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Start-up strategy and operational tests of gasoline fuel processor for auxiliary power unit

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ABSTRACT

In order to satisfy the needs for electrical power in future combat systems, a gasoline fuel processor (GFP) for an auxiliary power unit (APU) has been developed. This efficient design of a compact hydrogen-production system thermally and physically integrates the unit processes of autothermal reforming, high- and medium-temperature water gas shift, preferential oxidation, heat exchange and external burner into a single hardware package. The start-up strategy is established to turn the GFP on even at subzero temperature and reach the steady-state rapidly. In consideration of both energy consumption and system size, the sequence is initiated from start-burner mode. The catalytic-partial-oxidation (CPO) mode is second, followed by autothermal reforming (ATR). A glow-plug needed to ignite the gasoline is positioned behind the catalyst to minimize soot generation at start-burner mode. In ATR mode, feed rate of water for each heat exchanger is controlled to operate a reactor at target temperature and reduce the water condensation at surface of catalyst. Based on this start-up strategy, a GFP is able to produce a reformate gas that contained >40 vol.% H_2 and <0.5 vol.% CO within 30–35 min at room temperature and −32 °C. An APU with a GFP shows the stable start-up and continued operation.

Introduction

Most fuel cells, including polymer electrolyte membrane (PEM) fuel cells, use hydrogen as their fuel. However, there is a limitation in adopting fuel cells that use hydrogen in that the current hydrogen infrastructure is insufficient. Accordingly, a transitional system capable of using a fuel cell after generating hydrogen by reforming hydrocarbon fuels (e.g., natural gas, ethanol, gasoline or diesel) is necessary. The fuel cell system currently being developed is combined with a fuel processor for this reason. A fuel processor using gasoline has already been studied for developing fuel cell vehicles [1,2]. As a result, on-board reforming could reduce the mass and volume of the fuel cell vehicle, and increase the travel distance, in comparison with such a vehicle carrying a compressed-hydrogen tank. However, a fuel processor was not adopted for fuel cell vehicles due to its low level of technical readiness relative to that of compressed hydrogen tanks. Recently, interest in gasoline and diesel fuel processors

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has increased again due to the importance of APUs for passenger vehicles [3] or in future combat systems. In particular, troops have wanted to obtain stable electric power for communication and surveillance devices, without a lot of noise and vibration. For example, the loud noise generated by of the diesel generators presently used as power sources in the military most of the time, increases the possibility of being detected by the enemy.

A military fuel cell system which could extend well beyond the efficiency and interoperability of the conventional diesel generator is one of the leading candidates for a power-generation system for use on the battlefield. In order to use fuel cells, it is necessary for the army to obtain hydrogen by processing a logistic fuel due to insufficient hydrogen infrastructure. At present, gasoline and diesel are good candidates for APU fuel because the army of the Republic of Korea uses them as logistic fuels. However, a major disadvantage of diesel fuel in cold climates is that its viscosity increases as it cools; so that at very cold temperatures, it does not flow well in fuel systems. Therefore gasoline, which flows even at low temperatures, was selected for use with the fuel processor in this study.

Before integrating operation of the GFP and fuel cells, it was first necessary to develop a start-up strategy for the GFP that would meet system requirements. In the literature, a number of experimental and simulation-based studies concerning the start-up and control of fuel processors have been proposed. Ahmed et al. [4] studied a parallel-heating start-up strategy for a fuel processor. The design was based on catalytic reactor zones, separated by temperature-control zones; that used micro-channel, and foam, heat exchangers. Heat exchangers and liquid-water injectors were used for cooling, and air injectors for oxidative heating. The system setup; however, has not yet been investigated experimentally.

A diesel fuel processor for an LT-PEM, introduced by Lindström et al. [5], started by igniting the diesel burner and then using the off-gasses from the burner to heat up a separate air-stream that was used to supply heat directly to the reformer. By constructing such an indirect heating system, it was possible to heat the reformer without risking contamination by particulate matter formed in the burner during cold starts. Although the start-up time was longer than for a directly-heated fuel-processor, the life expectancy of the system was much higher, as soot deposition deactivates the catalysts and produces hotspots during start-up. Goebel el al. [6] studied a fast-start method for a fuel-processor for automotive fuel cell systems. By utilizing direct vaporization of water, and hydrogen for catalyst light-off, excellent start performance was obtained. However, this requires that a hydrogen tank be installed in the fuel cell system, and that hydrogen infrastructure be available in the military base.

It is equally important for effective fuel processors, to determine the start-up and control methods considering start-up time, durability of catalyst, controllability and manufacturing cost. In work described in this paper, a GFP was developed to install in a PEM fuel cell system which could be used as a military APU. Based on basic experimental results, a start-up strategy operating the GFP at target temperature was suggested and validated. In particular, the effect of the glow-plug position was analyzed by comparing the quantity of soot-generation affected the durability of the catalyst. The experimental GFP was operated at room temperature and −32 °C in accordance with United States Military Standard (MIL-STD-810G) [7]. Finally, a GRP was integrated with a high temperature PEM fuel cell and an APU showed stable start-up operation.

Experimental set-up

A schematic diagram of the GFP is shown in Fig. 1. This GFP comprised an auto-thermal reforming (ATR) reactor, a hydrodesulphurization (HDS) reactor, a high-temperature shift (HTS) reactor, a medium-temperature shift (MTS) reactor, a preferential oxidation (PROX) reactor, a heat exchanger (HEX) and an external burner.

The ATR reactor consisted of a vaporizer, a mixer and catalyst. The vaporizer, located in the head of the ATR reactor, evaporated liquid gasoline to form a gas. An electrical heater heated the vaporizer to more than the boiling point of gasoline during the start-up stage. The gasoline was evaporated not only by the electrical heater but also by heat transfer from the

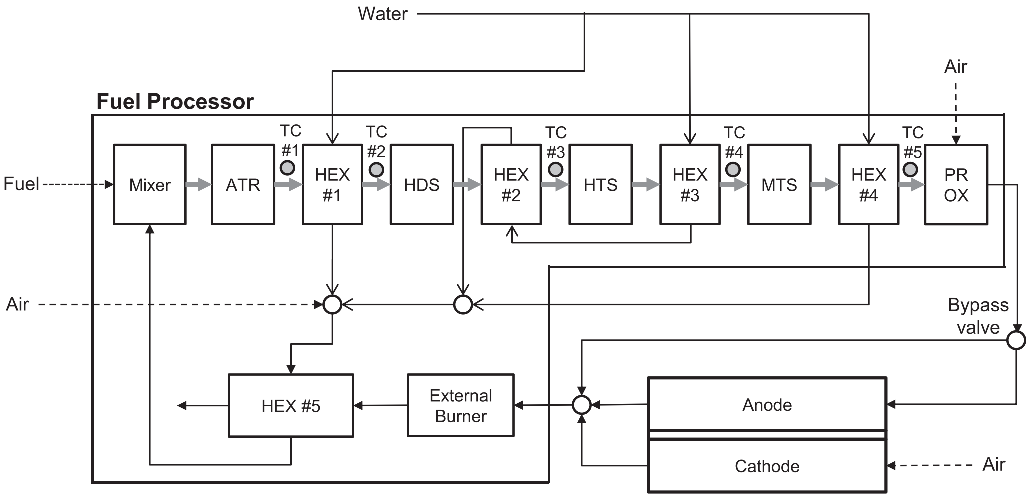

Fig. 1 – Schematic diagram of the GFP.