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Effect of Multifuel Approach on SOFC System Performance and Architecture Requirements

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Abstract

Introduction: Solid oxide fuel cell (SOFC) systems have the advantage to utilize different types of fuels including natural gas, liquified petroleum gas, ammonia (NH3), methanol (CH3OH) and pure hydrogen (H2). However, this often-cited fuel flexibility leads to complex system behaviors which need to be better understood with the help of extensive simulation and testing data.

Objectives: Within the FuelSOME project, one and the same system shall be operated with different types of fuels including NH3, CH3OH, and H2. The first objective of this work is to setup a comprehensive SOFC system model for all three types of fuels. The second objective is to use the model to better understand and steer the SOFC development into the right direction in terms of multi fuel applications for example in the maritime sector.

Material and methods: System understanding is the key for developing a SOFC system which shall be operated with different types of fuels. AVL has developed a 0-D system and stack analysis tool in recent years in order to develop optimized SOFC systems. This tool is based on a fully automized parameter study including a generic architecture. The generic architecture includes the stack and main BoPs such as reformer, oxidation catalyst/off-gas burner and all kind of fuel recirculation approaches. This is mandatory for system understanding and optimization [1]. This tool allows to get a very deep and comprehensive system understanding by building empirical models for more than 100 key performance indicators (e.g. system efficiency, cell voltage, etc.) based on several thousand stationary simulation results. The stack model used in this study was calibrated with test data from an anode supported SOFC stack. All system efficiencies within this work are defined as electric AC net efficiencies at beginning of life, based on the lower heating value.

Results: The investigations are done in an analytical way to better understand the effect of different parameters. In doing so, the system electric was optimized by considering additional typical stack specification (e.g. max. stack air outlet temperature, max. stack single pass fuel utilization, etc.). In case of a NH3 fueled system both effects of NH3 concentration at stack inlet and H2O discharge rate in the recirculation path was investigated compared to the base

case defined by a NH3 inlet concentration of 0 vol.% and a H2O discharge rate of 0 %. The analysis is done at 3075 W DC stack power output.

The results for NH3 show that the system electric net efficiency increases by 2.8 % points when the NH3 inlet concentration was increased to 30 vol.%. In case of 30 % H2O discharge and 0 vol.% NH3, the system electric net efficiency increased by 3.9 % points. The increase of efficiency in both cases has different origins. In case of NH3 increase at stack inlet, the cell voltage stays at the same level, however, the internal endothermic cracking of NH3 significantly reduces the required air flow for cooling of the stack, and thus the air blower power consumption. For the case of 30 % H2O discharge, the air flow is only slightly reduced but the cell voltage increases significantly because of the reduced H2O concentration inside the stack and thus higher H2 partial pressure inside the stack. With further increase of the H2O discharge to 90 % the efficiency reached 60.8 % with an NH3 concentration of 0 vol.% at stack inlet. For these results no lower limit on the stack air flow rate was considered.

Similar investigations have been carried out for a SOFC system fueled with H2 and CH3OH, where a lower stack air flow limit of 12000 Nl/h was considered. In case of CH3OH no H2O discharge in the recirculation path was considered because the H2O is used in the pre-reformer of the system. The analysis of the models showed that the system electric net efficiency of CH3OH, NH3, and H2 is similar for all three types of fuels up to 2400 W DC stack power (around 78 % load). However, only the efficiency of NH3 increases further to 65.1 % at 3075 W of DC stack power (around 100 % load). This is significantly higher than the 55.6 and 57.2 % for CH3OH and H2, respectively. The stack air flow rate provides one of the explanations for the different efficiencies. Only for H2, the low air flow limit is not a limiting factor at 3075 W. Higher electric efficiency for NH3 and CH3OH could be achieved by lowering the lower stack air flow limit. However, that would lead to a further mismatch of flow rates on the air path in the system for the three different types of fuels.

The analysis of the stack fuel flow rate at optimized operating conditions show that at 3075 W DC stack power the flow rates for the three types of fuels are between 2464 and 3762 Nl/h. That is an interesting result and shows that for full load operation the optimized operation points are quite similar in terms of fuel flow rate at stack inlet.

Conclusions: The overall analysis of the system models show that running a SOFC system with CH3OH and NH3 can lead to very high system efficiencies when optimizing the stack for low air flows rate. However, H2O discharge for NH3 is important to achieve electric net efficiencies >60 %. The same is true for H2 fueled system, however, other parameters must be optimized to also achieve an electric net efficiency >60 %. Overall, a multi fuel SOFC system has several challenges in terms of optimized operating conditions beside material compatibility and cost optimization and the tool developed by AVL and presented in this abstract is an innovative approach to help to solve the above-mentioned challenges.

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References

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