COMPACT FUEL PROCESSORS FOR FUEL CELL ELECTRIC VEHICLES (FCEVs)

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Introduction

Faced with tough emission standards, auto manufacturers have started looking into technologies that offer feasible alternatives to internal combustion engines. Fuel cells offer many advantages including almost-zero emissions. Epyx Corporation, a subsidiary of Arthur D. Little, Inc., has developed a fuel-processor design that reforms hydrocarbon such as gasoline and generates hydrogen – needed to run fuel cell. In fact, Epyx is the first company ever to demonstrate a gasoline-based reformer. In addition to its lightweight and compact configuration, Epyx fuel processor operates on multiple fuels such as gasoline, ethanol, propane, and natural gas.

Background

Proprietary hybrid partial oxidation (POX) fuel processor is shown in Figure 1. The fuel processor consists of a series of catalytic beds, viz., steam reforming, high temperature shift (HTS), low temperature shift (LTS) and exhaust clean-up, operating over a wide temperature range to maximize hydrogen output. The exit CO concentration from the fuel processor is 0.2-0.5 % depending on the steam/carbon (S/C) ratio and temperature. However, for a proton exchanged membrane (PEM) fuel cell applications, the CO concentration must be below 50 ppm. Therefore, an additional CO clean-up stage called preferential oxidation (PROX) is also included. For the processing of sulfur containing fuels, the fuel processor also contains a compact desulfurization bed integrated inside the reactor vessel.

A fraction of the feedstock is combusted in the POX zone at about 700-1500 °C. The process effluent from POX zone consists of a mixture of CO, CO_2, H_2, H_2O, N_2 and residual methane. A highly active steam reforming bed holds the key to full fuel conversion and high efficiency. The POX residual methane is reformed into hydrogen in the steam reforming bed and CO is converted in the two shift reactors, viz., HTS and LTS.

Experimental

Based on the results from previous work at Epyx/A. D. Little, Inc., a fuel processing power system was designed using assumptions consistent with a light duty vehicle. The fuel processor system consists of three subsystems, viz., fuel processor, CO clean-up, and tailgas combustor. The assumptions involved in the design of the fuel processor include a use of PEM fuel cell operating at 3 atm and at a design power level of 10 kW (electric). The design power rating power corresponded to a fuel processor system that could operate on a thermal input of 45 kW.

Experimental studies were carried out to permit characterization of the entire system with regard to thermal balances, pressure balances, hydrogen purity effects, tailpipe emissions, and required control interaction. The system was operated on several conventional and alternative automotive fuels such as California Phase II reformulated gasoline (RFG), ethanol, natural gas, etc. The performance of fuel processor was quantified by measuring the conversion efficiency at a particular S/C ratio and equivalence ratio (ϕ).

To quantify the emissions from the fuel processor assembly, the exhaust product sample was connected to various analytical instruments listed below:

- Gas chromatograph equipped with a thermal conductivity detector (GC/TCD) for detection and quantification of H_2, N_2, CH_4, C_2H_2, C_2H_4, CO_2, and CO;
- Non-dispersive infra-red (NDIR) analyzer for CO and CO_2;
- Chemiluminescent NOx analyzer;
- Flame ionization detector (FID) hydrocarbon analyzer;

- Paramagnetic oxygen analyzer.

Results and Discussion

Recent efforts have focussed on incorporating advanced catalyst and heat exchanger concepts into the fuel processor design. This new generation of the design is sized to accommodate a 22 kW (electric) fuel cell power system. Experiments were conducted on this design with a variety of fuels and the fuel processor was characterized in terms of temperature and composition of each zone, operating conditions for the POX zone, and conversion efficiency.

The performance of the fuel processor measured as hydrogen efficiency with all the fuels is shown in Table 1. Hydrogen efficiency is defined on the basis of lower heating value of H_2 exiting the fuel processor to the lower heating value of the fuel fed to the unit. The extended testing of this new design indicate that advanced concepts employed have led to significant improvements in the efficiency, which exceed the 2004 Department of Energy PNGV (Partnership for New Generation of Vehicles) efficiency targets for fuel processors – currently set at 80%. It is also evident from Table 1 that such high efficiency of the fuel processor results in high fuel conversion or low slip of unconverted hydrocarbons, which assist in obtaining very low exhaust emissions. No degradation in the performance of the catalyst beds was evident after 600 h on-stream – a ramification of high fuel conversion.

Table 1. Epyx transportation fuel processor performance with various fuels

Fuel	Dry H_2 concentration* (%)	Fuel conversion (%)	Efficiency** (%)
RFG	43	98	83
Methanol	46	99	88
Ethanol	42	99	84
Natural gas	45	95	83

*: at the exit of the fuel processor
**: defined as ratio of lower heating value of H_2 at the exit to the lower heating value of the fuel fed to the fuel processor

As a first step in verifying the low emissions produced from a gasoline fed fuel processor, steady state emissions analysis was performed at the exhaust of tailgas combustor. Emission data gathered at 25 kW (thermal) input to the fuel processor show CO < 5 ppm, hydrocarbons < 4 ppm, and undetectable levels of NOx. Assuming FUD cycle with 12.5 kW (electric) average power requirement yields emissions in g/mile as shown in Table 2.

Table 2. Comparison of Epyx fuel processor emissions with California SULEV standards

Contaminant	California SULEV standard (g/mile)	Epyx fuel processor (g/mile)
CO	1.0	0.013
Hydrocarbon	0.01	0.017
NOx	0.02	0.003

These emissions are expected to reduce with modifications and tighter integration of the system.

Conclusions

Compact automotive fuel processor was designed, fabricated and tested with gasoline, natural gas, methanol, and ethanol. This design demonstrated efficiency numbers greater than PNGV 2004 targets and emissions comparable with California SULEV standards. Pathways have been identified to further improve the overall performance of the fuel processor. Detailed reaction models are being generated and validated; these models will be used in the future designs.

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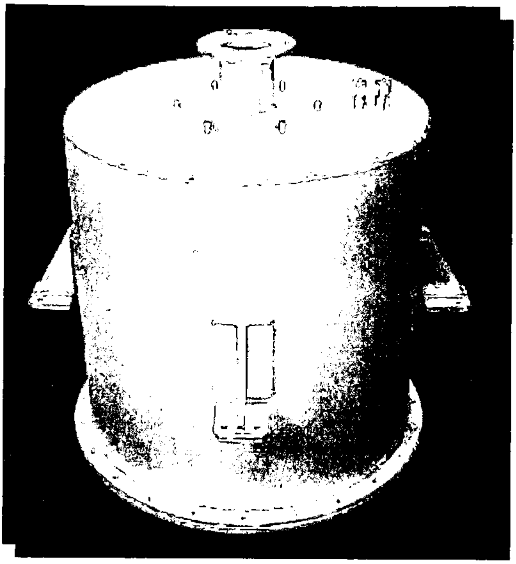

Figure 1. Epyx 22 kW (electric) multi-fuel processor