II.K.4 Generation and Solid Oxide Fuel Cell Carbon Sequestration in Northwest Indiana*

Norm Bessette
Acumentrics Corporation
20 Southwest Park
Westwood, MA 02090
Phone: (781) 461-8251; Fax: (781) 461-8033
E-mail: nbessette@acumentrics.com
Contracted by NiSource Energy Technologies, Inc.

DOE Technology Development Manager:
Pete Devlin
Phone: (202) 586-4905; Fax: (202) 586-9811
E-mail: Peter.Devlin@ee.doe.gov

DOE Project Officer: Reg Tyler
Phone: (303) 275-4929; Fax: (303) 275-4753
E-mail: Reginald.Tyler@go.doe.gov

Contract Number: DE-FC36-04GO14227

Project Start Date: October 01, 2004
Project End Date: September 30, 2007

*Congressionally directed project

Objectives

- Maximize capture of carbon monoxide and carbon dioxide from natural gas-fueled solid oxide fuel cell (SOFC) systems through optimization of cell and generator design.
- Develop an anode supported tubular cell capable of doubling the power density presently achieved.
- Isolation of the anode supported cell from the manifold.
- Modifications of manifold design for incorporation of next generation higher power multiple connection chromite cells.
- Reduce dependency upon foreign oil and gas through improvements in overall SOFC efficiency.

Accomplishments

Key Accomplishments in FY 2007 include:

- **Exceeded 350 mW/cm^2 on multiple interconnection cells:** Multiple interconnection cells have been fabricated achieving >350 mW/cm^2. This increases both the efficiency and the average value from 120 mW/cm^2 thereby cutting the required number of cells and cost for a desired power level.
- **Tested a high density, sintered bundle stack:** Utilizing multiple interconnection cells, a 45-cell sintered bundle operated at a current density of 350 mA/cm^2 and achieved a maximum power 1.14 kW.
- **Isolation of cells from the manifold:** Connection of cells to the manifold through an isolating media rather than conductive media has been successfully achieved.
- **Utilized a single manifold to run a sintered bundle stack and collect the off-gas stream:** By isolating the braze cap from the cell, a single stack manifold concept has been made possible. Design and fabrication of such a manifold with off-gas collection for CO_2 sequestration has been achieved. In addition, utilization of a single manifold reduces sealing requirements, thus increasing generator efficiency.
- **Fabrication of isostatically pressed closed one end (IP COE) tubular SOFC:** Further advancements in larger diameter tube technology and multiple take-off connections have been integrated into closed end pressed tubes allowing for minimization of fuel leakage since the closed end is integral to the tube rather than a brazed cap solution that has previously been utilized.
- **Achieved 83% effectiveness for a cathode air recuperator:** Continual enhancement of thermal energy recovery from an operating generator has yielded a recuperator design achieving 83% effectiveness. In addition, with this novel recuperator design it has been possible to achieve significant reductions in size, weight and cost.

Introduction

In order to stay aligned with the President's goal of reducing dependence upon foreign oil and gas through improvements in overall system efficiency, a number of avenues have and are being pursued to address such issues. Particular emphasis has been placed upon a system design to allow capture of all off-gas from a natural gas-fueled SOFC system while at the same time improving overall system efficiency. In addition, the Acumentrics project has focused upon the design and fabrication of a micro-tubular SOFC for enhanced power and efficiency to achieve double the power density from current state-of-the-art anode supported tubular designs.

Approach

To become less dependent upon foreign oil, work has focused upon increasing cell power and overall system efficiency. Operating systems at higher fuel utilizations and power densities will limit carbon monoxide emissions while reducing overall system cost by decreasing the number of cells per kilowatt. Generator component improvements in the areas of thermal recovery, gas sealing and off-gas sequestration have and are being investigated. To increase cell power, work is focused on enhanced materials as well as enhancements in cell geometry. Fabrication of tubes with closed ends, thus eliminating the need for brazing, and cells with increased diameter have been fabricated and evaluated along with cells supporting multiple contact points along the tube length.

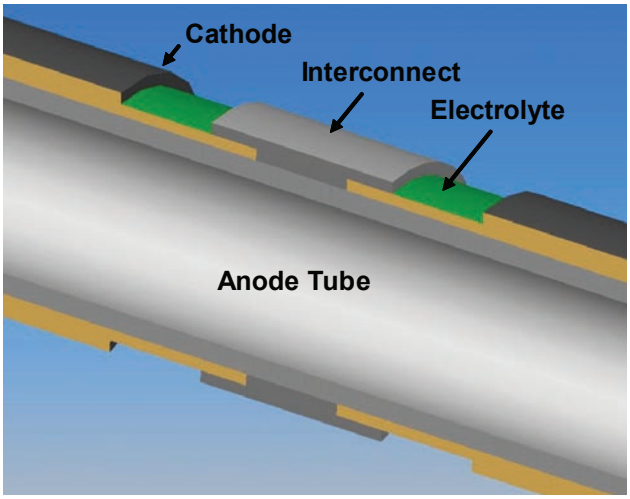

FIGURE 1. Anode Current Collection Through the Interconnect Coating

Results

Cell & Stack Performance and Power Density

With major achievements in cell and stack consistency, a considerable boost in stack power density has been achieved. A key contributor to this increase in power density is the implementation of interconnect bands to the cell design. Figure 1 shows a drawing of the interconnect coating applied to the outside of the cell allowing for multiple anode contact points along the tube, thus decreasing current path length and therefore minimizing resistive losses. This significant enhancement in cell power density has resulted in decreased cell count from 126 to 45 for a stack capable of 1.14 kW. Figure 2 shows the progression of reducing stack size by increasing cell power density.

FIGURE 2. Progress in the Reduction of Stack Size

Significant effort was extended into preparing tubes with mixed ionic and electronic conduction (MIEC) coatings to fabricate a viable oxygen transport membrane (OTM). After numerous attempts, utilizing various processing techniques and material selection, it was not possible to apply a stable MIEC coating to the tube during this period.

Tube Fabrication

Conventional horizontal firing of IP COE tubes resulted in slumping and as such vertical firing trials were required to produce bisque fired tubes that are straight, round and crack free. Vertical firing methodology required the use of an alumina collar to support the IP tube around the pressed flange during bisque firing. This same collar remained with the tube during electrolyte dipping, the methodology for which was also modified to preclude the usual tube inversion required for solvent removal. This was necessary due to the size and closed end nature of the pressed tube. The electrolyte-sintering step was developed to be similar to the bisque firing step in that an alumina collar was used for vertical hanging. Some issues have, however, been noted with the collar support in that the fired tubes are sometimes not straight and periodically fall through the supporting collar. An alternative design is therefore currently being evaluated which employs a chamfer around the circumference of the kiln furniture orifice in which the tube flange resides during firing. This chamfer design will promote perpendicular tube alignment with the furnace floor throughout the sintering process and therefore result in straight tubes.

Generator Design

A dual chamber single manifold was designed for testing a stack of 45 cells. The cells were isolated from the braze cap by encapsulating the inside of the cap with a non-conductive high temperature ceramic cement. This technique allowed for the cells with the caps to be

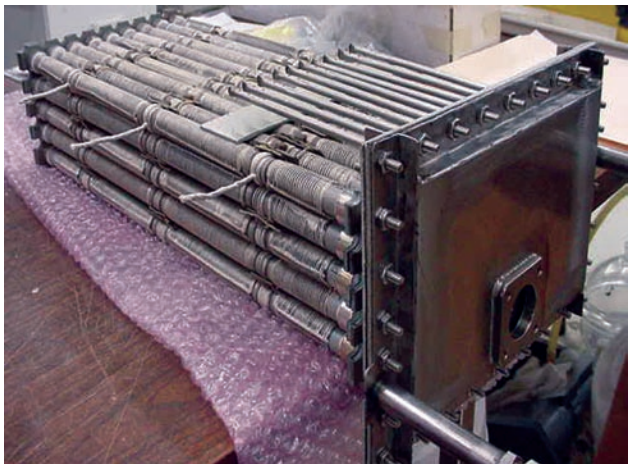

FIGURE 3. Common Manifold and Off-Gas Collection for a 45-Cell Stack

press fit into the metallic manifolds without causing a short between the cells and the manifold. In addition, the manifold allowed for capture of the off-gas from the cells. In this arrangement, the off-gas was channeled past the incoming cathode air stream to provide a boost in the cathode air temperature leaving the recuperator, thus providing a more efficient system. Figure 3 illustrates the common manifold and off-gas collection for the 45-cell stack.

Through fabrication of a recuperator test stand, different recuperator designs have been evaluated at simulated flow rates and conditions of an integrated generator installation. This has accelerated progress towards a high efficiency metallic recuperator for thermal recovery, culminating in an innovative recuperator design which allows for high heat exchange by providing a large heat transfer area and meeting the design requirement for greater than 83% effectiveness. With this design, significant reductions in size, weight, and cost have also been realized.

Conclusions and Future Directions

In conclusion, significant improvements in cell sealing, performance and therefore power density have been accomplished in the last year. Coupled with this, generator design has been optimized for efficiency of operation with minimization of seals and maximization of recuperator efficiency. In combination, the aforementioned factors have lead to successful SOFC generators which have been optimized for efficiency and power density with the added advantage of 100% off-gas capture.

Future work should include:

- Investigation into a viable OTM material.
- Evaluation of alternative ceramic/metal seals.
- Evaluation of enhanced kiln furniture for firing IP COE cells.
- Design, build and test a sintered stack using high power 22 mm diameter cells.

FY 2007 Publications/Presentations

1. A poster presentation was made at the 2007 DOE Hydrogen Program Review in Washington, D.C. on May 15th.