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Assessment of fuel interchangeability in domestic scale SOFC systems based on a reactor network approach

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Abstract

Optimum design of SOFC systems requires the development/application of versatile and robust approaches able to handle diverse fuel patterns and complex thermochemistry. In the present work a computational methodology based on the reactor network approach is developed, targeting the thermochemical assessment of fuel flexibility in SOFC systems. SOFC operation on methane, biogas, and ethanol is considered. The methodology results in a detailed quantification of the impact of fuel interchangeability on syngas yield, reformer thermal efficiency, and emission levels. The approach saves computational time and resources when compared, for example, to full CFD modelling, thus providing the opportunity for quick parameterisation.

Keywords: SOFC; Reactor network; Detailed chemistry; Fuel reforming; Fuel flexibility; System modelling

1. Introduction

Solid oxide fuel cell (SOFC) systems are highly efficient, fuel-flexible, environmentally friendly energy conversion devices, suitable for a wide range of applications in the energy (e.g. large scale electricity production) and transportation (e.g. aircraft and truck APUs) sectors. SOFCs are solid devices without any moving parts, and operate at relatively high temperatures (650–950°C) over varying load conditions to yield exploitable heat and electricity, thus constituting ideal combined heat and power (CHP) systems. Their operation is not limited by second law considerations, and they can achieve very high efficiencies, particularly at low to intermediate powers, while high pressure SOFC operation in hybrid systems (e.g. with gas turbines, SOFC-GT) is also a possibility [1–3].

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A unique feature of SOFCs is their fuel flexibility, which allows operation either directly on hydrocarbon or reformed hydrocarbon fuels [3, 4]. In almost all cases, SOFCs utilise a suitable reforming technology to convert the primary energy carrier into H_2 or a mixture of H_2 and CO (syngas). For the above reasons, SOFCs are ideal candidates to utilise locally produced fuels (e.g. landfill biogas, biogas from anaerobic digesters, liquid biofuels from fermentation processes such as bioethanol), with non-standardised and possibly significantly varying composition, in the frame of a decentralised CHP scheme.

Efficient and clean operation requires fuel chemistry optimisation along the whole system, and for a wide range of operating conditions. SOFC systems comprise components that feature different operating requirements, flow patterns, and chemical behaviour. Over the last decade, SOFC technology has reached a certain degree of maturity, both at component and system level. Significant progress has also been realised in the framework of EU-funded research projects, such as the FlameSOFC [5] and FC-District [6] projects. Both projects consider the development and integration of prototype SOFC systems for domestic CHP applications. A schematic representation of such a system, based on the knowledge acquired within the above-mentioned research projects, is shown in Fig. 1. The system comprises a fuel processing unit, the SOFC stack, and a balance-of-plant (BOP) section, which is responsible for the thermal integration of all the individual components. A fuel-flexible SOFC system can in principle operate on both liquid and gaseous fuels. In the former case, a liquid fuel vaporising unit is needed in order to suitably evaporate the liquid fuel and prepare the desired fuel/air mixture. Subsequently, the fuel/air mixture enters the reformer in order to be converted into a hydrogen-rich reformate mixture. The reformate mixture is then fed to the SOFC stack anode, where the electrochemical reactions take place.

A crucial aspect in terms of fuel flexibility is the choice of the reforming technology. Typical reformers are based either on steam reforming or catalytic partial oxidation, or even a combination of both, commonly described as autothermal reforming. An alternative option would be the use of a non-catalytic thermal partial oxidation (TPOX) reformer. The advantages of such a technology have been described in detail in previous publications [7, 8], and thus only the major points are summarised below.

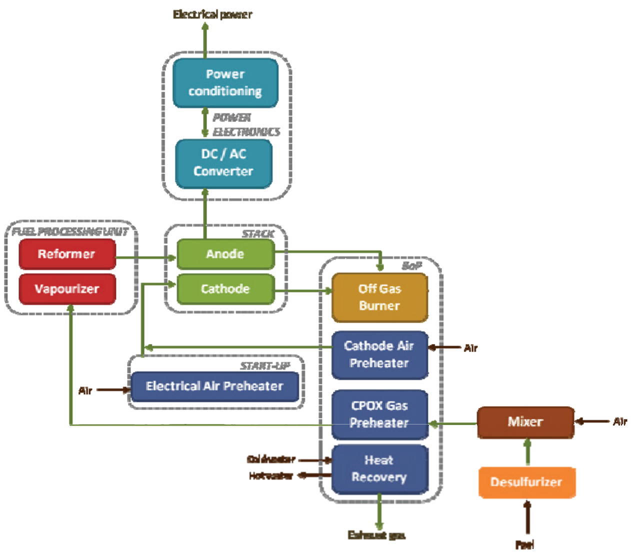

Figure 1. Schematic representation of an SOFC-based micro-CHP system for domestic applications, based on the results of the EU co-funded FlameSOFC and FC-District research projects.