

COMPACT FUEL CELL SYSTEM WITH DIESEL REFORMING

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ABSTRACT

A compact auxiliary power unit in the 7.5 kW_e class was developed. The system is composed of two high-temperature PEFC stacks operated on reformat produced by a diesel fuel processor and the corresponding balance of plant components. In order to maximize the power density, each fuel processor component is designed as a multifunctional reactor. The stacks and the fuel processor are combined using manifolds applying additive manufacturing technology. Using the developed reactors, manifolds, as well as the selected fuel cell stacks and the balance of plant components, a compact system was designed and manufactured with a volume of 187.5 l. Preparatory experiments with the fuel processor focused on the validation of the system concept, aiming to maximize the fuel conversion while keeping the CO level in the fuel processor outlet below 1 % for the ideal operation of the high-temperature PEFC. With various diesel and kerosene fuels, it was possible to identify the best operating parameters with each fuel at a very high fuel conversion of > 99.95% at full load of the fuel processor. In each experiment, the CO concentration remained stable and below the target value mentioned above.

Keywords: autothermal reforming, fuel cell system, fuel processor, HT-PEFC, jet fuel

INTRODUCTION

This study focuses on the development process of a compact fuel cell system using a combination of autothermal diesel reforming and high-temperature PEFC technologies. The motivation for such a system is to extend the availability of the fuel cell technology for areas in which it is hard to realize a hydrogen infrastructure. Today, the wide availability of diesel and jet fuels makes such a system concept attractive for mobile and distributed power supply. In the future, synthetic fuels from biomass or hydrogen produced from renewable electricity can be utilized.

The proof-of-concept was already demonstrated in a first system generation, which focused on the combination of diesel reforming and HT-PEFC technologies in an integrated 5 kW_e system [1]. The current development, however aims to achieve the 2020 power density target of U.S. DOE for diesel-based fuel cell auxiliary power units (APU). According to this target, the complete fuel cell APU must show a minimum power density of 40 W_e/l [2].

Despite the big progress in diesel reforming in the recent years [3-6], a fuel cell operated on diesel reformat brings a high level of challenges on the systems level [7, 8]. The main issues are start-up, load change, shutdown as well as stability and the overall complexity of the process. In this work, we firstly present the system layout and its final design. In the second part, we report on results from preparatory experiments from the fuel processing system.

SYSTEM LAYOUT AND DESIGN

To achieve a compact fuel cell system, multifunctional fuel processing reactors were developed. According to this approach, several system functions are integrated in the reactors of the fuel processing system. In addition to its main function of producing a hydrogen rich reformat from a mixture of diesel, air and steam, the reformer also includes a superheater, a mixer for producing a saturated steam mixture for further heat exchange and an electrical heating wire for the start. The shift reactor can on one side reduce the CO content of the reformat to ideally 1% in two stages placed under a single reactor shell before the stack inlet. On the other side the reactor includes system components such as evaporation cooling between stages, an electrical heating wire and a heat exchanger to cool the reformat and heat the cathode air before the stack inlets. Finally, the catalytic burner has the function of combusting the remaining H₂, CO and CH₄ present in the anode off-gas during normal operation and system start. In addition to its main function, this reactor also includes several heat exchange functions in order to pre-heat the reforming air, superheat a big share of reforming water during normal operation and heat up the heat transfer fluid to heat the fuel cell during start-up. Additionally, a glow plug is integrated in this reactor for start-up.

The system layout presented in Fig. 1 (left side) shows the above-explained system design approach with several heat recovery functions. The conceptual design of the reactors is also displayed. On the right hand side, Fig. 1 shows the 3D design of the system including the fuel processing system, the fuel cell stacks and the balance of plant components. Two HT-PEFC fuel cell stacks are used in the system, which are originally designed for commercial methanol-fueled systems [9]. In order to combine both stacks effectively, manifold plates were developed and optimized with CFD simulations, and

finally produced via laser-additive manufacturing technology. The balance of plant components include turbo-compressors, pressure sensors, a micro diesel pump, diaphragm pumps, flow meters, check valves, relief valves, filters, coolers, a peripheral pump, fluid reservoirs and further valves. Following a tight packaging approach analogous to automotive architectures, the APU volume could be restricted to 187.5 l. Based on the previous experience with similar stack technology, a power output of 7.5 kW_e is expected. These figures result in the target power density of 40 W_e/l.

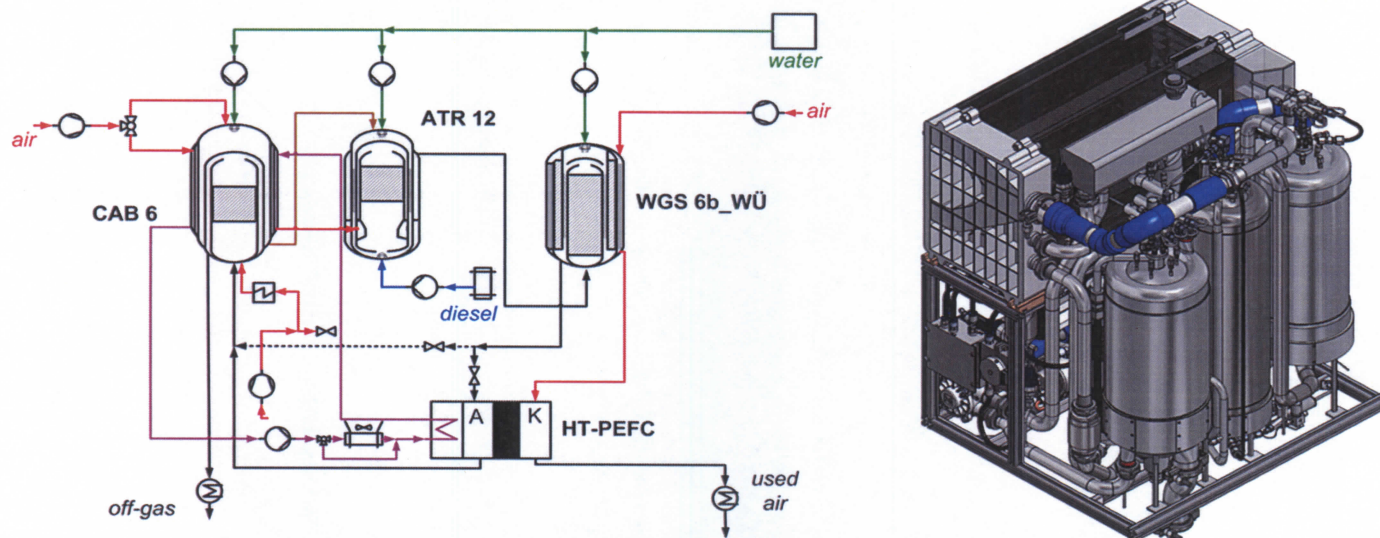


Fig. 1. System layout and CAD design of the HT-PEFC system in the 7.5 kW_e power class including the diesel fuel processor and the balance of plant components.

RESULTS AND DISCUSSION

In preparatory experiments several system aspects were tested, validated and optimized using a fuel processor with the same architecture as explained above. The characterized system utilized the same reformer type (ATR 12) and the same water-gas shift reactor (WGS 6B) except its heat exchanger. One challenge of the system was to identify the best operation parameters with various fuels to maximize the fuel conversion on one side and to keep the CO content at the target level of < 1 % at the anode inlet on the other side. For this purpose, various fossil-based and non-fossil based diesel and kerosene fuels including desulphurized Jet A-1, NExBTL diesel and Aral Ultimate diesel were utilized. Fig. 2 shows the results from 12 experiments focusing on the undesired by-products at the reformer outlet using different fuels and operation parameters. In all of the experiments, the reformer was operated at 100% load with 2.7 kg h⁻¹ fuel and the CO content could be kept below the target. Due to the high level of system integration, all reactors are thermally coupled with each other. The reformer can however be considered as the key component of the system since it defines the main control parameters, which are the molar O₂/C ratio and the H₂O/C ratio. In addition, two additional ratios must be tuned, which influence the reformer - catalytic burner coupling and the reformer - shift reactor coupling. The first one is the ratio of water superheated in the burner to the total amount of water used for reforming. Higher ratios increase the temperature level in the reformer, which can have a positive effect on the reforming processes, but simultaneously the inlet temperature of the shift reactor increases, which might be negative for achieving the target CO level in the shift steps. The second is the ratio of cold air feed to the reformer to the total amount of reforming air. Since the remaining part of air is pre-heated to the same temperature with steam in the reformer, higher ratios lead to the opposite effect compared to the first case. Using NExBTL diesel, it was possible to achieve a very high conversion level in the reformer with all by-products below 2 ppmv. A switch to desulphurized Jet A-1 showed a very slight increase in the by-products with the same operation parameters, where ethane, ethene and benzene concentrations reached the 2 ppmv level. Still, further experiments were performed to check, if even lower concentrations can be achieved. Operation with lower heat input to the ATR with a reduced share of superheated steam (exp. 2) led to a sharp increase in ethane and benzene concentrations. Higher heat input (exp. 4&5) led to lower concentrations, which were however not better than those with standard parameters (exp. 3). Operation with higher oxygen to carbon ratio (exp. 6) did not lead to a better performance. After switching to Ultimate diesel, the same parameters were applied in experiments 7 – 11 as in experiments 2 – 6. The overall trend being the same, Fig. 2 shows that the measured concentrations are higher than those with desulphurized Jet A-1. The lowest concentrations were observed in experiments 9 and 10. Therefore, it can be concluded that the higher heat input to ATR had a positive effect in this case. A stronger increase in terms of increasing the O₂/C ratio in exp. 11 or even increasing the H₂O/C ratio and pre-heating the complete reforming air in exp. 12 did not improve the conversion further. As a result, experiments 1 (NExBTL), 3 (Jet A-1) and 9 and 10 (Ultimate), resulted in the parameter combinations leading to maximum conversion with each fuel used.

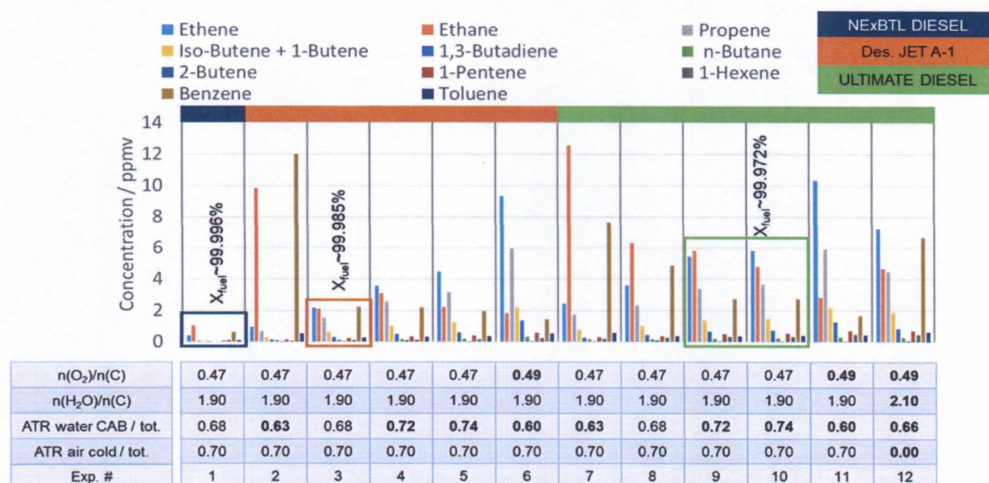


Fig. 2. Analysis of the side products of autothermal reforming using NExBTL, des. Jet A-1 and Aral Ultimate for different combinations of operation parameters.

CONCLUSIONS

In this work, the design of a compact fuel processor based on diesel reforming and high-temperature polymer electrolyte fuel cells was presented. Furthermore, results from preparatory experiments with the fuel processing system were shown. The focus of the system design was given to achieving the 40 W_e/l power density target defined for fuel cell APUs operating on diesel for the year 2020 by U.S. DOE. The validated heat integration concept was further developed, so that the three key components of the fuel processor include all necessary heat transfer and start functions in addition to their main function to save space. After a high-level engineering of the complete system components, it was possible to design and manufacture a 7.5 kW_e system including all balance of plant components at a volume of 187.5 l achieving the target power density. Parallel to system design, operation parameters were optimized using a fuel processor containing the same reactors using various fuels. It was possible to identify proper operating parameters, which led to a very high fuel conversion of > 99.95 % at full load, at the same time keeping CO content at the shift outlet < 1 % for stable operation of a HT-PEFC with reformat gas. With this result, the steady-state performance of the fuel processor part of the system is validated. As the next step, the developed fuel cell system will be characterized. The results from the operation of the complete system will be presented in the conference talk.

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