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Performance analysis of HT-PEFC stacks

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ABSTRACT

The performance analysis of a five-cell HT-PEFC stack is presented. The stack was operated either with pure hydrogen or synthetic reformate on the anode side and air on the cathode side. The overall electric performance and the heat management were analyzed. The local performance was assessed by current density and temperature distribution measurements. For this purpose, a tailor-made measuring board was integrated into the stack assembly. It is shown how the choice of fuel gas composition, reactant stoichiometry, flow direction and cooling affect the current density and temperature distribution.

1. Introduction

High temperature polymer electrolyte fuel cells (HT-PEFCs) have gained importance in the research community ever since Wainright [1] first tested fuel cells using polybenzimidazole (PBI) membranes doped with phosphoric acid as electrolyte. The new membrane material allows elevated operating temperatures up to 200 °C. This leads to higher tolerance of fuel gas impurities such as carbon monoxide, which is advantageous when a fuel cell stack is combined with a reforming system to form an auxiliary power unit (APU). In addition, the replacement of Nafion as electrolyte omits the need for a water management system. A higher operating temperature also permits easier waste heat removal and improved heat recovery. The complexity of system design and the number of balance of plant components are thus reduced [2]. A very good overview regarding past HT-PEFC fuel cell research activities can be found in Ref. [3].

First experiments with PBI-based HT-PEFCs at Forschungszentrum Jülich were performed by Wannek et al. [4]. Further development and design of a stack with a power output in the kW range was done by Bendzulla [5]. Other HT-PEFC stack developments and tests with up to 25 cell stacks have been described in the literature [6–17].

In order to improve stack performance and lifetime it is necessary to obtain a detailed picture of the behavior of the fuel cell stack. In the following, an oil-cooled HT-PEFC stack developed at Forschungszentrum Jülich and the measuring techniques applied for its characterization are presented: (i) The overall performance was assessed by recording polarization curves and studying the heat balance. (ii) The local performance of the fuel cell stack was analyzed by current density and temperature distribution measurements, especially their dependence on different operating conditions. For stable operation, high performance and longevity, an evenly distributed current density across the cell area is favorable. Whereas current density and temperature distribution measurements across the active cell area are well established in NT-PEFC research, so far only a few experiments have been reported in the literature for HT-PEFCs. For single cells the

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influence of different flow fields, reactant composition, stoichiometry and flow direction on current density and temperature distribution are presented [10,18,19]. As far as the authors know, nothing has yet been published on current density measurements in HT-PEFC stacks.

At the anode side, the fuel cell stack was supplied with pure hydrogen or synthetic reformate simulating the product gas of a fuel processing system based on autothermal reforming of middle distillates. At the cathode side, the stack was fed with dry air.

In parallel to our experimental work, a HT-PEFC stack model was developed. A detailed description of this model is given in Ref. [20].

2. Experimental

2.1. HT-PEFC stack

The stack design used for this study was engineered at Forschungszentrum Jülich in order to demonstrate the feasibility of constructing a HT-PEFC stack with an electric power output in the kW range [5]. A fuel cell stack consists of a series of repeating units of fuel cells. The main components of one repeating unit are the membrane electrode assembly (MEA) and bipolar plates (BPP). The repeating units are clamped together by two aluminum endplates connected with tension bolts. For this study, a five-cell short stack with an active cell area of 200 cm^2 was assembled (cf. Fig. 1). The MEA was manufactured by BASF Fuel Cell Inc. It is sold under the brand name Celtec-P-1000. Its properties can be found in Ref. [21].

The reactants are supplied through flow channels milled in the bipolar plates. The bipolar plates consist of graphite stabilized by a phenolic resin. One flow field consists of 10 parallel meander channels. The channels have a cross sectional area of $1 \times 1\ mm^2$. The land-to-channel ratio is 1:1 (cf. Figs. 1 and 6). Designed for reformate operation, the same flow field is used on the anode and cathode side in the stack. The supply of reformate from middle distillates and air with the same stoichiometry on the anode and cathode side leads to almost equal gas flow rates. As a result, an almost equal pressure drop on both sides and subsequently a minimized differential pressure is achieved for reformate operation.

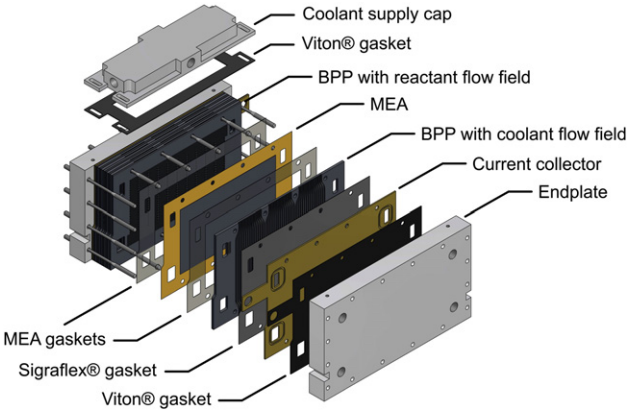

Fig. 1 – HT-PEFC short stack.

Reactant distribution to multiple flow fields and product gas collection is performed by stack internal manifolds. Flow channels and manifolds are dimensioned to ensure an equal distribution of reactants to each cell and each channel in stacks with up to 100 cells. At the same time, the aim was to keep the pressure drop as low as possible. The PFA gaskets between the MEA and bipolar plates have to (i) seal the anode and cathode compartment of the stack to the environment, (ii) provide electrical insulation to prevent short circuits and (iii) ensure a predefined compression of the MEA by setting the distance between two bipolar plates. The elevated temperature of up to 200 °C and the acid environment in the fuel cell limit the choice of available sealing materials.

To integrate a cooling and heating system into the stack, each bipolar plate is separated into an anode and a cathode bipolar plate. The coolant flows through 45 vertical channels milled into the rear sides of the cathode bipolar plates (cf. Figs. 1 and 9). Each channel has a width of 2 mm and a depth of 1.5 mm. The land-to-channel ratio is 1:1. The coolant flow zone is sealed by an electrically and thermally conductive flat SIGRAFLEX® gasket. The cooling agent is distributed and collected by two caps placed on the top and bottom of the fuel cell stack. Both air and liquid cooling are suitable for this stack design.

At both ends of the stack, stainless steel plates serve as current collectors. They are coated with a thin gold layer to reduce contact resistance. The collector plates are electrically insulated against the aluminum endplates of the fuel cell stack. Otherwise the connection of the endplates caused by the mountings of the coolant caps would lead to a short circuit. The fuel cell stack is thermally insulated against the environment by two layers of silicon foam mats with a thickness of 10 mm.

It has to be kept in mind that results obtained by a short stack are not generally transferable to full stacks of the same design. The differences between a short stack and a full stack affect (i) the reactant distribution and (ii) the temperature distribution. (i) Flow field and manifold sizing is performed for 100 cells. The manifold is oversized for five cells. Accordingly, it is not possible to establish whether an equal reactant distribution to all cells in a full stack can be achieved by this design or not. However, the flow through one cell, which is important for the analysis presented here, is the same in short and full stacks. (ii) Convective heat transport at the stack surfaces generally leads to a temperature decrease toward both stack ends. Due to the higher number of cells, the influence of the bordering cells on performance is greater in short stacks than in full stacks. This is compensated in the current design by the oil cooling of the stack and the insulation. As will be shown later, the oil cooling governs the temperature distribution inside the fuel cell stack. The temperature difference between the cells is below the tolerance of the temperature measurement device used.

2.2. Test station

A Hydrogenics® test station was used for operating and testing the fuel cell stack. Core components are a TDI RBL232 50-400-200 load bank operated in galvanostatic mode, Bronkhorst EL-Flow® flowmeters for reactant supply and a Beckhoff cell