II.A.1 Low-Cost Hydrogen Distributed Production System Development

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Süd Chemie, Inc., Louisville, KY

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Objectives

- Design, build and test a steam methane reformer (SMR) system that will achieve the DOE cost and efficiency targets for 2015.
- Demonstrate the efficacy of a low-cost renewable hydrogen generation system based on distributed production of hydrogen from ethanol.

Technical Barriers

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

(A) Fuel Processor Capital Costs
(B) Reformer Manufacturing
(C) Operation and Maintenance (O&M)
(D) Feedstock Issues
(E) Carbon Dioxide Emissions
(F) Control and Safety

Technical Targets

- Total production system (SMR + pressure swing adsorption [PSA]) efficiency (lower heating value [LHV] of fuel cell-grade hydrogen out)/(LHV of fuel in + electricity in): 70%
- Distributed hydrogen cost from natural gas: \$2.50/kg (production capital cost component: \$0.47/kg)
- Distributed hydrogen from ethanol cost: \$3.60/kg (production capital cost component: \$0.50/kg)

Accomplishments

- Collected over 42,000 hours of field test data (multiple units) on the 113 kg/day commercial H_2Gen SMR systems to verify system efficiency and reliability, exceeding the original goal of over 2,500 hours field test experience.
- Based on this extensive test experience at 113 kg/day scale, H_2Gen redesigned the reactor and flow sheet for a 565 kg/hr platform, including:
  - Low pressure drop burner
  - Compact, low stress steam generator
  - Linear combustion air supply system
- Designed the SMR plus PSA skid to industry standards including B31-3, VIII-1, API 618, National Fire Protection Association 70A, 497, 496 and Canadian Standards Association 5.99.
- Completed fabrication of the first 565 kg/day reformer and PSA system and began field testing in the fourth quarter of 2007.
- Set-up and ran the HGM-10,000 under automatic control for a total of 3,963 hours in the field in the first quarter of 2008, exceeding our goal of 2,500 hours of field testing.
- Completed the ethanol catalyst screening tests and successfully demonstrated reforming of neat ethanol in micro-reactor tests.
- Started the long-term (>1,000 hours) catalyst life testing with ethanol, and prepared for testing of ethanol reforming with gasoline additives found in E-95 used in commercial ethanol fuel transport.

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Introduction

Achieving the DOE cost targets will require improved efficiency and also larger hydrogen capacity compared to the current HGM-2000 system (2,000 scfh or 113 kg/day capacity). We are also reducing catalyst cost while improving SMR, shift and PSA performance and increasing feedstock diversity.

Approach

To meet the DOE cost targets, the HGM system must be improved both in terms of higher efficiency (to cut down the cost of natural gas [NG]) and also in reduced capital cost. Furthermore, the capacity of the HGM must be increased, both to cut the cost of hydrogen (since many HGM components will scale less than linearly with increased hydrogen capacity) as well as to meet the demands of a full service fueling station. We have therefore designed, built and field-tested an HGM-10,000 with five times the capacity of our current system.

While we expect that the HGM-10,000 (565 kg/day) technology scaled to 1,500 kg/day will meet or exceed the DOE 2015 cost targets for the hydrogen production and gas cleanup portion of a fueling station, it will still depend on natural gas. To reach the DOE renewable hydrogen goal, we, in collaboration with our catalyst partner, Süd Chemie, also began evaluating the cost and efficiency of reforming ethanol at the local fueling station using the H_2Gen technology. We expect that hydrogen made from ethanol will be the least costly renewable hydrogen option for at least a decade or two.

Results

WGS Catalyst Development The water-gas shift (WGS) catalyst remains one of the highest cost items on the HGM-10000 unit. Süd-Chemie in cooperation with H_2Gen continued the development of improved and less expensive catalysts. Primarily modifications to the support materials and support preparation procedures were investigated. The new materials were tested by Süd-Chemie to compare the performance to the current WGS catalyst used in HGM-10000.

Pre-Reforming Catalyst Development Süd-Chemie and H_2Gen previously have identified pre-reforming catalyst formulation and operating procedures that perform well with liquefied petroleum gas and ethanol fuels. The cost of this catalyst remains higher than the cost of a standard NG pre-reforming catalyst currently used in HGM-10000 units. Süd-Chemie continues development work on the pre-reforming catalyst formulation with the main objective of reducing the cost while preserving the performance characteristics. The development is primarily focused on material substitution in the support material preparation. As the new procedures for the catalyst manufacturing are developed H_2Gen will conduct testing of the catalyst activity and stability to compare it to the current pre-reforming catalyst.

HGM-10,000 Field Testing The first HGM-10,000 system was fabricated and shipped to the field in the third quarter 2007. The system was installed and successfully started for the first time on October 10, 2007. The start-up and shut-down sequences were refined over several runs and are now fully automated; no operator intervention is required to start up the HGM-10000 from a cold condition through burner firing, reactor warm-up, PSA automatic operation and ramping up hydrogen output. Hydrogen production occurs within 90 minutes of starting the machine.

Total accumulated field testing time was 3,963 hours by the first quarter of 2008, when the system was shut down and returned to H_2Gen for examination and refurbishment. As shown in Figure 1, the output flow reached 8,000 scfh. The higher heating value (HHV) efficiency reached approximately 75% after two mechanical upgrades to the system as shown in Figure 2. A new superheater was installed with 66% of the original heat transfer area to cut down excessively high reactor flue outlet temperatures. The second change was to install a larger secondary air blower with 50% more capacity, since the previous blower was limiting the ability to cool the reformer outlet gas to the WGS section. It should be noted that we were not able to measure the NG heating value at the remote test site, so these efficiency numbers could be higher. We assumed that the natural gas had a HHV of 1,036 BTU/scf, the average value measured at our Alexandria, Virginia plant for the purposes of these efficiency calculations.

Ethanol Testing A long-term aging test was placed in a reactor furnace to verify stable performance of the ethanol reforming catalysts. A sequence of reforming catalysts (pre-reforming/steam reforming/ultra-high temperature WGS/WGS) was used to simulate the complete reforming process. Reflux ethanol fuel (7.76% water content in pure ethanol) was used in the test.

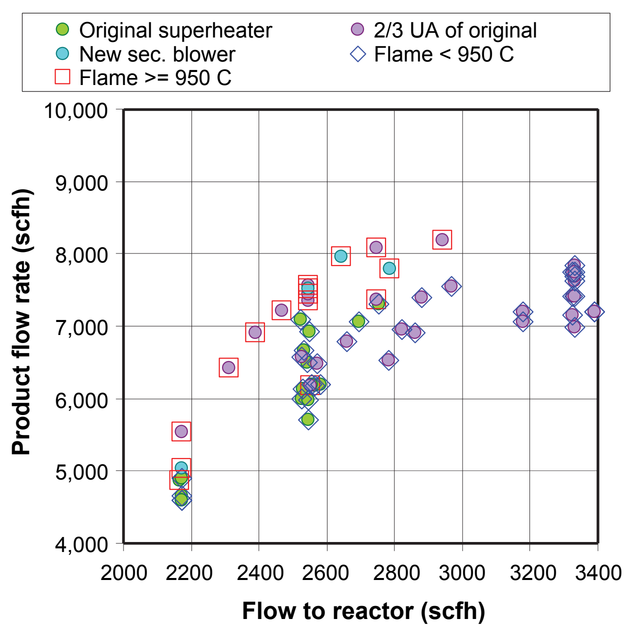

FIGURE 1. Hydrogen Production Rate as a Function of NG Flow to the Reformer

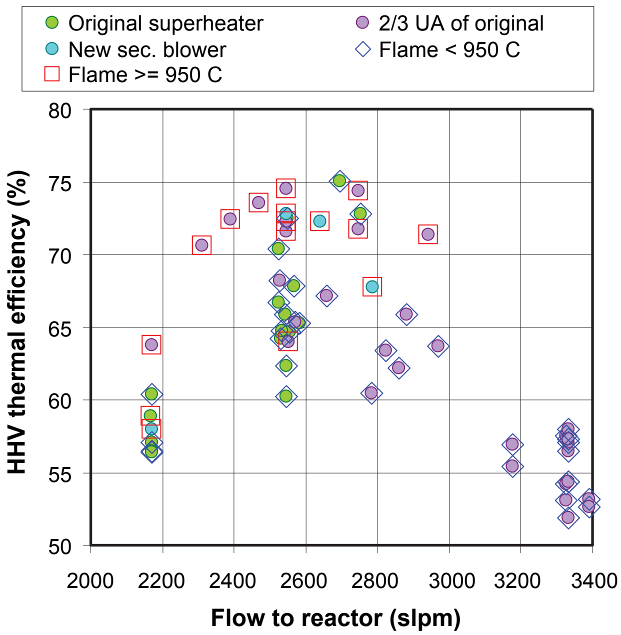

FIGURE 2. HHV Thermal Efficiency as a Function of NG Flow to the Reactor

Stable performance was observed throughout the 1,900 hour test with no change in the reformate composition at the tube exit as well as pre-reformer outlet and low concentration of methane and CO at the tube exit. Hydrogen was added to the input, unlike the previous 1,000 hour test. The test was stopped when all available ethanol was consumed (purchasing reflux ethanol required a special permit from the Alcohol and Tobacco Tax and Trade Bureau and was limited to about 50 gallons). After the test the tube was cut open. Despite stable performance of the catalyst throughout the test, coke was observed on the catalyst surface of the pre-reforming section. All downstream catalysts (reforming and WGS sections) were clean and coke-free.

Ethanol Test Details An aging test was performed with ethanol feed to determine the activity of the different catalysts, and their aging characteristics. The catalyst bed was 27" long consisting of four sections. From the top position, the first 6" of the catalyst bed was filled with pre-reforming catalyst, the next 9" catalyst bed was filled with reforming catalyst, followed by 6" of ultra-high temperature WGS and finally the bottom 6" catalyst bed was filled with high-temperature WGS catalyst. The test was run at 180 psig. The reactor tube had a sampling port after the pre-reformer section and reformate was also sampled at the outlet of the reactor.

Observations after the Test Coke was visible in the top 2" section of the pre-reforming section.

No corrosion or coke deposition was observed in the other sections of the reactor tubes. All catalysts retained their original colors with no sign of pellets being crushed.

FIGURE 3. HGM-10,000 at the Field Test Site

Conclusions and Future Directions

The initial HGM-10,000 has been returned to H_2Gen after extensive field testing. The second HGM-10,000 incorporating the changes learned in the first field test was shipped to the field on April 15, 2008 for the beginning of field testing (Figure 3). This completes the DOE cost-shared portion of this project, as all funds have been expended. H_2Gen will continue the development of the HGM-10,000 with its own resources to reach commercial production in 2008.

The project for testing ethanol reforming has been extended by the DOE late in the second quarter of 2008 after funding ran out in the last quarter of calendar year 2007. The ethanol experiments were discontinued, since there is no current commercial interest in reforming ethanol, but H_2Gen will now reassemble these ethanol experiments in the third quarter of 2008. The goal of this extended work is to demonstrate the efficacy of reforming ethanol in the HGM-3000. If successful, we propose that an ethanol version of the HGM-3000 be designed, fabricated and tested in a future program as a main approach to demonstrating low cost renewable hydrogen generation.

FY 2008 Publications/Presentations

1. Presentation to the 2008 DOE Annual Peer Review meeting.