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T. Kurz, J. Keller

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A Compact, Open-cathode HTPEM Fuel Cell Module for Portable Applications

Timo Kurz, Julian Keller, Fraunhofer Institute for Solar Energy Systems, Germany

1 Introduction

High Temperature PEM fuel cells based on a phosphoric acid doped polybenzimidazole (PBI) membrane are a relatively young technology compared to standard PEM fuel cells. The main advantage of this cell type is the operating temperature above the boiling point of water, leading to a simplified water management and to a strongly increased CO tolerance. Because of this higher CO tolerance and a higher usable temperature level, they are considered to be a promising technology for CHP systems.

Besides CHP systems, HTPEM fuel cells offer new possibilities also for other applications: Due to the absence of liquid water, they show a more stable operation, especially at high current density. Because the membrane is conductive in dry conditions, the cell can be operated with high, non-humidified air flow by using simple flow field geometry. This leads to the possibility of an open cathode design that acts as both the air supply and the cooling channel.

This work presents the development and characterisation of a stack module for portable applications in the range of some 100 W. The aim was to develop a small and compact system with few components and stable operation.

2 Stack Design and Housing

To realise a system with few additional components, a stack concept with open cathode has been designed: The cathode air is used also as coolant, so only one fan or air pump is needed. PBI membranes need no humidification and therefore high flow rates can be used without damaging the cells.

With high flow rates, the pressure drop in the cathode flow field has to be as small as possible to enable a standard fan for the air supply. To achieve this, simple parallel channels could be used.

On the other hand, high flow rates of cool air can lead to a strong temperature gradient along the channel. To reduce this, single serpentines have been used in the air flow field. The resulting temperature distribution at inlet and outlet is analysed in section 3.

To validate this system concept, a 5-cell test short-stack including complete housing and connectors has been developed. Figure 1 shows a cross section of this module with the air path in the housing and the flow field design. In front of the stack inlet, a heating wire is inserted to heat up the inlet air during start-up. The stack is fully enclosed in the housing with glass wool for thermal insulation. The box can be closed on inlet and outlet to avoid moisture absorption after shutdown that can be critical for membrane degradation. Gas supply and electrical connectors for load and heating are attached. Table 1 shows an overview of stack and module properties:

Table 1: Module characteristics.

Module dimensions	240 x 120 x 100 mm
Module weight	2.2 kg
Heating	electrical, 100 W / 12V
Cell number	5
Cell active area	31.4 cm²
Stack nominal power	45 W @ 15 A
Stack max. power	> 90 W
Hydrogen supply	dead end or recirculation with purging
Air supply	open cathode, up to 50 slpm

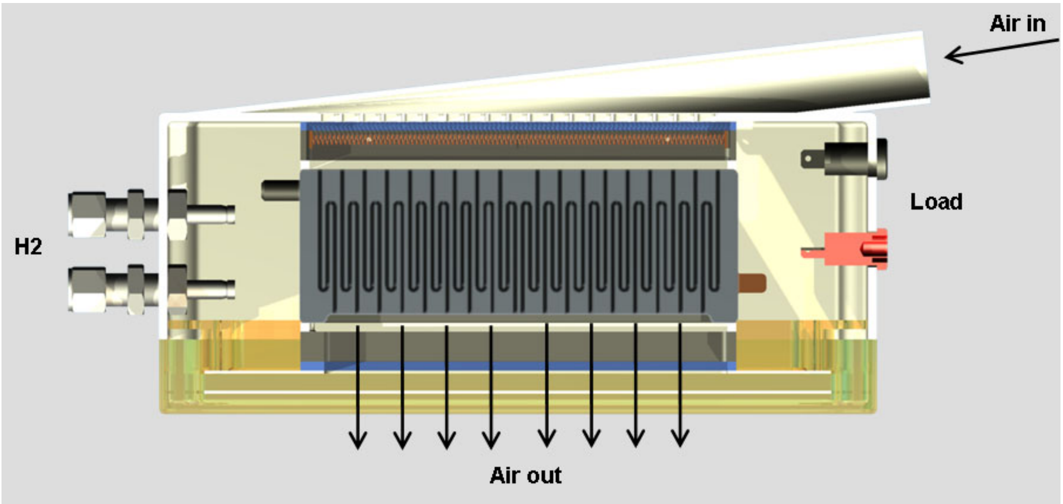

Figure 1: Cross section of the stack module.

3 Results and Discussion

During operation, temperature distribution has been measured with 16 type-K thermocouples attached to the stack: 6 near the serpentines at the inlet and 8 near the outlet. These sensors provide a complete picture of the temperature distribution in plane as well as from top to bottom. Figure 2 shows the location of the thermocouples. They measure the bipolar plate temperature near the channel without blocking the channels.

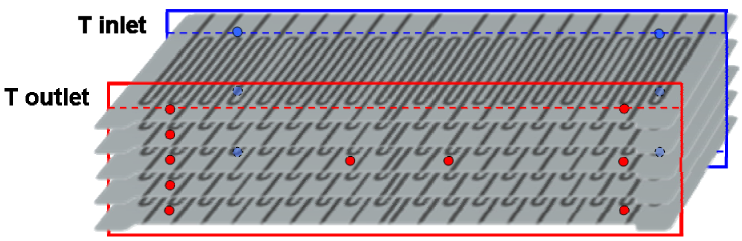

Figure 2: Schematic view of the location of the thermocouples in the stack.

3.1 Start-up

Figure 3 shows the average stack temperature during heating at start-up. The stack is heated only by air passing the heating wire. Heating is switched on at 950 s. The stack temperature rises and reaches 120 °C at 1950 s. From this moment on, the stack is switched on and reaches nominal power (15 A, 0.6 V_{cell}) at 2090 s. The nominal working temperature, 160 °C, is reached at 3450s.

In this configuration, it needs 100 kJ electrical energy and 16:40 min for heating this system up to starting temperature. This consumption / time can be further optimised by lowering the possible starting temperature (with more stable membranes), increasing the stack-to-system-weight-ratio using a bigger stack (30 instead of 5 cells) or by an improved heat transfer to the incoming air.

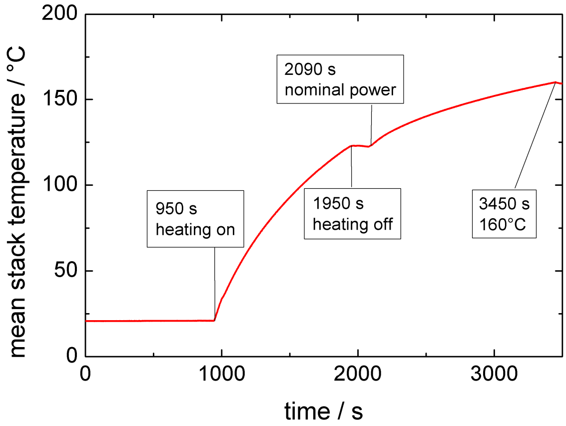

Figure 3: Mean stack temperature during a standard heating procedure. In the first period, the stack is heated only electrical (@ 100 W). After reaching 120 °C, the stack is started and operated at 15 A.

3.2 Operation

Figure 4 shows polarisation curves of the stack in galvanostatic mode at different mean stack temperatures. The temperature has been controlled only by cathode air flow. Hence, stoichiometry during this measurement varies in a wide range from $\lambda = 3$ (high temperature, low current) to $\lambda = 15$ (low temperature, high current).

The stack shows excellent characteristics, (608 mV_{cell} / 500 $mAcm^{-2}$ at 160 °C) and as expected a slightly increasing voltage with increasing temperature (570 mV at 130 °C up to 618 mV at 170 °C).

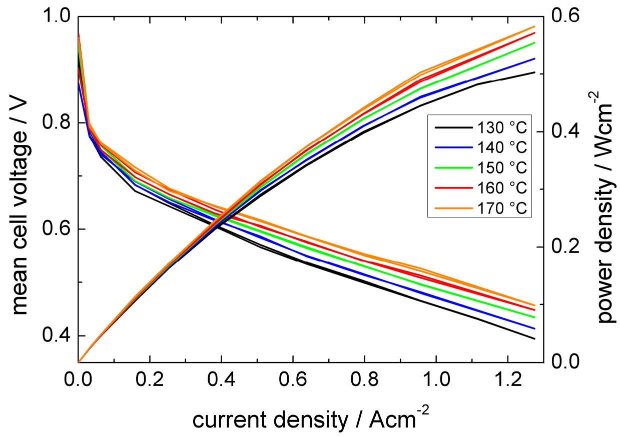

Figure 4: **Polarization curves of the stack at different mean temperatures at λ_{H2} = 1.5. Oxygen stoichiometry varies between 3 and 15 due to temperature control by cathode air.**

3.3 Temperature distribution

Figures 5 and 6 show the temperature distribution in the left side of the stack (see figure 2) at two different operation points; at nominal operation (15 A, 11 slpm, filled symbols) and at high power operation (30 A, 35 slpm, hollow symbols).

Figure 5 shows temperature variation from top to bottom; temperatures at the outlet (red) are slightly higher than at the inlet (blue) due to the cool inlet air. The difference is larger at higher air flow due to a higher cooling rate: At 30 A, the maximum difference is 8.6 °C, and it is only 5 °C at 15 A. The temperatures show an increase from top to bottom cell, this can be due to an inhomogeneous inflow and/or due to less insulation material on top.

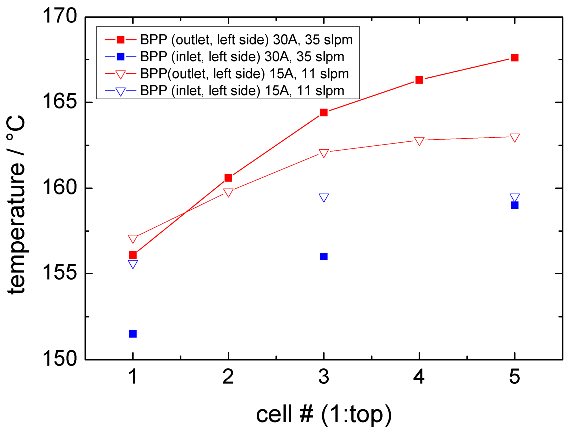

Figure 5: **Temperature distribution during operation at 160 °C on the left side of the stack from top (1) to bottom (5). The plots show the difference between inlet (blue) and outlet (red) and between the operation at 30 A / 35 slpm (filled) and 15 A / 11 slpm (unfilled symbols).**

Figure 6 shows the variation from left to right in the cathodic bipolar plate of cell 3. The temperature distribution is nearly symmetric, indicating good inflow geometry in this direction (see figure 1, top). The highest difference between left and right side is 3.7 °C at the inlet (at 30 A). The outlet temperatures show higher values in the middle of the cell. This can be explained by heat losses through the side faces of the stack. As also seen in figure 5, temperature variation between inlet and outlet increases at higher air flow rate. The maximum difference is here 10.4 °C on the right side.

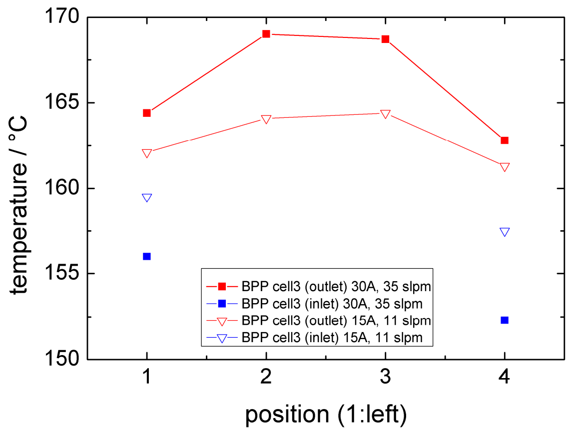

Figure 6: Temperature distribution during operation at 160 °C in BPP 3 at inlet (blue) and outlet (red) from left to right. The air flow comes from the right side (see figure 1). The plots show the difference between the operation at 30 A / 35 slpm (filled) and 15 A / 11 slpm (unfilled symbols).

4 Conclusions

A compact fuel cell module for small portable systems has been presented. It consists of a HTPEM fuel cell short-stack with open cathode that can be operated with a controllable fan only (besides the fuel connection). Thermal insulation, gas and electrical connectors as well as electrical heating are integrated.

Polarisation and temperature measurements have been performed. They show that electrical heating only by heating the inlet air is possible and leads to a heating time of < 17 min. In operation, the stack shows an excellent power characteristics and small temperature variation even at high flow rates of ambient air due to a specific designed flow field. In high power mode (high air flow), the maximum temperature difference (at 160 °C mean temperature) is 17.5 °C, and it is only 8.8 °C at nominal power operation. These results show that this stack module concept with open cathode works excellent and leads to a simple system design, ready to be scaled up to higher cell numbers.

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