collecting from the mapping will be used in the system analysis tasks to refine the system models and to aid in system optimization. Mapping of stack performance as a function of fuel flow rate was initiated during this reporting period. A typical set of data for performance mapping is shown in Figure 3. This data shows the performance of a 1-cell stack module for ambient and pressurize operation. This stack module was tested under the same conditions as the stack module presented in Figure 2 but at a higher fuel flow rate. This data will be combined with tests at other conditions to map the operating space for the fuel cell.

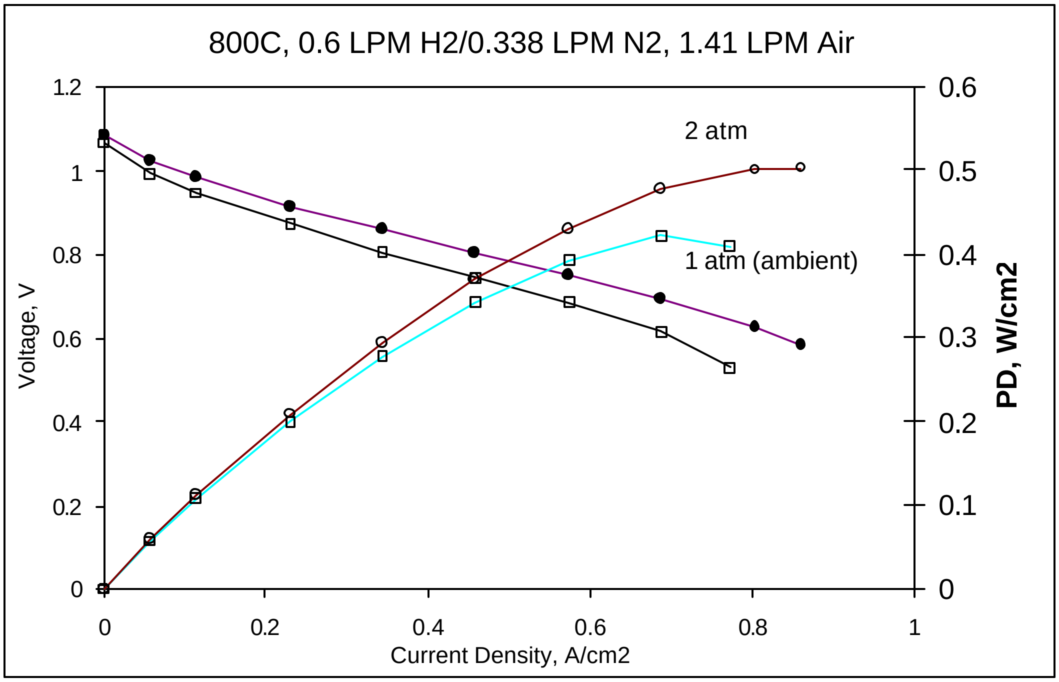

Figure 3. Performance curve for a baseline stack tested at 800°C and at ambiant and elevated pressures.

Program Management

An internal program kickoff was held in Torrance, CA for all participants on the program. The program objectives and goals were presented to the technical task teams and the teams developed detailed task schedules. The team meets weekly and provides task status/highlights at each meeting.

Conclusion

An internal program kickoff was held in Torrance, CA. The output of the kickoff meeting as a team consensus on the program objectives and a detailed program schedule was developed. Work has been initiated in the areas of system design and pressurized SOFC. Performance model capability was expanded in the system design task, and performance mapping of stack operation was initiated on the pressurized SOFC task. These models and stack data are essential for developing the preliminary concept designs that will be completed in April 2002.

APPENDIX

TASKS TO BE PERFORMED

PHASE I

BUDGET PERIOD 1A

Task 1A.1 – System Design

Subtask 1A.1.1 – Design Concept Development. The purpose of this task is to develop a system design concept for a hybrid system incorporating a planar SOFC with Honeywell commercial Parallon™ turbogenerator. Several system configurations based on pressurized fuel cell operation will be evaluated, and a configuration shall be selected as a baseline for reference design. The purpose of this task is to develop a set of criteria for the selection of the baseline design. Studies shall be performed to permit definition of all components/subsystems in term of type, performance, and input and output requirements. Focus shall be placed on the development of the fuel cell configuration including power level and control strategy including control structure.

Subtask 1A.1.2 – Performance Analysis. The purpose of this task is to develop models to analyze performance of the system under specified operating conditions. The analysis shall cover both system operation and system control. Heat and mass transfer, gas flow rates, and key state points within the system shall be evaluated. System performance as a function of various parameters, such as fuel cell operating temperature, operating voltage, and operating pressure, shall be evaluated. System efficiency shall be established. The purpose of this task is to revise performance as appropriate using data from other tasks. The purpose of this task is to obtain control dynamic models for critical areas of the overall process and simulate to determine significance of process and component responses to control.

Subtask 1A.1.3 – Trade Studies. The purpose of this task is to conduct trade studies to identify an optimal configuration for the system. The purpose of this task is to identify key parameters/arrangements for the studies and carry out sensitivity studies. Consideration shall be given to the SOFC subsystem design and how the fuel cell may be arranged to meet performance and cost objectives. The purpose of this task is to perform trade analysis regarding control performance versus system/component responses or existing subsystem controller capability.

Task 1A.2 – Technical Barrier Resolution

Subtask 1A.2.1 – High-Temperature Heat Exchangers. The purpose of this task is to develop, design, fabricate and test a high-temperature heat exchanger capable of operating with high-temperature exhaust gases to heat up the air before it is introduced into the fuel cell stack. The heat exchanger will be made of high-temperature material such as Inconel 625 alloy. The purpose of this task is to perform structural analysis of the heat exchanger core and enclosure to ensure pressure containment of the heat exchanger from the high exhaust gas side operating pressure. Fabricated heat exchangers shall be tested for performance and quality to demonstrate applicability. Performance maps of the heat exchanger shall be developed.

Subtask 1A.2.2 – Pressurized SOFC. The purpose of this task is to fabricate and test planar SOFC's under pressurized conditions. The work will involve fabrication and testing of laboratory scale cells and stacks of increasing size to investigate their properties in pressurized environments. Electrochemical performance and structural integrity at pressures shall be evaluated. Analysis and modeling shall be carried out to identify performance degradation mechanisms under pressures, if any. Performance maps will be determined for various operating parameters. Thermal cyclability and lifetime under pressurized operation shall also be investigated. The purpose of this task is to modify cell and stack designs if required to improve cell performance and structure.

Task 1A.3 – Economic Evaluation. The purpose of this task is to estimate the market size for the system concept. Based on the market size, the purpose of this task is to conduct sensitivity studies of the system economics. Comparison with conventional technologies shall be performed. The overall finance of the system shall be evaluated for various commercial scenarios.

BUDGET PERIOD 2/PHASE II

Task 2.1 – System Analysis and Design

Subtask 2.1.1 – System Concept Design. The purpose of this task is to develop a design for the proposed full-scale system concept, consisting of a planar SOFC and a Parallon™ 75 turbogenerator. The design shall be developed in sufficient detail to permit definition of all components in term of performance, weight, size, and cost. The purpose of this task is to produce drawings for the system including key components/subsystems and control system. The purpose of this task is to evaluate the packaging of the system. Drawings of the packaged system shall be provided. Based on the system concept design, a design of a subscale hybrid system for feasibility demonstration shall be developed.

Subtask 2.1.2 – Component Specifications. The purpose of this task is to develop and compile specifications for all components of the system. Consideration shall be given to specifications of the Parallon™ turbogenerator, the SOFC module, the fuel processor, key heat exchangers, and the control system.

Task 2.2 – Cost Analysis

Subtask 2.2.1 – Baseline Cost Estimate. The purpose of this task is to carry out a cost study to determine system costs for proposed full-scale system concept consisting of a planar SOFC and a Parallon^{TM} 75 turbogenerator. The purpose of this task is to estimate the cost of the system in $/kW. The purpose of this task is to use system cost and performance information to determine operating and maintenance costs. These costs shall be used to develop a cost of electricity for the system. All assumptions and methodology used in estimating the cost shall be clearly defined.

Subtask 2.2.2 – Sensitivity Study. The purpose of this task is to conduct a cost sensitivity study for the proposed full-scale system. The key parameters for the sensitivity study shall be defined. Focus shall be placed on certain factors such as operating parameter, equipment option, and location. The purpose of this task is to establish the interrelationship between cost and specific parameter.

BUDGET PERIOD 3/PHASE III

Task 3.1 – System Definition. The purpose of this task is to refine the design of the sub-scale system for feasibility demonstration developed in Task 2.1.1. The purpose of this task is to specify all the components required for the assembly of the system.

Task 3.2 – Assembly and Testing. The purpose of this task is to procure or fabricate and assemble system components for the demonstration testing. Samples shall be produced or acquired according to the specifications established in Task 3.1. The purpose of this task is to perform required tests to demonstrate suitability of samples before integration. The purpose of this task is to test integrated components/subsystems to verify suitable operation. The purpose of this task is to prepare a test plan aiming at demonstration of a small hybrid system. The plan shall include (a) statement of objective, (b) test description, (c) statement of success criteria, (d) description of methods for assessing test results, and (e) description of post-test analysis.

Task 3.3 – Feasibility Demonstration. The purpose of this task is to conduct a demonstration test according to the test plan prepared in Task 3.2. The purpose of this task is to prepare a summary test report and compare test results with success criteria and provide conclusions. **Testing under this Task shall, at a minimum, total at least fifty (50) hours.**