V.D.4 Hydrogen Refueling Technology

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Subcontractors:
SunLine Services Group, Thousand Palms, CA

Objectives

- Demonstrate hydrogen fueling station.
- Develop and demonstrate on-site autothermal reforming of natural gas.
- Hydrogen cost analysis vs. target of $5/kg in 2003.
- Evaluation of fuel cell (FC) vehicle refueling under real-world conditions.
- Public education on hydrogen and fuel cells.

Technical Barriers

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

- Distributed Hydrogen Production from Natural Gas or Liquid Fuels:
  - A. Fuel Processor Capital Costs
  - B. Operation and Maintenance (O&M)
  - E. Control and Safety
- Technology Validation:
  - C. Hydrogen Refueling Infrastructure
  - D. Maintenance and Training Facilities
- Education:
  - A. Lack of Awareness
  - B. Lack of Demonstrations or Examples of Real World Use

Approach

- Fabrication and testing of prototype (50 Nm^3/hr) natural gas reformer with pressure swing adsorption (PSA).
- Design and fabrication of demonstration (100 Nm^3/hr) natural gas reformer with PSA.
- Installation and commissioning of demonstration unit.
- Process design of compression, storage & dispensing (CS&D) system.
- CS&D equipment design and selection.
- CS&D installation and permitting.
- Training of system operator.

- Demonstration of integrated system.
- Data acquisition, analysis and reporting.
- Continuing public education on hydrogen and fuel cells at SunLine.

Accomplishments

- Completed fabrication of demonstration unit.
- Delivered and installed demonstration unit at SunLine.
- Commissioned demonstration unit.
- Installed & commissioned CS&D equipment.
- Demonstrated and evaluated integrated hydrogen refueling station.

Future Directions

- The project was completed in June 2004. The HyRadix Adéo hydrogen generator passed the contractual acceptance test in April 2004 and the unit was permitted for 24 hour, unattended operation in June 2004. The refueling station will continue to operate, providing hydrogen and hydrogen/compressed natural gas (HCNG) fuel for SunLine's vehicle fleet.

Introduction

The objective of this project was to develop and demonstrate a hydrogen refueling station that combines HyRadix's on-site hydrogen generation technology with compression, storage and dispensing facilities designed by SunLine Services Group. The refueling station is located at the SunLine facility in Thousand Palms, California and will provide low cost hydrogen to fuel three fuel cell buses and several fuel cell cars and street sweepers. The refueling station will also provide hydrogen that will be blended with compressed natural gas (CNG) to form HCNG and used in SunLine's fleet of converted CNG buses.

Approach

The HyRadix hydrogen generation technology is based on auto-thermal reforming at a small scale, producing a reformate stream of 40-50% hydrogen. This gas stream is then purified to 99.95+% through a purpose-designed small-scale PSA unit. HyRadix built and tested a prototype 50 Nm^3/hr unit – half the output of the final demonstration unit – in order to incorporate learned improvements into the final design of the 100 Nm^3/hr demonstration unit. Auto-thermal reforming combines partial oxidation and steam reforming, making efficient use of heat but does not require exotic metallurgy.

The CS&D system designed by SunLine compresses the hydrogen to 6,250 psi, stores it at that pressure and then dispenses it to the vehicles at a maximum of 5,000 psi. The compression system comprises two-stage diaphragm compressors, which maximize energy efficiency, reduce manufacturing costs and increase flexibility, while maintaining contamination-free hydrogen. The two-stage design permits startup under the high inlet pressure of the gas stream coming from the PSA. The storage component consists of high-pressure carbon fiber wrapped cylinders rated at a maximum pressure of 7,250 psi. The dispenser system is a two-hose dispenser capable of dispensing at 3,600 psi on one side and at 5,000 psi on the other side for HCNG and fuel cell vehicles respectively. The entire dispensing system is rated for 7,250 psi for safety reasons.

Results

The Adéo^{TM} HFG arrived on site on 22 July 2003. All of the catalysts and adsorbents were shipped uninstalled to prevent damage during shipping. The catalyst inventory consisted of monolithic catalyst for the autothermal reactor, shift reactor and waste gas burner. Pelletized adsorbent was supplied for the sulfur removal system and the PSA. Catalyst and adsorbent loading began on 6 August and was completed the next day.

First gas to the unit occurred on 9 October 2003. For the next month, the Adéo HFG was continuously operated and all systems were tuned to optimize performance. The controller operations as well as the automated startup and shutdown functions were tested and verified. Analytical equipment was brought online and calibrated. The PSA was commissioned and the unit consistently produced hydrogen product with a purity of 99.95 vol%. The Adéo HFG and hydrogen product compressor integration logic was tested for the first time on 4 November 2003.

The October-November testing produced data that was used to further upgrade the performance of the heat exchanger design. The new modifications were completed by the end of March, 2004. The Adéo HFG was started up on 6 April 2004 and successful pre-demonstration run testing was performed through 16 April 2004.

The goal of the demonstration run was to operate the Adéo HFG at 90% of its rated capacity (90 Nm^3/h) for ten consecutive days within a 30 day period. A product hydrogen purity greater than 99.5 vol% and carbon monoxide concentration less than 1 ppm by volume, was to be maintained during the run. SunLine and HyRadix will then continue to operate and monitor the unit for an additional period of 36 months, under a contract with the South Coast Air Quality Management District. During this time, long-term data will be collected to verify maintenance requirements and costs, system performance, hydrogen production costs and on-stream availability.

The demonstration run started at 1400 hrs Pacific standard time on 17 April 2004. The natural gas feed rate and PSA cycle time were chosen to maintain a hydrogen product flow greater than 90 Nm^3/h and product hydrogen purity greater than 99.5 vol%. The feed rate chosen for the test was 47 Nm^3/h. The ten day (240 hour) demonstration run was successfully completed at 1800 hrs on 30 April 2004. A plot of the demonstration run can be found in Figure 1. During the run the average product hydrogen purity was 99.68 vol% and the carbon monoxide concentration was less than 1 vppm. The average

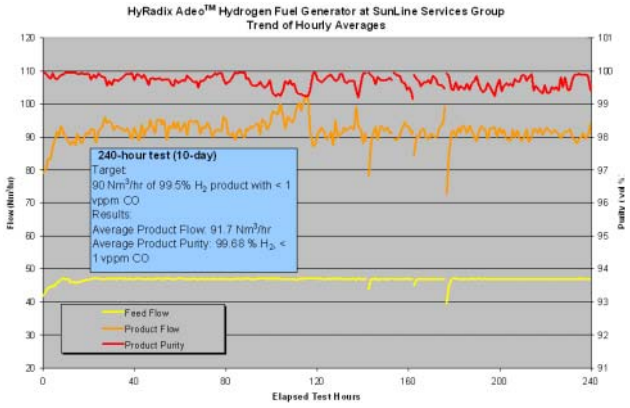

Figure 1. Plot of Demonstration Run Data for the HyRadix Adéo™ Hydrogen Fuel Generator, 17 April through 30 April 2004

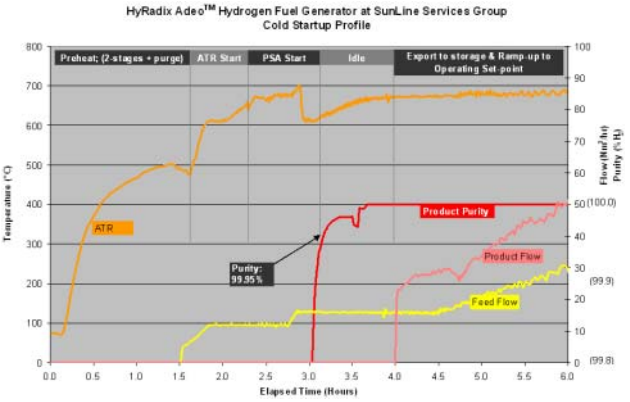

Figure 2. Plot of Cold Startup Data for the HyRadix Adéo™ Hydrogen Fuel Generator

feed and product flow rates were 47.0 Nm^3/h and 91.7 Nm^3/h, respectively.

Also provided in Figures 2 and 3 are plots of the cold and warm startup performance. A cold startup is defined as one in which all temperatures within the Adéo HFG are less than 50°C. A warm startup is one that occurs within one hour after a shutdown while the unit temperatures are still elevated. As shown in Figure 2, the time needed to progress from a cold start to product with a 99.95 vol% hydrogen purity is about 3 hours. In Figure 3 it is shown that the time required to go from a warm startup to product with a 99.95 vol% hydrogen purity is 1.6 hrs.

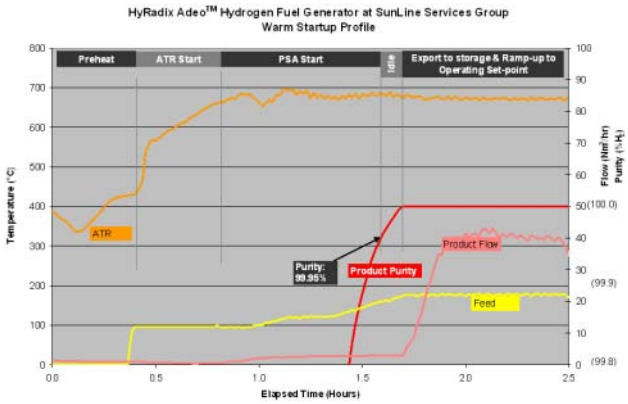

Figure 3. Plot of Warm Startup Data for the HyRadix Adéo™ Hydrogen Fuel Generator

Hydrogen product was first compressed and exported to storage on 7 May 2004. Only three of the cylinders in the DOT trailer were inventoried in order to isolate the hydrogen from the rest of the storage system prior to sampling and third party certification of purity. Sample results showed that the hydrogen purity exceeded 99.95 vol% with less than 1 ppm by volume of carbon monoxide. Sale of Adéo HFG produced hydrogen began shortly after SunLine's acceptance of the analysis results. The remaining 13 tubes on the DOT trailer were filled by 12 May 2004. The Adéo HFG continues to run as required in order to inventory the DOT trailer.

Prior to the start of this project, SunLine has shown that the installed dispensing equipment is capable of meeting contract requirements of filling a hydrogen fueled bus with 40 kg of hydrogen to 5,000 psig within 15 minutes. Likewise, hydrogen powered automobiles take less than 5 minutes to refuel.

Conclusions

The hydrogen production cost, on a direct operating cost basis, for the Adéo HFG is $2.06 per kg of hydrogen product ($0.94/lb). This includes the cost of natural gas feed, cooling and process water, and the electricity required to operate the Adéo HFG as well as the compression, storage and dispensing equipment. At $0.71/therm, the natural gas price used to calculate the hydrogen production cost is high by historical measures. Using a more historical average natural gas rate of $0.50/therm translates to a direct cost for producing hydrogen of $1.55/kg ($0.70/lb).

Assuming a 90% on-stream factor, a ten year life expectancy, annual maintenance and consumable costs of 5% of capital (similar to what is being observed at SunLine) and combined with the current pricing for a 100 Nm^3/h Adéo HFG, the calculated fully loaded cost of hydrogen, with the current utility prices, is $4.27/kg ($1.94/lb). Once again, if the historical natural gas price of $0.50/therm is used, the calculated hydrogen production cost is $3.82/kg ($1.73/lb).