Fuel Cell Distributed Power Package Unit: Fuel Processing Based on Autothermal Cyclic Reforming

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Objectives

- Design, fabricate and operate an integrated pre-commercial fuel processor to produce a continuous proton exchange membrane (PEM) fuel cell grade hydrogen-rich stream.
- Assess the reliability, potential cost and performance of the fuel processor.

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Production section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year R,D&D Plan:

- A. Fuel Processor Capital Cost
- B. Operation and Maintenance (O&M)
- C. Feedstock and Water Issues
- D. Carbon Dioxide Emissions
- E. Control and Safety

Approach

- Design a pre-commercial 50-kWe fuel processor to produce PEM fuel cell grade hydrogen-rich gas from natural gas based on GE's Autothermal Cyclic Reforming (ACR) technology.
- Analyze several process configurations that include ACR reactors, shift reactors, preferential oxidation reactors (PrOx) and heat exchangers, and select the best configuration with high efficiency, high reliability and low capital cost.
- Design, fabricate and operate the ACR-based fuel processor.
- Develop a control system for safe operation of the fuel processor with low O&M cost.
- Develop tools to quantify the efficiency, cost and reliability of the fuel processor.

Accomplishments

- Designed, fabricated and operated a pre-commercial 50-kWe fuel processor that includes the ACR, shift and PrOx reactors and heat exchangers to produce a continuous hydrogen-rich stream with less than 50 ppm CO.
- Developed a control system for safe operation of the fuel processor.

- Developed a cost analysis model to estimate the delivered electricity cost from the ACR and PEM fuel cell based power system as a function of capacity and mass production rate.
- Developed tools (Failure Reporting, Analysis and Corrective Action System {FRACAS} and Reliasoft) to track and quantify the reliability of the fuel processor.

Future Directions

- Optimize the ACR-based fuel processor to get <10 ppm CO in the product stream.
- Integrate the fuel processor with a PEM fuel cell.
- Develop an ACR catalyst that is active and durable for over 5,000 hours to reduce the O&M costs further.

Introduction

GE is developing a proton exchange membrane (PEM) fuel cell based distributed power generation unit that uses a proprietary fuel processor to convert fossil fuels to a hydrogen-rich gas for use in the PEM fuel cell. The target application is commercial and residential buildings with electric demand in the 20-200 kWe range and with cogeneration needs. The goal of this project is to design, develop, and demonstrate an integrated unit for generating electric power in buildings. Phase II is a demonstration of the integrated fuel processor to continuously generate PEM fuel cell grade hydrogen. This integrated unit will be used to generate data needed in the design of a prototype power generation package. The unit promises high efficiency, low emissions and low cost by utilizing a novel process called autothermal cyclic reforming (ACR).

ACR is an autothermal cyclic catalytic steam reforming technology for converting hydrocarbons to a hydrogen-rich stream. The ACR process operates in a three-step cycle that includes steam reforming of the fuel in a Ni catalyst bed (Step 1 - Reforming), heating the reactor through oxidation of the Ni catalyst (Step 2 - Air Regeneration), and finally reducing the catalyst to the metallic state (Step 3 - Fuel Regeneration). The heat required for the endothermic reforming step is provided during the exothermic air regeneration step. The ACR process consists of two low pressure reactors cycling between the reforming and regeneration (air and fuel) steps to produce a continuous stream of hydrogen-rich gas. The fuel processor produces a 70-80% hydrogen stream that can be purified downstream for PEM fuel cell quality using a shift and a PrOx reactor. The ACR process is a unique technology that can be applied for the production of hydrogen from different fuels, including natural gas, diesel fuel, and renewable feedstock, such as bio-fuels. The ACR process represents a significant technological advancement in comparison with autothermal reforming (ATR) and partial oxidation (POX), as the ACR-produced syngas is not diluted with nitrogen, and the overall efficiency of the ACR process is higher than ATR and POX. When compared to conventional steam methane reforming (SMR), the ACR process has significantly lower capital costs and lower emissions. In addition, the ACR process is fuel flexible and has been successfully demonstrated using high-sulfur fuels.

Approach

A major goal in the Hydrogen, Fuel Cells & Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan is to reduce the cost of H_2 or electricity produced from natural gas or other fossil fuels. The ACR technology promises to reduce the capital cost and improve the efficiency and reliability of the fuel processor as compared to other reforming technologies (SMR, ATR and POX). The final process configuration for the ACR-based fuel processor was selected after detailed process analysis of several configurations to achieve the desired performance targets including capital cost and efficiency.

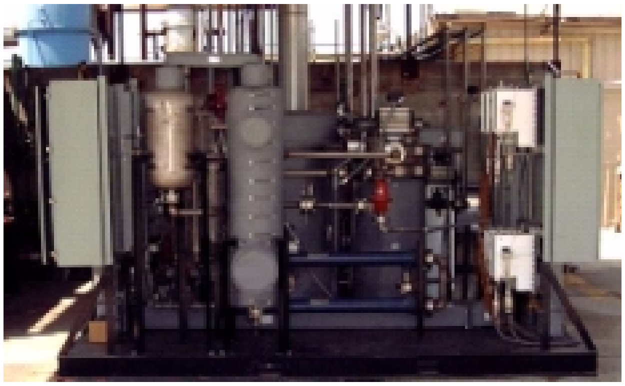


Figure 1. ACR-based 50-kWe Fuel Processor

A 50-kWe fuel processor was designed and fabricated. The integrated fuel processor consists of ACR reactor, shift reactor, PrOx reactor and heat exchangers. Figure 1 shows the picture of the fuel processor. A control system was developed for automatic and safe operation of the fuel processor. A detailed safety review, including preliminary hazard analysis (PHA), hazardous operations review (HAZOP) and accident scenario review (ASR) of the fuel processor, was carried out before operating the fuel processor. The integrated fuel processor was operated to produce a continuous hydrogen-rich stream.

Process analysis tools were developed to quantify the efficiency, cost and reliability of the fuel processor. The efficiencies of several ACR-based process configurations were calculated and compared with efficiencies of existing reforming technologies. An economic model was developed to calculate the capital and O&M costs for the fuel processor under different scenarios of capacity and mass production. The reliability of the fuel processor is being tracked and quantified by using GE's tools, such as FRACAS and Reliasoft.

Results

The ACR unit produces a continuous hydrogen-rich stream (70-80% hydrogen on a dry basis) through cyclic operation of two reactors. Methane slip from the ACR reactors is less than 5%. Figure 2 shows the typical dry gas composition of the product gas from the ACR reactors. The reformate stream contains 8-10% carbon monoxide.

The shift reactor reduces the concentration of CO in the product gas to less than 0.5% via water gas shift reaction ($CO + H_2O \Rightarrow H_2 + CO_2$). The PrOx reactor further reduces the CO concentration below 50 ppm via selective oxidation of CO to CO_2. Further optimization of PrOx reactor operating conditions will result in reducing the CO concentration in the product below 10 ppm. Figure 3 summarizes the typical product dry composition after ACR, shift and PrOx reactors.

The cost analysis model was developed to estimate the cost of electricity produced by the ACR fuel processor integrated with a fuel cell. The model takes into account the capital cost, O&M costs, fuel cost and consumable cost. Figure 4 shows the relationship between the cost of electricity and the

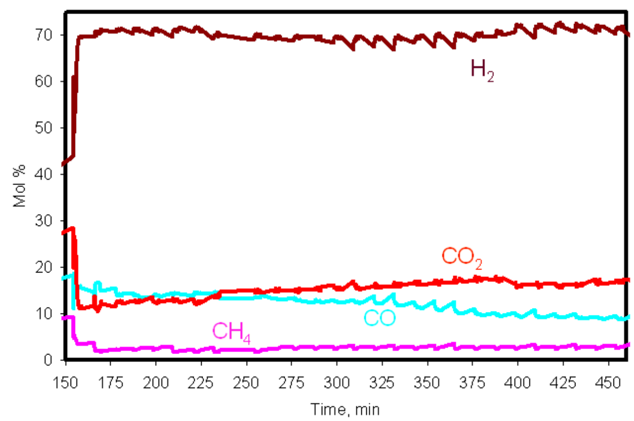
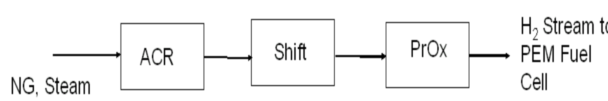


Figure 2. Composition of the Product Gas (Dry Basis) from the ACR Reactors



Reactor	H_2	CO	CO_2	CH_4
ACR	69%	9%	19%	3%
Shift	73%	0.6%	23%	3%
PrOx	72%	< 50 ppm	25%	3%

Figure 3. Composition at the Outlets of ACR, Shift and PrOx Reactors (Dry Basis)

fuel processor/fuel cell capacity at different mass production rates based on the cost analysis model. The plot shows that the fuel processors will be cost effective at higher capacities (> 300 kWe) and when mass-produced (> 5,000 units/year).

Figure 5 shows the cost of electricity as a function of catalyst life for a 200-kWe fuel processor. If the catalyst life is over 2,000 hours, the fuel processor becomes cost effective. Nearly 30 different reforming catalysts were studied in a related project funded by the California Energy Commission. A catalyst that is active and durable for 2,000 h has been identified.

The reliability of the fuel processor is currently being tracked in the failure reporting, analysis and corrective action system (FRACAS). Once the FRACAS system is populated with statistical failure data, the reliability of the entire fuel processor will be calculated using a software tool called Reliasoft. Reliasoft links the reliability of individual components through a block diagram to calculate the reliability of the integrated fuel processor.

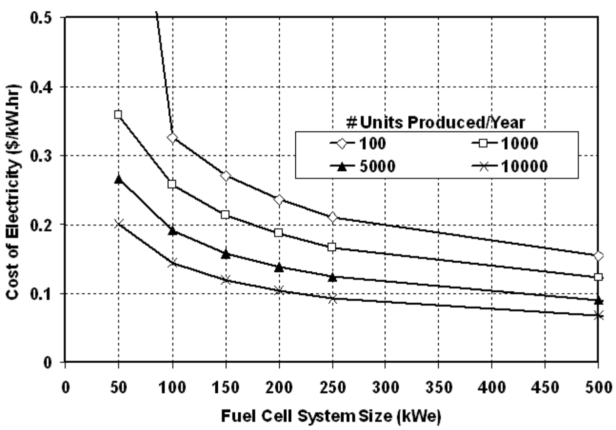


Figure 4. Relationship Between the Cost of Electricity and the Fuel Processor Capacity at Different Mass Production Rates

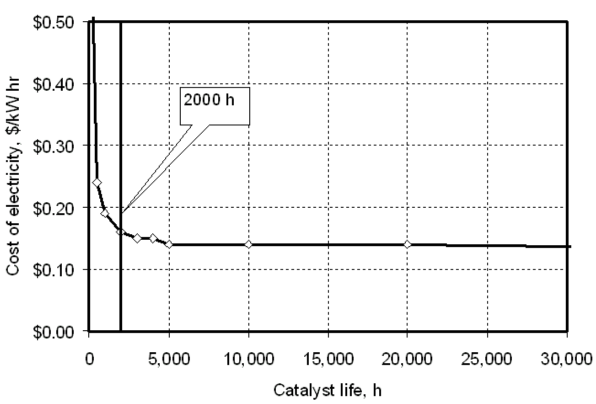


Figure 5. Cost of Electricity as a Function of Catalyst Life

Conclusions

- The ACR-based fuel processor produces a continuous hydrogen-rich stream (70-80% hydrogen on a dry basis) through cyclic operation of two ACR reactors. The heat required for the endothermic reforming process is generated by exothermic oxidation reaction of the nickel catalyst followed by its regeneration.
- The shift and PrOx reactors reduce the CO concentration in the product stream below 50 ppm, thus generating a PEM fuel cell grade hydrogen-rich stream (further optimization of the PrOx reactor will reduce the CO concentrations below 10 ppm).
- Optimization of the ACR-based fuel processor will improve the efficiency and reliability of the system and will result in cost reduction.

FY 2002 Publications/Presentations

1. Hydrogen Refueling System Based on Autothermal Cyclic Reforming, Kumar, R., International Energy Agency Annexe XV Meeting, Palm Springs, CA, Nov 17-18 2002.

2. Hydrogen Refueling Station Based on Autothermal Cyclic Reforming, Kumar, R., Barge, S., Kulkarni, P., Moorefield, C., Zamansky, V., Fuel Cell Seminar, Palm Springs, CA, Nov 18-22 2002.