



## Short communication

## Externally cooled high temperature polymer electrolyte membrane fuel cell stack

J. Scholta\*, M. Messerschmidt, L. Jörissen, Ch. Hartnig

ZSW, Helmholtzstr. 8, D-89081 Ulm, Germany

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## ABSTRACT

One key issue in high temperature polymer electrolyte membrane fuel cell (HT-PEMFC) stack development is heat removal at the operating temperature of 140–180 °C. Conventionally, this process is done using coolants such as thermooil, steam or pressurized water. In this contribution, external liquid cooling designs are described, which are avoiding two constraints. First, in the cell active area, no liquid coolant is present avoiding any sealing problems with respect to the electrode. Secondly, the external positioning allows high temperature gradients between the heat removal zone and the active area resulting in a good adjustability of appropriate reformate conversion temperatures (e.g. 160 °C) and a more compact cell design. Different design concepts were investigated using modeling techniques and a selection of them has also been investigated experimentally. The experiments proved the feasibility of the external cooling design and showed that the temperature gradients within the active area are below 15 K under typical operating conditions.

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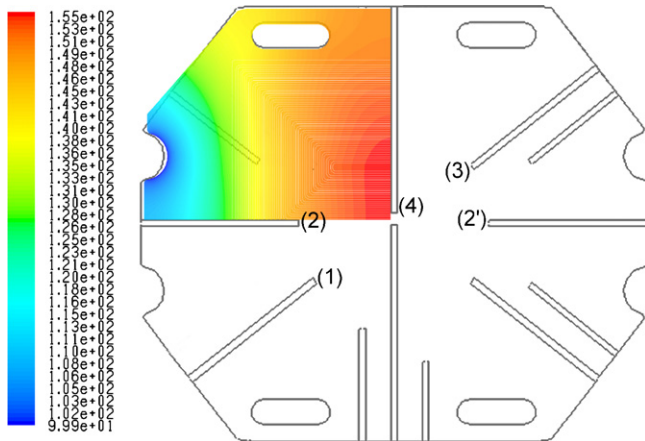
## 1. Introduction

Due to their operating temperature up to 180 °C HT-PEM fuel cells are less sensitive to fuel contaminations such as CO. Recently HT-PEMFC MEAs based on a polybenzimidazole membrane saturated with phosphoric acid became commercially available. These materials offer a great potential for the use of reformate originating from a simplified gas processor in which the final CO purification step can be eliminated. On the other hand, the stack cooling medium has to withstand temperatures of up to 200 °C with respect to chemical stability, ignition temperatures, and sufficiently low vapour pressure. Moreover, tough sealing requirements of the cooling loop to the electrode compartments exist since traces of the coolant, typically a thermooil capable of withstanding high temperatures, can poison the catalyst. Furthermore, steam or liquid water can dilute the phosphoric acid electrolyte. Nevertheless, it would be beneficial to use a water-based coolant for HT-PEMFC. In this case, however, two major problems occur: primarily, water has to be kept fully separated from the active components because of the hygroscopic behaviour of the H<sub>3</sub>PO<sub>4</sub>-soaked MEA. Secondly, it is difficult to maintain a defined degree of heat removal if cooling is based on the evaporation of water inside the stack. If liquid water is used inside the stack active area, either the result-

ing cell temperature level is too low for efficient conversion of CO-containing reformate or the pressure requirements in the cooling loop will lead to expensive designs like pressure resistant pipes made from stainless steel in each cell cooling unit [1]. A detailed discussion of material selection for HT-PEMFC is given in Ref. [2]. Moreover, it is known that the degradation of a HT-PEMFC is strongly influenced by the operating temperature [2,3], such that it is advantageous for cell lifetime and performance to keep the operating temperature in a small, well-defined range. Detailed information on degradation and relevant mechanisms is given, e.g. in Ref. [4]. Only a limited amount of contributions with respect to HT-PEMFC stacks is available, as shown in Refs. [2,5].

In this contribution, external liquid cooling designs are described which are avoiding both constraints. First, in the cell active area, no cooling water is present avoiding any sealing problems with respect to the electrode. Secondly, the external positioning allows high temperature gradients between the heat removal zone and the active area resulting in a good adjustability of appropriate reformate conversion temperatures (e.g. 160 °C) and a more compact cell design. Air cooled designs using a bipolar plate integrated coolant flow are known for low temperature PEMFC [6,7]. They are using an active area of either 50 cm<sup>2</sup> [6] or 100 cm<sup>2</sup> [7]. Different design concepts for an internally or externally cooled HT-PEMFC have been presented in Ref. [8]. In this contribution, a synopsis of modeling and experimental results on externally cooled HT-PEMFC stacks will be reported.

\* Corresponding author. Tel.: +49 7319530206; fax: +49 7319530666.  
E-mail address: [joachim.scholta@zsw-bw.de](mailto:joachim.scholta@zsw-bw.de) (J. Scholta).



**Fig. 1.** Cell temperature distribution (°C, modeling) with borderline cooling from four tubes (borderline fixed at  $T_{\text{tube}} = 100\text{ °C}$ ,  $0.28\text{ W cm}^{-2}$  at active area) and sensor positions.

## 2. Experimental and modeling procedure

Modeling results are obtained using the CFD-code FLUENT™. Symmetry relations were used and thus just one quadrant of the bipolar plate (bpp) was modelled with its original geometry. It was assumed that the wall to the cooling pipe (upper left corner in Fig. 1) is fixed at a constant temperature of  $100\text{ °C}$ . Within the active area ( $10.4\text{ cm} \times 10.3\text{ cm}$ ) a constant heat source of  $0.28\text{ W cm}^{-2}$  was positioned at the top of the cathode ribs. All other outer walls were assumed to be adiabatic. Heat removal with the reactant gases was not taken into account. The calculation assumed stationary conditions. The heat flow density is given by

$$\dot{q} = \lambda \nabla T \quad (1)$$

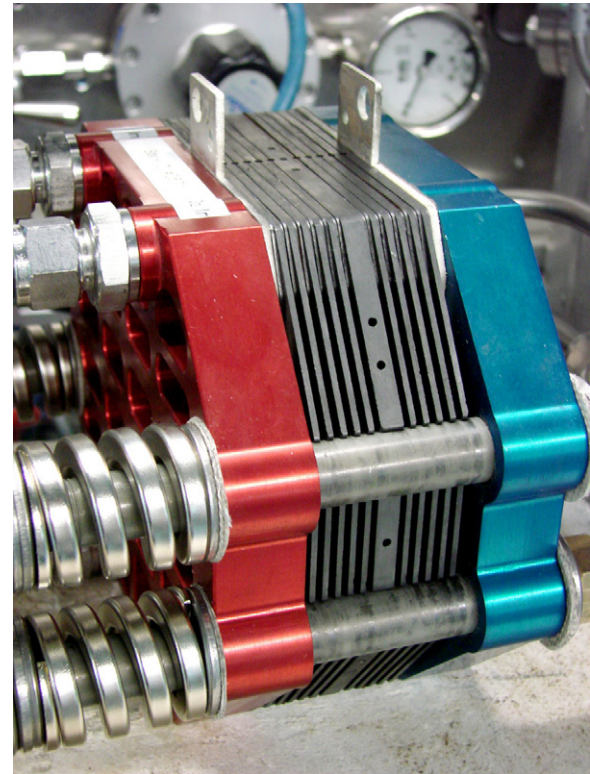
In that equation,  $\lambda$  is heat conductivity and  $\nabla T$  is the temperature gradient. Thus, the energy equation in FLUENT is composed of the heat conducting, the heat source and the heat sink term.

Cell experiments have been performed for verification tests using stacks with 5–10 cells. Test benches having a double cooling/heating loop based on water and thermooil have been designed. The test bench layout has been described in Ref. [9]. Protective means (e.g.  $\text{N}_2$ -purge, monitoring on low and high cell voltage) were added. The temperature distribution inside the active area has been measured using a special bipolar plate inside the stack having different thermocouples (type K) inserted into the active area. The experimental results are compared to the temperature distribution calculated from CFD-modeling. Additional information on temperature distribution was gathered by IR-imaging from the outside of the stack.  $\text{H}_2$  and simulated reformat (including appropriate amounts of CO) were used on the anode side. The cathode has been operated with air.

## 3. Results and discussion

From the modeled design concepts for non-standard cooling which are presented in Ref. [8], a design concept allowing heat pickup from two sides was selected and investigated in more detail. A concept with four external cooling tubes was identified to have a sufficiently high temperature gradient for cooling with a liquid of a temperature level in the range of  $100\text{ °C}$  at an active area temperature of  $160\text{ °C}$ . Fig. 1 shows the modeled temperature distribution and the position of the temperature sensors.

This configuration shown in Fig. 1 has been used for the design of a verification stack. The external positioning of the cooling medium

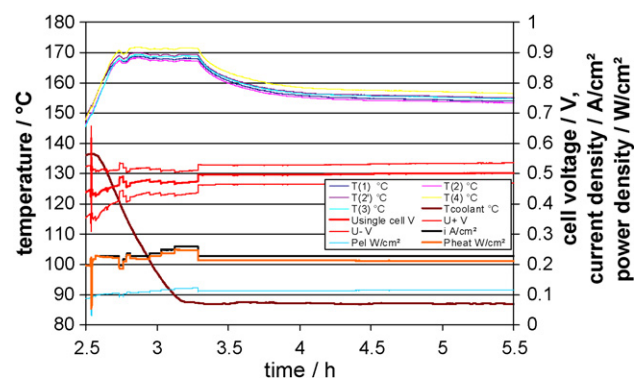


**Fig. 2.** 10 cell stack (including T-sensor plate).

allows high temperature gradients between the cooling medium and active area resulting in a good adjustability of cell temperatures (e.g.  $160\text{ °C}$ ) appropriate for the conversion of reformat containing significant amounts of CO. The 10 cell verification stack which is shown in Fig. 2 includes a special bipolar plate, which is equipped with thermocouples.

The operation time chart of the stack is given in Fig. 3. It could be shown that a stable temperature distribution within the desired temperature range could be obtained. The measured temperature distributions for two operating points (heat release of  $0.21$  and  $0.25\text{ W cm}^{-2}$ ) are given in Fig. 4.

The modeling results (Fig. 1) predict a temperature deviation of  $10\text{ K}$  between  $T(2)$  and  $T(4)$  at  $0.28\text{ W cm}^{-2}$ . The maximum temperature deviation in the active area is calculated to be  $21\text{ K}$ . For more than 90% of active area less than  $15\text{ K}$  of temperature difference are expected. The experimental data displayed in Fig. 4 show an even lower temperature deviation than expected from modeling. The cell tests showed that, at a specific heat production of  $0.248\text{ W cm}^{-2}$ , a



**Fig. 3.** Time chart of 10 cell stack operation.

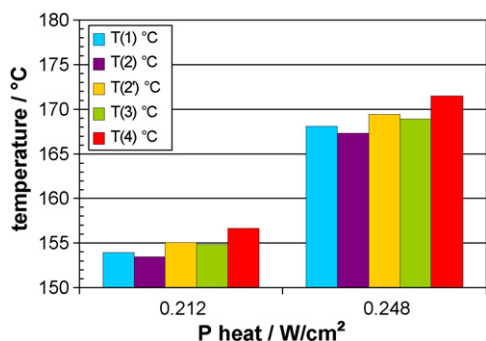


Fig. 4. Cell temperature distribution (experimental) with borderline cooling from four tubes (borderline fixed at  $T_{\text{tube}} = 88^\circ\text{C}$ ).

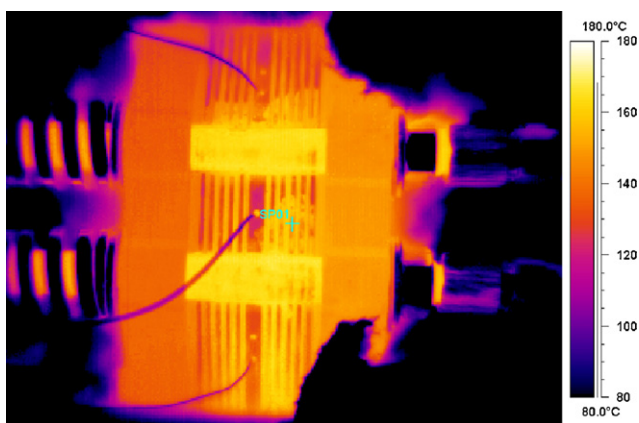


Fig. 5. Cell temperature distribution (IR photo) during heatup (pipes fixed at  $T_{\text{tube}} = 155^\circ\text{C}$ ).

temperature deviation of 4 K is measured between T(2) and T(4). Thus, at a specific heat production of  $0.28\text{ W cm}^{-2}$ , a temperature deviation of 5 K between T(2) and T(4) is expected based on the experimental data and assuming a linear relationship between heat flux and temperature difference. If the temperature distribution as calculated from the modeling is assumed, which is multiplied by a factor of 0.4 to fit it to the experimental data, a temperature deviation of less than 10 K is obtained. A linear extrapolation to a specific heat production of  $0.4\text{ W cm}^{-2}$  would lead to expected temperature difference of less than 15 K, which is still in the allowable operating range. The deviations observed between modeling and experimental data may be explained at least in part by the disregarding of the reactant gas and air flow in the modeling calculations as well as radiative heat losses from the cell edges. Summarizing, the obtained results verified the concept of an externally cooled stack as a viable option for fuel cell stacks converting reformat gases.

The temperature gradient is a function of the heat flux to be removed from the cell. This behaviour is reflected by the increase in temperature level by 15 K, as soon as the heat production changes from  $0.212$  to  $0.248\text{ W cm}^{-2}$ . So, for high load changes, either the coolant temperature has to be changed appropriately, or the thermal coupling between the stack and the coolant has to be modified, if the stack operating temperature level has to be kept constant.

The temperature distribution along the cells ( $z$ -direction) was checked by IR-imaging. Temperature distributions (IR-pictures) are given in Figs. 5 (startup) and 6 (stationary operation).

Only small temperature deviations in the range of 5 K in  $z$ -direction could be detected. This deviation may be caused by the

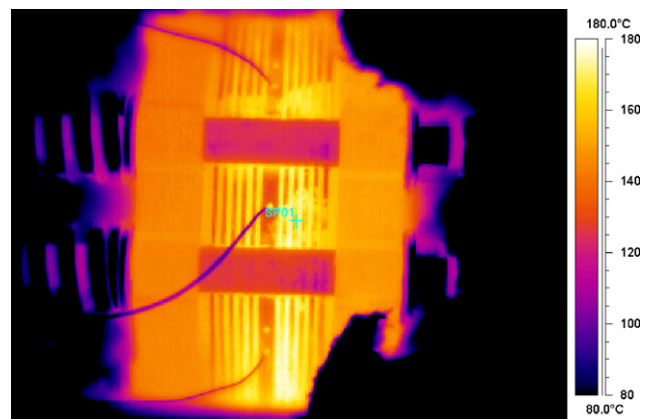


Fig. 6. Cell temperature distribution (IR photo) during operation (pipes fixed at  $T_{\text{tube}} = 88^\circ\text{C}$ ).

only partial isolation of the stack during the experiment. It is expected, that the cell concept can be scaled up for long stacks without problems in thermal distribution along the  $z$ -axis.

#### 4. Conclusion and summary

The comparative assessment of modeling and measured data showed that the temperature gradients between active area and the coolant temperature were high enough such that cooling media (e.g. thermo transfer liquid, air, etc.) with an inlet temperature of  $100^\circ\text{C}$  or less can be used. If the thermal coupling between stack and coolant is varied, a broad power range can be used with small changes in stack temperature. It is expected that power densities of up to  $0.4\text{ W cm}^{-2}$  can be realized with the presented concept, if a moderate increase in active area temperature range is accepted.

#### 5. Outlook

Further experiments are planned to analyze the influence of temperature, gas utilization and CO concentration on the localized current density distribution, and by doing so, estimate the influence of those operating parameters on electrode and cell lifetime.

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#### References

- [1] J. Larminie, A. Dicks, Fuel Cells Explained, 2nd edition, Wiley & Sons, Chichester, UK, 2003, p. 180.
- [2] J. Zhang, Z. Xie, et al., J. Power Sources 160 (2) (2006) 872–891.
- [3] C. Wannek, B. Kohnenl, H.-F. Oetjen, H. Lippert, J. Mergel, Fuel Cells 8 (2) (2008) 87–95.
- [4] Th.J. Schmidt, ECS Trans. 1 (8) (2006) 19–31.
- [5] S.J. Andreasen, S.K. Kær, ECS Trans. 5 (1) (2007) 197–207.
- [6] C. Spitta, J. Mathiak, M. Dokupil, A. Heinzl, Fuel Cells 7 (3) (2007) 197–203.
- [7] K.P. Adzakpa, et al., J. Power Sources 179 (2008) 164–176.
- [8] J. Scholta, W. Zhang, L. Jörissen, W. Lehnert, ECS Trans. 12 (1) (2008) 113–118.
- [9] J. Scholta, N. Berg, P. Wilde, L. Jörissen, J. Garche, J. Power Sources 127 (2004) 206–212.