IV.A Distributed Reforming

IV.A.1 Autothermal Cyclic Reforming Based Hydrogen Generating and Dispensing System

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Praxair, Tonawanda, NY
University of California, Irvine, CA

Start Date: January 1, 2002
Projected End Date: December 31, 2005

Objectives

- Develop a reformer based hydrogen generating system capable of delivering 60 kg/day of hydrogen.
- Produce fuel cell vehicle grade hydrogen (99.99+% purity; < 1 ppm CO).
- Achieve 69% hydrogen generator efficiency (lower heating value basis).

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 Research, Development and Demonstration Plan:

- A. Fuel Processor Capital Costs
- C. Operation and Maintenance (O&M)
- D. Feedstock Issues
- F. Control and Safety
- L. Durability
- M. Impurities

Technical Targets

A key technical target has been to increase the energy efficiency of hydrogen production from 65% to 69% and achieve a hydrogen production cost of $3/kg by the end of FY 2005.

Approach

- Design a pilot-scale hydrogen generating and refueling system to produce fuel cell vehicle grade hydrogen from natural gas, based on GE's autothermal cyclic reforming (ACR) process.
- Fabricate and operate the ACR based hydrogen generator.
- Develop a control system for safe operation of the hydrogen generator with low operating and maintenance (O&M) cost.
- Quantify the efficiency and cost of the system.

Accomplishments

- Designed and fabricated a pilot-scale high-pressure reformer (150 psig) and pressure swing adsorber (PSA).
- Designed a hydrogen compression, storage and dispensing system.
- Installed the reformer and PSA at University of California, Irvine (UCI).

Future Directions

- Operate the high pressure reformer and PSA system at UCI.
- Optimize the high pressure reformer and PSA system.
- Update the cost analysis.

Introduction

GE is developing a hydrogen generation system designed for vehicle refueling. The hydrogen generation system uses a proprietary ACR unit to convert natural gas to a hydrogen-rich gas that is purified downstream. The generating system includes a Praxair PSA unit to purify the hydrogen. The basics of the ACR process and its advantages over the conventional reforming processes are discussed in the 2003 annual report [1].

Approach

The project is broken down into three phases:

- Phase I - Conceptual design and analysis
- Phase II - Sub-system development
- Phase III - System design, fabrication, and operation

Phase I has been completed. During this phase a conceptual design of the entire ACR-based refueling system was developed. The mass and energy balances, process flow diagrams and systems design for the ACR reactors and other components were completed. An analysis was performed to determine the competitiveness of the design relative to alternative concepts.

Phase II has also been completed. The major tasks in this phase are the development of ACR and PSA units. During Phase II, a low-pressure pilot-scale reformer has been operated. The operational data was used to design a high-pressure pilot-scale reformer. A bench-scale PSA unit has also been operated and these data were used to design a pilot-scale PSA unit.

Phase III was initiated in December 2004. The ACR and PSA units have been fabricated and installed at UCI. The ACR and PSA units will be operated at UCI.

Results

Design of the High Pressure ACR Unit

The high pressure ACR unit was designed using three dimensional stress and thermal modeling tools (see Figure 1). Several reactor components experiencing the highest mechanical and thermal stresses were identified and redesigned to increase reliability. Particular attention was focused on reliability of the high-temperature welds in the reactor.

GE is currently evaluating the cost of hydrogen from all the production technologies on a consistent basis utilizing the just released hydrogen analysis (H2A) model. Based upon the old models and assumptions, we expect this technology to achieve a hydrogen production cost of $3.00/gge. When GE has completed a thorough internal review of all the hydrogen production resources and technologies (natural gas reforming, electrolysis, coal, solar, nuclear), the results will be reviewed with DOE.

Fabrication of Reformer and PSA Units

The fabrication of ACR and PSA units by American Society of Mechanical Engineers (ASME) certified welders has been completed as shown in Figure 2. A weld-check test procedure was followed during the fabrication process. These tests include x-ray, ultrasound, and dye-penetrant weld tests. A third party inspector was required to sign-off on the drawings, weld checks, and fabrication of the reactors.

The components and piping on the unit were upgraded for high-pressure operation. Pipes were socket welded according to American National Standards Institute (ANSI) B31.3 codes. The electrical components on the unit were upgraded to Class I Division II components to meet National Electric Code (NEC) and National Fire Protection Agency (NFPA) codes and standards.

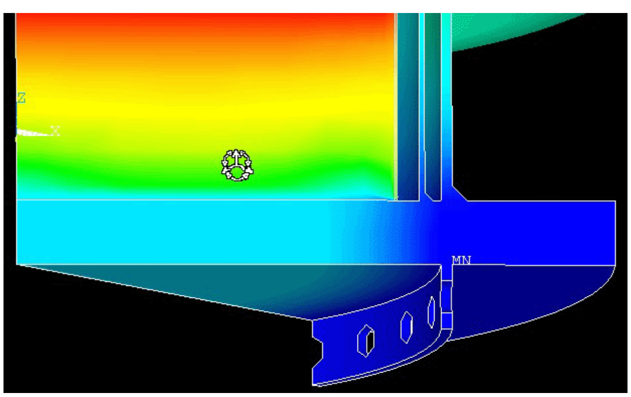

Figure 1. Thermal Model of the ACR Reactor

Installation at University of California, Irvine (UCI)

Extensive professional engineering work was completed to ensure the safety of the operation at UCI. This included mechanical, electrical and structural reviews by professional engineers.

The different areas of the test bay were either de-classified or rated Class I, Group B, Division II according to the NEC and NFPA codes and standards. This area classification was designed according to the amount and composition of gases present, the potential for leaks, and the available ventilation in the test bay. Lower explosion limit (LEL) and CO monitors are installed to maintain the designed area classification. These monitors will detect a leak of gas well below the explosion limit and activate the safety systems, which include (1) electrical shunt trips, (2) alarm to 24 hr monitoring station, and (3) emergency egress lights. The reformer and PSA units are designed to shutdown in a safe mode.

The design allows for preventative shut downs before unsafe conditions occur. These include loss of room ventilation, process conditions such as high temperature, or high pressures in the units. These preventative shut-downs stop the introduction of natural gas and shut down the reformer and PSA units. In addition, there is a natural gas excess flow valve that can shut down all natural gas to the test bay, if there is a large leak. Relief valves and rupture disks are installed to relieve gas if the pressures are higher than the safe operating limits. Also, a detailed hazard and operability study (HazOP) on the reformer and PSA was conducted.

Figure 2. High Pressure Autothermal Cyclic Reforming (ACR) and PSA Units Installed at University of California, Irvine (UCI)

The bulk of the structural work was designing anchorage systems for all components according to seismic Zone 4 specifications. The structural design included anchorage for the units, routing of pipes between ACR and PSA units and to relief valves.

Fire Marshal Approval

The structural, mechanical, and electrical design of all the interfaces between the ACR and PSA units has been completed. The detailed drawings have been submitted to UCI fire marshal for final approval. These drawings included:

- Interconnecting process and instrumentation drawing
- Electrical area classification plan
- Electrical area classification detail
- Electrical panel schedule
- Shutdown system schematic
- Electrical plan
- Panel elevation
- Block wiring diagram
- Conduit schedule
- Equipment anchorage detail
- Pipe support location plan
- Pipe support detail

The fire marshal is expected to give approval to operate by July 15, 2005.

Conclusions

- Thermal and stress modeling is required to design reformer reactors with high reliability
- Professional engineers certified by the local state facilitate the discussions with the fire marshal
- The vessels on the reformer need to be ASME stamped. Pipes need to be welded according to ANSI B31.3 codes. The electrical components on the unit need to be Class I Division II components to meet NEC and NFPA codes and standards.

Special Recognitions & Awards/Patents Issued

1. Patent # 6,878,362 "Fuel processor apparatus and method based on autothermal cyclic reforming" was issued to GE.

FY 2005 Publications/Presentations

1. Kumar R., Moorefield C., Kulkarni P., and Zamansky V., "Autothermal Cyclic Reforming Based H_2 Generating & Dispensing System," World Hydrogen Energy Conference, Yokohama, Japan, June 2005.
2. Kumar R, "Autothermal Cyclic Reforming and H_2 Refueling System," DOE Project Review, Arlington, VA, May 2005.

References

1. Kumar R., Barge S., Kulkarni P., Moorefield C., Zamansky V., Smolarek J., Manning M., Baksh S., and Schwartz J., Autothermal Cyclic Reforming Based Hydrogen Generating And Dispensing System, DOE Annual Report 2003.