VII.G Stationary Power Systems

VII.G.1 150 KW PEM Fuel Cell Power Plant Verification

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Objectives

- Improve polymer electrolyte membrane (PEM) cell stack assembly (CSA) durability to achieve lifetimes >40,000 hrs
- Verify reliability of low-cost PEM cell stack components
- Verify the design, durability, and reliability of natural gas fueled PEM power plant
- Complete a fuel cell stationary power plant market assessment
- Complete waste heat thermal integration assessment

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- A. Durability
- B. Cost
- C. Electrode Performance
- D. Thermal, Air and Water Management

Technical Targets

This project covers several aspects of technology development that will be applied toward the design of a durable, reliable and low-cost PEM stationary fuel cell power plant. Some of the key DOE 2010 stationary fuel cell technical targets are:

- Durability: <10% rated power degradation @ 40,000 hrs
  - Currently at 20,000 hrs
- Average electrical efficiency: 40% (LHV)
  - Prototype 150 KW power plant design is at 34%
- Combined heat and power (CHP) energy efficiency: 80%
  - CHP- Waste Heat Thermal Integration Assessment Study initiated.
- Cost: $750/Kwe @ 2000 units/yr
  - Current projection is $1500/Kwe to $1800/Kwe

Approach

- Improve the durability of PEM CSA technology
- Verify reliability of low-cost PEM cell stack components
- Verify the specification, durability, and reliability of a natural gas fueled PEM power plant
- Assess fuel cell stationary power plant market
- Analytically confirm useful application of PEM power plant heat

Accomplishments

- Accelerated testing shows advanced reinforced membrane lifetime of >20,000 hours.
- Several seal materials were screened and one non-silicone materialselected. The material has superior mechanical and chemical properties.
- Good performance and limited durability time achieved with low-cost plates and unitized electrode assemblies (UEAs).
- Reviewed four fuel processing system (FPS) concepts to improve the PEM natural gas fueled power plant.
- Identified two potential noble metal catalysts; currently examining different ways to integrate this catalyst technology within a catalytic steam reforming (CSR) assembly in the improved PEM natural gas fueled power plant. Initial efforts are focused on a multi-tube reformer design, where the tubes are loaded with monolithic structures.
- Completed the initial market assessment for the fuel cell stationary market. Results indicate that there is an excellent outlook for distributed generation, cogeneration, and anaerobic digester gas (ADG) and landfill applications. The international markets for green power generation and the use of renewable energy technology are growing.
- Reviewed several thermal integration concepts, markets, regional aspects and evaluation methodologies to select 4 primary concepts, 5 markets and 7 regions for systematic evaluation and identification of the high value thermally integrated concept.

Future Directions

- Begin quantified accelerated testing of advanced membranes to show 40,000 hours durability
- Continue advanced seal development for long-life stacks
- Initiate short-stack evaluation of low-cost components

- Continue with the preliminary design of the improved PEM natural gas fueled stationary power plant with the pressure swing adsorption (PSA) system concept.
- Perform market analysis and develop necessary cost models and low fidelity physics based component models for next level of analysis.
- Evaluate selected system concepts with thermal integration for varied markets to identify the concept that provides highest power plant payback.

Introduction

This project has several aspects of technology development that needs to be completed in order for a 150KW power plant to be validated in the field by real utility customers. The first phase is to improve the PEM cell component and stack durability to increase stack life to greater than 20,000 hours with a goal of 40,000 hours. Second is to integrate this improved technology into a demonstration power plant fueled by natural gas. This power plant is to be validated for reliability and connect-ability to a commercial distribution feeder at a selected utility. The final configuration of this power plant is based on the fuel cell stationary commercial experience from UTC Fuel Cells PC25C 200 KW power plants, the PEM 150 KW Beta test experience completed from earlier in this project and the integration of the advanced cell stacks from resulting from phase one. In addition to the extensive cell stack technology and the power plant design activities, we are currently working on thermal heat utilization for CHP applications, and have completed an extensive market analysis study for stationary fuel cells in this size range.

Approach

Our approach to improving the durability of PEM CSA technology is to determine the root cause and corrective action for high severity/frequent CSA failure modes, to develop a mathematical model to optimize inlet flow channel design for maximum humidification, to identify seal materials with chemical and mechanical stability in a fuel cell environment, and to verify accelerated test conditions that demonstrate representative failure modes. To verify the reliability of our low-cost PEM cell stack components, we focus on the performance and durability validation of the low-cost plate and UEA components.

We will verify the specification, durability, and reliability of natural gas fueled PEM power plants by constructing and evaluating a 150 KW PEM stationary power plant that includes a high pressure FPS that uses a CSR with the PSA system. The heat utilization analytical assessment approach includes the identification of concepts that utilize waste heat and evaluation of selected concepts using system level models. These models are simulated for select markets and regions, using 8760 hourly building loads. The fuel cell stationary power plant market assessment was done by identifying how strong the market for stationary fuel cells is currently and where its potential growth will be. Extensive use of the UTCFC database of PC25C power plant experience was integrated into the applications and market segments of the study.

PEM CSA Results

Durability

An accelerated chemical-mechanical test was developed to screen membranes. This test is cyclic in relative humidity (RH) and load. RH cycling accelerates mechanical failure and load cycling in the presence of pure oxygen accelerates chemical degradation rates. The first cycle involves cycling the RH with no load. The second cycle contains the application of cyclic load in an O_2 environment. In between cycles, the cross-over current density is measured to assess the state of the membrane. Membrane failure is defined as a crossover current density of 10 mA/cm^2. The results for 6 state-of-the-art membranes are shown in Figure 1. The difference in the time to failure between samples “reinf1” and “reinf5” is approximately 100 hours. The ratio of their lifetimes is approximately 2.25.

Accelerated testing strategies were developed to characterize the mechanical and chemical stability of seal materials. Per this strategy, selected seal

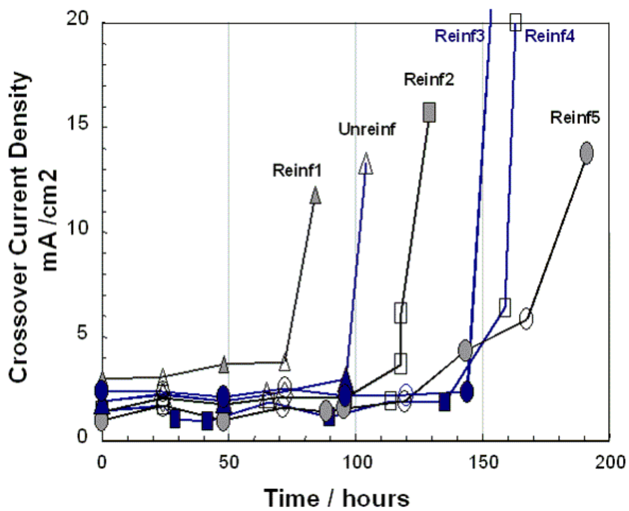

Figure 1. Accelerated Membrane Testing Under the Relative Humidity and Load Cycling Protocol

materials are tested for chemical and mechanical stability. The chemical stability tests include plate deposit test, hydrothermal leach test and thermo-gravimetric analysis (TGA). Mechanically, accelerated compressive stress relaxation and hydrothermal elongation tests are performed to verify sealability. The compressive stress relaxation of the individual seal materials is measured to characterize compression set. Using this testing strategy, a non-silicone seal system was selected and compressive stress relaxation testing was initiated. Comparison of the compressive stress relaxation and hydrothermal elongation data for the baseline silicone and the selected non-silicone seal system is shown in Figure 2.

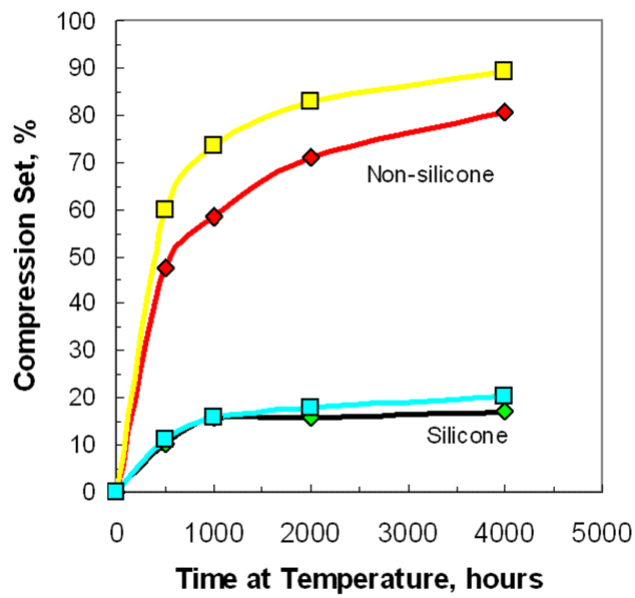

Figure 2. Compression Set Data for Silicone and Non-Silicone Seal Materials at 80 and 95 C

Cost Reduction

Performance and limited time durability of low-cost UEAs and water transfer plates (WTPs) were verified in a single cell. The data is presented in Figure 3. The WTPs were fabricated by an advanced manufacturing process that is capable of significant cost reduction. The UEAs were fabricated with low-cost components. As seen from the Figure 3, the performance of the single cell with low-cost components is better than the specification. One thousand hours of limited time durability data was also collected on the low-cost components and minimal performance loss was seen during the course of the test.

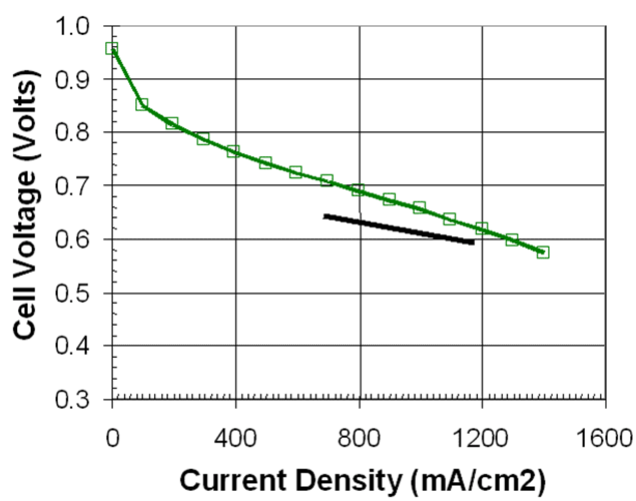

Figure 3. Performance and Limited Time Durability Validation of Low-Cost UEAs and WTPs

<u>Power Plant and FPS Design Results</u>

The power plant concepts analyzed were configured to operate on natural gas and meet a 40,000-hour service life. An electrical system efficiency requirement (based on LHV) of greater than 35% was used to quantify the performance of each concept. Technical risks, which are defined as technological risks associated with the maturity of the concept and the concept's ability to meet a "time to test" constraint of less than 1.5 years, were also used to rank concepts. The four power plant design concepts reviewed were: CO_2 membranes, H_2 membranes, pressure swing adsorption, and preferential oxidation (PROX). A summary of the system analyses is provided in Table 1.

Table 1. Summary of System Performance Studies

	Concept 1	Concept 2	Concept 3	Concept 4
FPS	**Reformer Type – CSR**			
Operating Pressure	4 bar	6 bar	10 bar	1 bar
CH_4 Conversion	90%	85%	75%	90%
Purification				
Method	CO_2 Membrane	H_2 Membrane	PSA	NONE - PROX
H_2 purity (dry)	97%	>99%	>99.9%	78%
CSA	**CSA Type – S900**			
Anode Recycle	No	Yes	Yes	No
Power Plant				
FPS Efficiency	73.9%	62.2%	73.9%	73.8%
Mech. Efficiency	97.0%	95.5%	94.9%	98.7%
CSA Efficiency	52%	52%	52%	51%
System Efficiency	37.2%	30.8%	36.4%	37.0%
Technical Risk	Membrane	Membrane	Reformer	CSA - Reformate

As depicted in Table 1, Concept #3 (PSA system) is capable of delivering the desired efficiency, because it has the highest technology readiness level (lowest technical risk). The only technical risk related to Concept #3 is the pressurized fuel processor development cycle, which currently is estimated at approximately 1 year. It is our recommendation that we proceed with the PSA power plant concept as the primary path, unless further data from Concepts #1 and #4 suggest otherwise.

Waste Heat Thermal Integration Assessment

A set of concepts that utilize the waste heat from the PEM system were generated and the concepts were down-selected for performance, ease of integration with existing PEM power plant, and cost. The down selected PEM waste heat integration concepts are thermally activated technologies for cooling, heating and dehumidification needs. The markets selected for the study, based on more uniform building loads throughout the year and dehumidification/air quality needs, include hospitals, supermarkets, data centers, hotels, and labs/clean rooms. The regions selected are San Francisco (CA), Los Angeles (CA), Chicago (IL), Boston (MA), New York City (NY), Miami (FL), Washington D.C. based on humidity levels, spark spread (BTU equivalence for natural gas and electricity), density of population, and credits for green technologies.

Conclusions

Accelerated testing demonstrates advanced reinforced membrane life of > 20,000 hrs. We will continue our testing efforts to show 40,000-hr durability. Several seal materials were screened and one non-silicone material was selected. Good performance and limited durability time has been achieved with low-cost plates and UEAs. We will continue advanced seal development for long-life stacks and will initiate short-stack evaluation of low-cost components.

UTCFC will continue with the preliminary design of a pressurized FPS/PSA system concept (#3). We will focus our efforts on performing detailed component analyses, and will also initiate, if necessary, the identification of key design risks associated with the development of a high-pressure fuel processor. In addition to the fuel processor development, we will continue to monitor the technological progress of FPS Concepts #1 and #4. The next phase of fuel processing activities will continue with the verification of noble metal reformer catalysts, and a detailed examination of a new reformer tube structure proposed for the PSA power plant concept (#3). In parallel to the reformer development effort, we are planning to assess potential PSA suppliers and continue the characterization of PSA purification technology.