ISSUES IN HYDROCARBON FUEL PROCESSING

K. Durai-Swamy, Daniel G. Loffler, Dylan Mason, Kyle Taylor & David Edlund,

IDATECH, P.O. Box 5339, Bend, OR, 97701

Abstract:
Fuel cell applications require fuel processors for hydrogen production that are small, lightweight, and durable. In addition, they must operate with commercial-quality fuels under different load schedules. Finally, economic restrictions on hardware cost and fuel efficiency must be satisfied. The present communication describes our approach to design a commercially viable fuel processor addressing all those problems. In particular, we discuss issues related to thermal management (heat recovery, supplying heat to a small reactor), fuel variability (seasonal composition changes, contaminants such as sulfur content), balance of plant (fuel delivery, controls, power management), and load-following. This paper will present test results obtained with a fuel processor prototype confirming the design assumptions.

Introduction:

IdaTech is committed to developing and marketing cutting-edge fuel cell products that will accelerate the transformation of the industry from infancy to maturity. IdaTech's attractive and compact fuel cell system is being put through its paces by federal and private utilities. Our core technology is our patented methanol fuel processor, remarkable both for its small size and for the purity of the hydrogen it produces.

Since a widespread hydrogen fuel distribution infrastructure does not exist in any substantial capacity, and it is not likely to be introduced in the near term due to prohibitively high costs; a fuel processor (or reformer) is often considered to be an enabling component to a practical commercial fuel cell system. For instance, the PC-25 family of 200 kW fuel cell systems (commercially available from International Fuel Cells) utilizes a fuel processor that generates hydrogen from the feedstock, typically natural gas, propane, landfill gas, or digester gas. And Ballard's 250 kW stationary fuel cell system likewise incorporates a natural gas fuel processor to generate a hydrogen fuel stream.

Practical fuel-cell systems rated <10 kW for the stationary and portable markets, and that use conventional fuels (feedstocks), have not yet been commercialized. In many cases, the preferred fuel for these applications will be a liquid hydrocarbon fuel. Liquid fuels offer the advantage of ease of transport and storage. Sulfur compounds and carbon monoxide, if present in the product hydrogen stream, will also poison the electrocatalysts used in the fuel cell.

CONVENTIONAL FUEL PROCESSOR

The fuel processor comprises a device for generating a hydrogen-rich product gas from a conventional fuel such as alcohols and hydrocarbons. The hydrogen-rich reformate stream produced by the fuel processor must be purified prior to feeding the hydrogen to the fuel cell. Both the fuel processor and the fuel cell are supported by a balance of plant (BOP) that includes pumps, fans, sensors, plumbing, heat exchangers, and at least one controller.

A conventional fuel processor (see Figure 1) typically is based on either steam reforming or autothermal reforming and utilizes a series of unit operations to purify the hydrogen- rich reformate. However, the purification methods (high- and low-temperature shift reactors followed by selective oxidation of carbon monoxide) only partially purify the product hydrogen[2-4]--common impurities such as sulfur compounds, unsaturated hydrocarbons, and amines, are not removed by the conventional purification methods.

IDATECH™ FUEL PROCESSOR

In contrast, IdaTech is developing a unified fuel processor that incorporates a universal hydrogen purifier as an integral part of the device (see Figure 2). The concept behind our methanol fuel processor is as follows:

A fuel, such as a 67-33 mixture of methanol and water, is vaporized and fed into a reaction zone heated to 350 degrees centigrade. The methanol and water molecules in the vapor split into their component hydrogen, oxygen, and carbon atoms. This is the steam reformation process.

The gas then enters the purification chamber. There, the hydrogen molecules pass through a palladium-membrane complex developed by Dr. David Edlund. The membrane diverts unwanted molecules from the product hydrogen stream. The hydrogen is further purified in a catalytic bed and sent to the fuel cell.

The diverted molecules, including CO and CO2, are sent back into the combustion chamber, where they fuel the steam reformation process. After the initial start-up period, the fuel processor is entirely self-powered.

The hydrogen that exits the reformer has less than one part per million (ppm) carbon monoxide and less than five ppm carbon dioxide. And all this happens in a cylinder roughly twice the size of a breadbox. As small as it is, the processor is shrinking. IdaTech is developing an even more compact unit, about half the size of our current version.

Our fuel processor is also attractive to industries needing on-site hydrogen production. In addition, the purification chamber that uses the palladium alloy membrane is useful to industries needing to purify hydrogen.

This universal purifier is based on a palladium-alloy membrane (hydrogen selective) that rejects all impurities in the hydrogen-rich reformate stream, essentially passing only hydrogen[5]. Hydrogen-rich reformate is produced by steam reforming, but the product hydrogen is very pure (typically >99.95% hydrogen with <1 ppm CO). More importantly, trace contaminants such as sulfur compounds, unsaturated hydrocarbons, and amines, are rejected by the hydrogen purifier to yield a product hydrogen stream of superior quality.

The high purity of the product hydrogen has been verified by analysis. Using a hydrocarbon feedstock containing about 3 ppm alkyl thiols (commercial natural gas) the product hydrogen stream was found to be >99.95% hydrogen with <1 ppm CO and <1 ppb total sulfur compounds. Hydrogen of this quality exceeds typical specifications for PEM fuel cells, typically given as <10 ppm CO and <50 ppb total sulfur.

The hydrogen-selective membrane also yields the fuel-gas stream that supplies heat necessary to vaporize the feedstock and satisfy the endothermic enthalpy of the steam reforming reactions. This fuel-gas stream consists of the impurities that are rejected at the membrane along with some of the hydrogen produced by reforming.

Fuel Composition:
The IdaTech™ unified fuel processor for commonly available gaseous and liquid hydrocarbons (Natural gas, LPG, gasoline, naphtha, kerosene and diesel) has been carefully designed to take into consideration of fuel composition variability.
Seasonal variations in the composition of the commercial hydrocarbon fuels are large. These variations include types and quantities of sulfur compounds, olefins and other unsaturates' levels and the presence of non-combustibles such as air, N2, CO2, H2O. Fuel processor must be designed to handle such variations.

Thermal Management:
In steam reforming hydrocarbons, the endothermic heat of reaction must be supplied externally. Process steam needs to be generated by vaporizing water. The raffinate (waste gas) from the purification membrane module and/or the anode off-gas contains heat value that could be used to supply the process heat. It is necessary to balance the available heat to the thermal needs of the process to achieve high thermal efficiency. The IdaTech™ unified fuel processor is designed with high degree of thermal integration achieving high thermal efficiency.

Balance of Plant:
The balance of plant in steam reformer based fuel processor includes feed delivery systems, control systems for fast startup and fast response in load following. Since the IdaTech™ unified fuel processor has essentially one catalytic reactor, namely, the steam reformer, its load following ability is much greater than other fuel processors having multiple reactors in series such as the high- and low- temperature shift reactors and PROX reactors.

Conclusion:
The IdaTech™ unified fuel processor has been tested with different hydrocarbon fuels and offers a compact hydrogen generator to get high purity hydrogen for PEM fuel cells.

Acknowledgement. The authors gratefully acknowledge the help of Travis Bizjak, Jay Castino and Russ Zinner with the construction and operation of the unified fuel processor system.

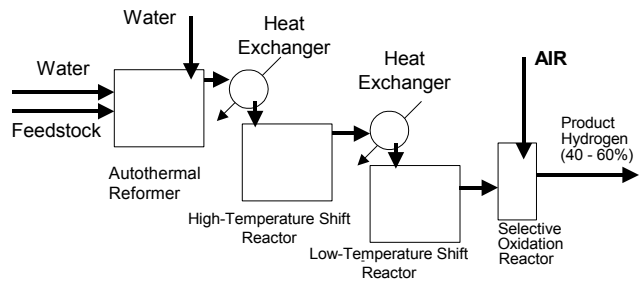

Figure 2. The conventional fuel processing- autothermal reforming with multiple reactors and heat exchangers.

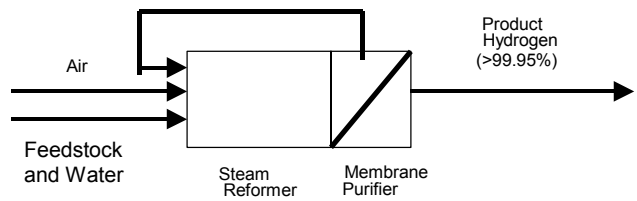

Figure 3. The IdaTech™ unified fuel processor

REFERENCES

1. Wang, M.Q., GREET 1.5 - Transportation Fuel-Cycle Model, Vol. 1 and Vol. 2, (Aug. 1999), http://www.ipd.anl.gov/anlpubs/1999/10/34035.pdf
2. Stell, S., and J. Cuzens "Fuel-flexible, fuel processing technology" Fuel Cells Bulletin, 7 (April 1999) 9-12
3. McNicol, B. "The oil industry response to the challenge of fuel cells" Fuel Cells Bulletin, 9 (June 1999) 6-11
4. Ahmed, S., R. Kumar, and M. Krumpelt "Fuel processing for fuel cell power plants", Fuel Cells Bulletin, 12 (September 1999) 4-7
5. Edlund, D. "Versatile, low-cost and compact fuel processor for low-temperature fuel cells" Fuel Cells Bulletin, 14 (November 1999) 8-11