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Experience in Stack Development for High Temperature PEM Fuel Cells

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1 Introduction

High temperature PEM fuel cells (HT PEMFCs) offer tremendous flexibility when used as energy converters in stationary as well as mobile power devices. Coupling HT PEMFC stacks with fuel processors which use liquid as well as gaseous fuels to generate hydrogen rich gas is a promising prospect which paves the way for a possible hydrogen economy. One core challenge of the integration of these membranes operated at approx. 160 °C is the realization of stable and producible fuel cell stacks.

Within several research projects various innovative stack designs with different active areas (28 cm^2, 50 cm^2 and 200 cm^2) have been developed, constructed and operated at ZBT. Realized solutions for cooling structures, fuel channels, gasket technologies and the stack assembly are derived from these experiences. Furthermore operational results of these stacks and system solutions are being summarized.

2 High Temperature PEM

High temperature PEM fuel cells (HT PEM) can be operated in the temperature range between 130 °C and 200 °C and offer a number of potential advantages compared to low temperature PEM fuel cells (LT PEM), e.g., high CO tolerance, no need for humidification of reactant gases, and simplified heat management of the fuel cell system. The fuel cell research centre ZBT GmbH ("Zentrum für BrennstoffzellenTechnik") has started development work for small scale HT PEM fuel cell stacks in 2004, based on commercially available MEAs (Membrane Electrode Assemblies) of different suppliers. This technology offers a variety of potential advantages such as simplified system management, water management and adaptability to fuel reformers.

Comparing the efficiencies of the single fuel cell of a LT PEM and a HT PEM surely the HT PEM shows a slightly poorer performance. Neither the voltage stability nor the maximal current densities today reach the values of the classical PEM technology. Nevertheless comparing full system efficiencies of reformer based systems the HT PEM proves a better performance and offers the reduction of significant system components such as gas purification and humidification and in parallel an increase of operational stability of the fuel cell stack and the overall system.

But integration of a HT PEM MEA into a long term stable fuel cell stack environment and integration of this stack into a complete working system is yet another challenge. Identification of stack and system materials is a critical issue as long term and even short term operation of fuel cell stacks have proven [1]. This results in high material costs for the components of the fuel cell stack, namely MEA, bipolar plate, gasket and also the endplate setup, all have to stand the high temperatures as well as the complex electrochemical and chemical cell environment.

3 First Approaches in HT PEM Fuel Cell Stack Construction and Operation

Starting 2004 ZBT has constructed first single cells and fuel cell stacks based HT PEM MEAs which at that time had been provided by PEMEAS GmbH, now BASF Fuel Cell GmbH. Based on the well proven LT PEM fuel cell stack design a 50 cm^2 approach was chosen, using milled graphite bipolar plates and foamed gaskets. As results of stack manufacture as well as cell and stack operation it became obvious that not only the temperature stability of the used materials is critical. A single cell was operated for 3000 hrs showing a good performance in principle but still a significant voltage decrease. In post mortem analysis the cell components were analysed, the bipolar plates surface deterioration was negligible, no cracks were to be identified and the electrical conductivity as well as the gas tightness was still comparable to the starting point. Also the MEA did not show any visible changes. Surprisingly a significant part of the increased cell resistance was identified to be caused by the gold plated copper current collectors: The gold plating was diffused during the high temperature operation resulting in conductivity deterioration. During cell operation furthermore the product water was analysed, here carbon particles were found to be usually < 1 mg/litre, Pt particles were found to be < 0,003 mg/litre and traces of phosphoric acid were found at 0,2 $\mu g/m^2/s$ (peak: 0,44 $\mu g/m^2/s$).

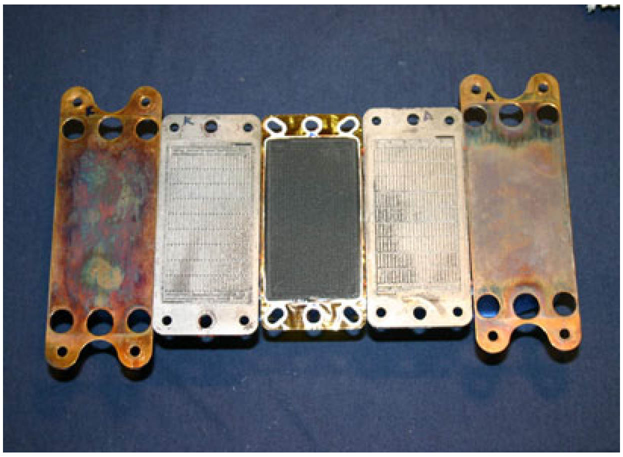

Figure 1: Single cell components after 3000 hrs of operation.

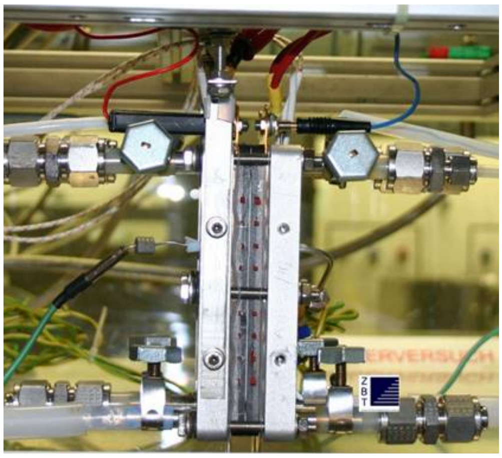

Figure 2: 50 cm^2 single cell (2006).

As result of the experience of this and other experiments also with respect to operation regimes, short and long stacks were to be manufactured and operated. A first milestone was the realization of a 12 cell stack which was constructed for the Boreskow Institute of catalysis in Novosibirsk (BIC). This stack was manufactured and proved a comparable performance even under different media supply at ZBT and BIC. Even after laboratory and development use, long storage times (about 1 year) and further transportation still very stable performance was reported.

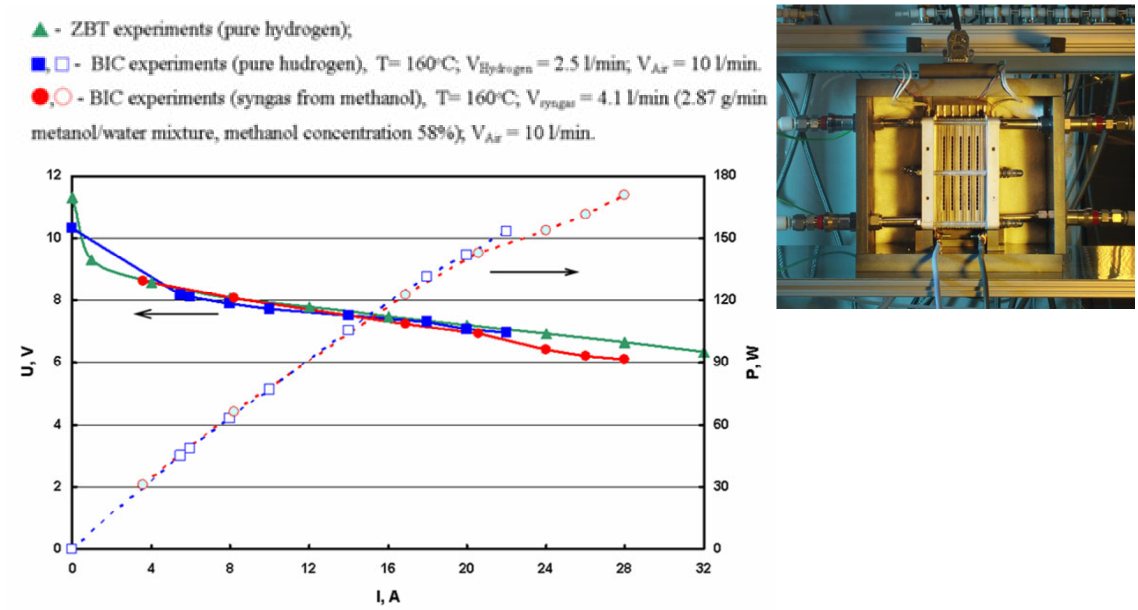

Figure 3: **12 cell stack operation at different test setups and feeding gases.**

4 Micro Fuel Cell Stack

On the basis of the described pre-work in 2006 a joint research project was initiated to design and construct a compact 140 W_{el} HT PEM fuel cell stack to be integrated into a methanol reformer setup [2]. The aim of the overall project was the development of an efficient and robust portable power generation device applying methanol as fuel with an electrical net power output of 100 W_{el}. ZBT for this purpose has developed a 24 cell air cooled compact, lightweight HT PEM-stack. Different flow-field geometries were designed and optimized regarding pressure drop and performance, active area of the cell geometry was 27,6 cm^2. During the project a concept for HT PEM suitable gaskets was developed based on injection moulded FKM materials. Finally the stack was coupled to a methanol reformer and both integrated into system environment. In co-operation with project partners a system control concept was developed and integrated into the test stand control system. Laboratory equipment was replaced by low cost peripheral components stepwise and automated operation of the system was established. A coupled reformer HT PEM stack system could thereby be demonstrated.

The main new approach for the stack development was using single peace bipolar plates with external cooling fins. Instead of the classical approach of two bipolar half plates integrating cooling structures on the back side of the active area of a fuel cell, the approach utilizes the good thermal conductivity of the bulky graphite compound material (Schunk FU4369). The generated heat is transferred to the cooling fins. By alternating the position of the fins an effective cooling is secured. Simulations using multiphysics software COMSOL [3,4] have first been used to verify the concept which has finally also been approved by real stack and system performance tests. The fin technology was also successfully used for the heating process at stack start-up: exhaust gas and hot air was blown past the stack and the fins resulting in start up times of approx. 15 min for the fuel cell stack.

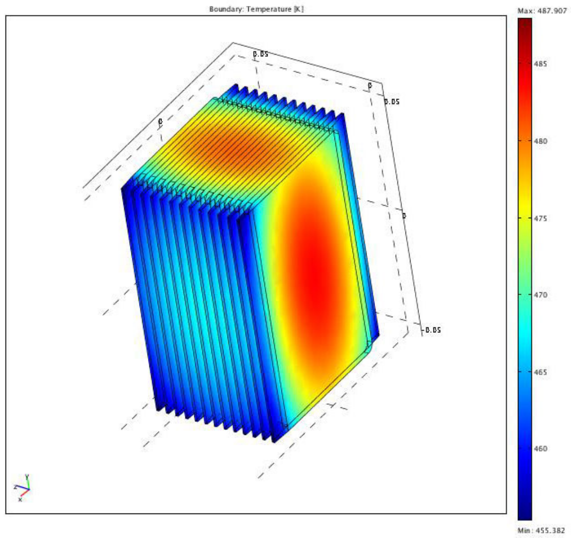

Figure 4: Simulation of the temperature profile using external cooling fins and moderate air flows.

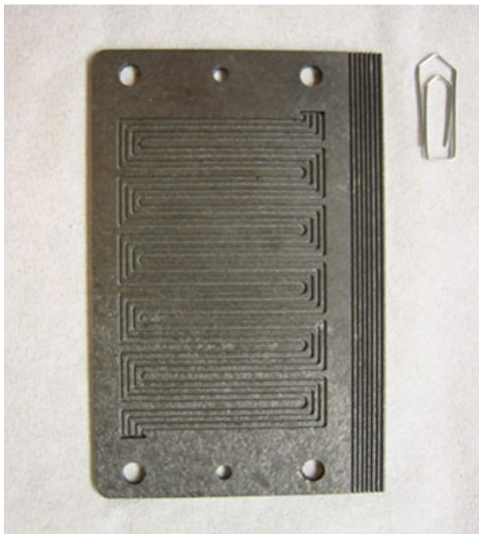

Figure 5: 27,6 cm^2 active area bipolar plate based with cooling fins.

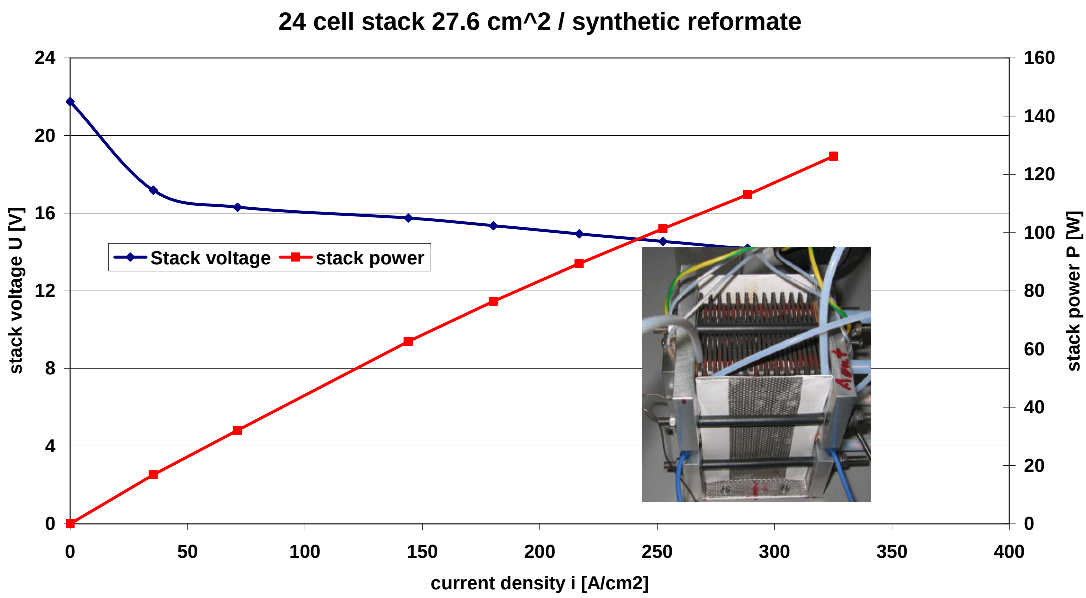

Figure 6: Performance curves of 24 cell stack / 27.6 cm^2.

5 Air Cooling versus Liquid Cooling

As described above air cooling of HT PEM fuel cell stacks is suitable using internal cooling structures or external cooling fins. The external concept was adapted again to the standard 50 cm^2 stack design and HT PEM fuel cell stacks have been constructed for industrial partners based on different commercial MEA. The stack concept thereby has proven to be functional also for power ranges up to at least 500 Watt.

Furthermore special applications demand the liquid cooling for efficient heat integration into the applications. Fuel cell stacks with liquid cooling have been designed and demonstrated with additional inserted cooling plates [5]. As it is necessary to keep cooling media suitable for operation at 160 °C (e.g. thermo oil) strictly away from the MEA an approach based on laser sintered metallic heat exchanger plates was chosen. By laser sintering three dimensional components can be produced integrating cooling channels; every fifth bipolar plate one cooling plate has to be integrated additionally into the stack. The concept has been proven to be suitable for heat integration topics regarding HT PEM fuel cell stacks. Nevertheless the effort for producing the cooling plates and the parallel connection of the plates to the cooling circuit is high. A single port solution transferring the cooling media through the fuel cell stack would be more beneficial. As gaskets do not guarantee a full tightness against cooling oils alternative cooling media have to be identified to realize low cost liquid cooled HT PEM stacks.

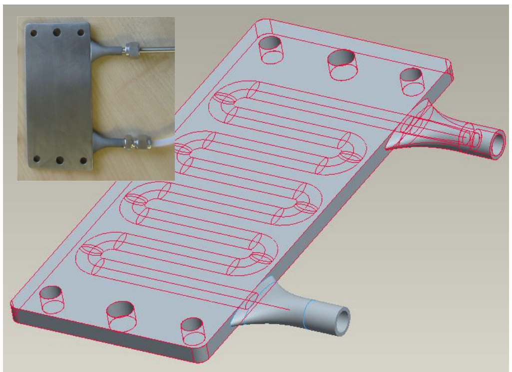

Figure 7: Laser sinter cooling plate (3D design).

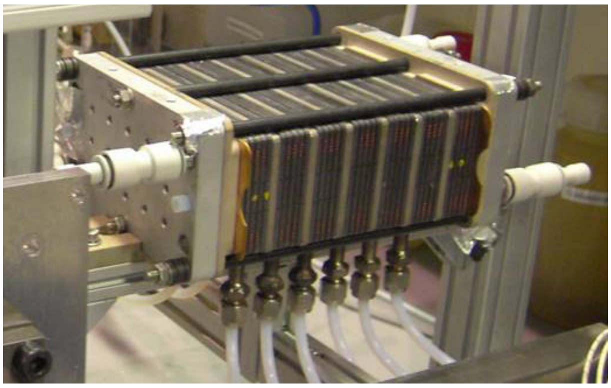

Figure 8: Cooling plates integrated into 50 cm^2 (active) 28 cell fuel cell stack.

6 Conclusion

High temperature Membrane Electrode Assemblies (MEA) do have high benefit for fuel cell applications. Systems either powered by pure hydrogen or by hydrocarbons via reforming processes do run more stable operated at higher temperatures. But the integration of the MEA in fuel cell stacks demands high efforts regarding materials to be used for gaskets, bipolar plates and most other stack and system components. As the operating temperature is high air cooling is suitable even at extreme outside temperatures but increases the effort for start-up-heat integration. Liquid cooling is still a challenging topic as no contact between cooling media and MEA is acceptable.

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