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Validation of a HTPEMFC Stack for CHP Applications

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Abstract

Fuel cell systems are very attractive for stationary co-generation applications as they can produce heat and electricity efficiently in a decentralized and environmentally friendly manner. PEMFC stacks operating at temperatures above 120 °C, specifically in the range of 140-180 °C, are ideal for co-generation purposes.

In this study, preliminary results from a HTPEMFC stack designed for CHP applications is presented and discussed. A short, five-cell, HT-PEMFC stack was assembled with Celtec–P-2100 MEAs and validated in terms of electrical performance. The stack was operated with hydrogen and air at 160 °C and the utilization curves for anode and cathode were recorded for a wide range of gas utilization at a current density of 0.52 A/cm^2. The current voltage characteristic was measured at optimal utilization values at 160 °C. A 1 kW stack is assembled and is currently being validated for its performance under various operating conditions for use in CHP applications.

1 Introduction

A domestic combined heat and power (CHP) system, which is a replacement for conventional heating boilers, providing both heat and power is attracting considerable commercial interest. Among the competing technologies, fuel cells offer significant advantages and in fact fuel cell technology is ideal for CHP generation as it offers high fuel efficiency together with very low environmental impact [1, 2]. Fuel cells in the range of 3 - 5 kW are appropriate for residential applications as it will be sufficient to cater for all the energy needs of a family. Among fuel cells, PEMFC, SOFC, AFC and PAFC have been regarded as potential candidates for CHP applications with PEMFC and SOFC at the forefront [2]. Recent developments in PEMFC technology, the HTPEMFC (operating above 120 °C) has increased the potential of this technology for CHP applications.

Development of HTPEMFC based CHP systems is part of the HySA Programme, a national hydrogen and fuel cell technology strategy in South Africa. In this paper, the work carried out by one of the three competence centres, HySA Systems, on the development of HTPEMFC stacks for CHP systems is presented. A five-cell short stack and a 1 kW stack was assembled and tested for gas utilization and performance. Currently experiments are underway to evaluate the performance in terms of electrical, thermal and combined efficiencies. Preliminary results on the gas utilization and performance of the stack is presented and discussed.

2 Experimental

The experimental part of the work consists of two stages, namely the HT PEM fuel cell stack assembly and stack testing.

2.1 Stack assembly

In the construction of the HTPEMFC stack, the Celtec –P-2100 MEAs delivered by BASF were used. The thickness of the MEA was 884 µm and the active area of electrodes was 96.04 cm^2. The graphite bipolar plates with serpentine flow patterns were used to supply reactant gases to the electrodes. Silver coated current collectors were used to minimize contact resistance bipolar plates. An oil based external cooling/heating system was applied to avoid possible leaks during internal cooling which might cause MEA damage. The four pipes mounted on two sides of the stack allowed appropriate heating and cooling, ensuring a homogeneous temperature distribution along the bipolar plates. More detailed description of the external cooling system used is available elsewhere [3]. A picture showing the stack installed on the test bench is shown in Fig. 1.

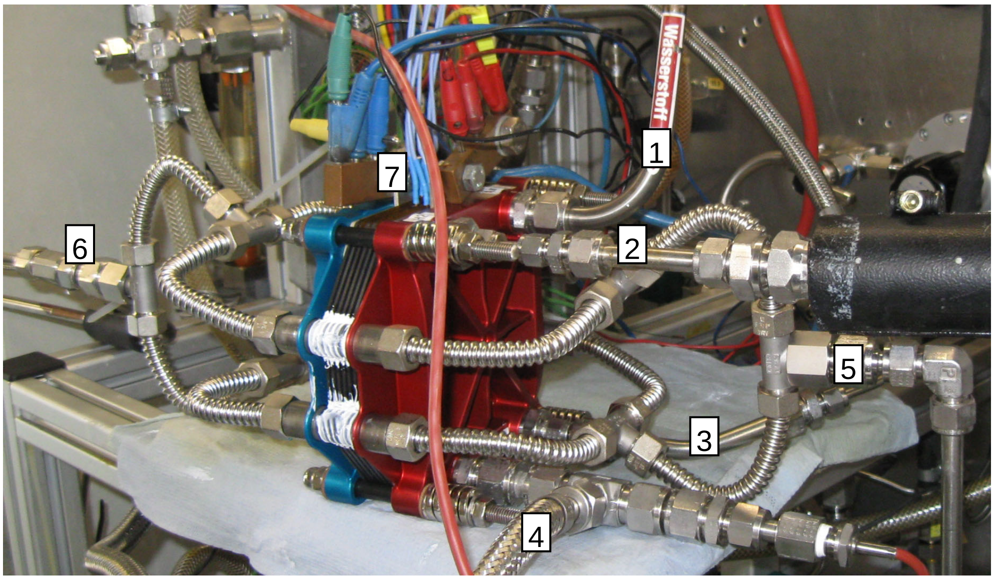

Figure 1: The view of 5-cell HT-PEMFC installed on the test stand. 1-Anode inlet, 2-Cathode inlet, 3-Anode exhaust, 4-Cathode exhaust, 5-Cooling/heating system inlet, 6-Cooling/heating system outlet, 7-Electrical connections.

2.2 Testing station

The performance tests of the stack were performed with the aid of testing station developed and available at ZSW. The testing station allowed control of all parameters, having influence on performance of the stack. More detailed description of the test bench is available elsewhere [4].

In addition to the standard test bench layout the high temperature circulator was used for the stack temperature control. The thermal oil was used in the high temperature system to heat up the stack to operation temperature at the start up and maintain proper temperature during stack operation. Moreover, data were recorded with the aid of test stand built in data logging system and Yokogawa Data Acquisition Station. The latter was used to record single cell voltage and air outlet temperature.

2.3 Stack testing

The stack was evaluated in a test stand which allowed precise control of all the parameters expected to influence its performance. A detailed description of the test stand can be found elsewhere [4]. An AC Milliohmmeter was used to measure high frequency resistance at a frequency of 1 kHz which corresponds to the stack resistance closely related to water management and cell construction [5]. The stack was tested using pure hydrogen as a fuel that was supplied to the anode and air that was supplied to the cathode. Non-humidified gases at ambient pressure were supplied to both electrodes. Only air was preheated up to 100 °C before entering the stack. The nominal operation temperature of the stack was set to 160 °C. The utilization curves were recorded for various cathode and anode utilization levels. The cathode utilization curve was measured at cathode utilization level from 50% to 85% while anode utilization curve was recorded from 80% to 100% utilization range. Cathode utilization was changed at 5% steps while the anode was initially changed at 5% steps and 2% steps for utilization levels higher than 90%. The polarization curve was then recorded at the nominal temperature and at 80% and 50% utilization level for anode and cathode respectively. A stabilization time of five minutes was applied for each utilization point for cathode utilization curve measurements and six minutes stabilization time for anode utilization curve measurements.

3 Results and Discussion

In this section of the paper preliminary testing results performed on a 5 cell HT-PEMFC are presented and discussed.

3.1 Gas utilization curves

The utilization curves of the stack were measured for the anode and cathode separately at 0.52 A/cm^2. When the cathode utilization curve was measured, the anode utilization was kept constant at 80%. When the anode utilization curve was measured, the cathode utilization level was kept constant at 50%. The single cell voltages for each cell, as well as high frequency resistance of the stack, were recorded during measurements. The average voltage value and resistances are shown in the Fig. 2 (a) and (b), for cathode and anode respectively.

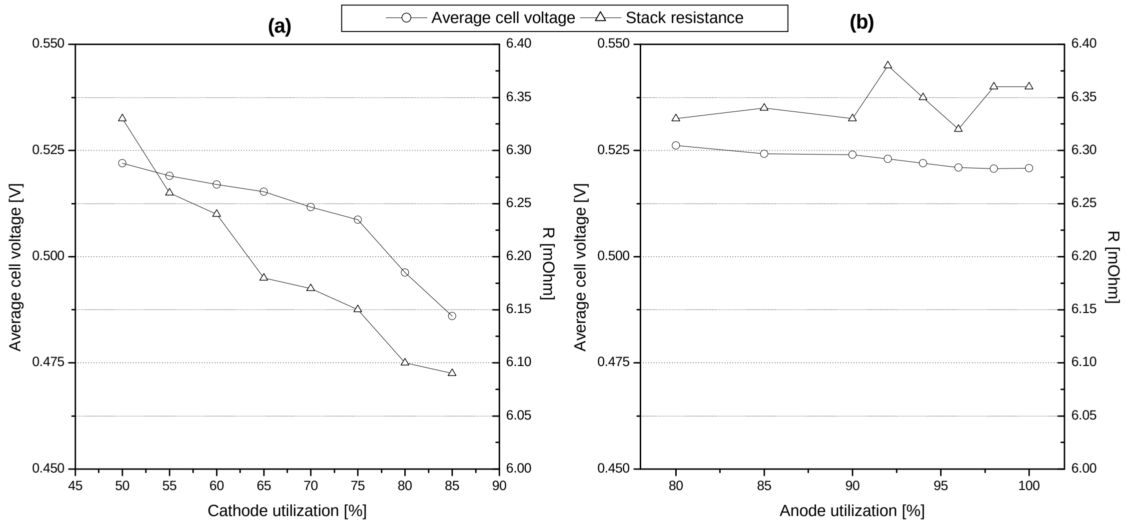

Figure 2: The cathode (a) and anode (b) utilization curves.

The initial value for high frequency resistance in both cases was about 6.33 Ohms. In Fig.2 (a), it is seen that the average voltage starts to drop for each point of utilization for utilizations from 50% to 75% and the slope is steeper for utilizations above 75%. This allows us to conclude that for cathode utilization higher than 75%, mass transport effect starts to have a significant influence on the stack or average cell voltage. Further, the reason that no increase in high frequency resistance was noted during the above measurements shows that the drop in the voltage with increasing utilization value is due to mass transport limitations. For the following measurements the cathode utilization value was set to at 50%. The change of anode utilization (Fig. 2 (b)) on average cell voltage is not very influential on electrical parameters although the average cell voltage decreases with increasing utilization level from 80% to 100%. The changes in high frequency resistance are negligible. For the following measurements the value of 80% anode utilization was used.

3.2 Polarization curve

The polarization curve of the stack was measured for the average single cell voltage ranging from 700 mV to 500 mV. The OCV was measured only for a few seconds to avoid degradation mechanisms to occur. A constant current was drawn during the measurements. For high currents, from 10 A to 60 A, a 5 A step with 2 minutes stabilization time was applied and for low currents, below 10 A, 2 A steps with the same stabilization time were used. The stack temperature during measurement was set to 160 °C. The anode and cathode utilization was 80% and 50% respectively. The minimum flow rates of the gases were kept at a value that is required by the stack to generate 0.2 Acm^{-2}. In parallel to current and voltage measurements the high frequency resistance of the stack was measured and data is displayed in the Fig.3.

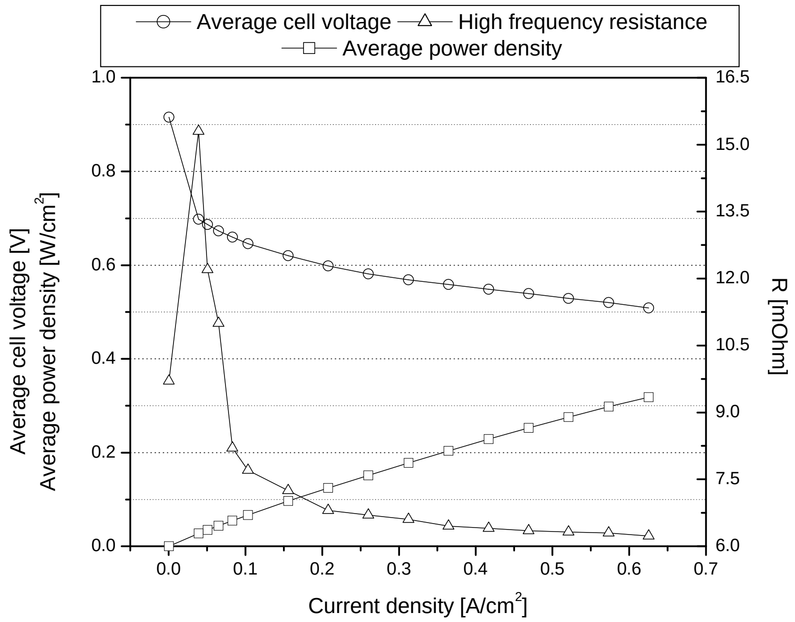

Figure 3: The polarisation curve of the 5 cell HT-PEM stack with active area of 96 cm².

A stable stack performance was recorded during the measurements of the polarization curve. It was possible to generate more than 0.3 W/cm^2 at current densities higher than 0.6 A/cm^2 and average cell voltage of 0.5 V. A total stack power of 150 W was generated at 0.625 A/cm^2 and 0.5 V average cell voltage. A sharp increase in the high frequency resistance was noted when the load was applied to the stack i.e., when the voltage was changed from OCV to 700 mV, most likely due to the internal membrane resistance expected at those voltages. The high frequency resistance decreased with increasing current density from the initial value of 15 Ohms (at 700 mV) to 6.33 Ohms (at 500 mV).

A 1 kW stack has been built using similar components and stack design, and performance of the stack is currently being evaluated with respect to electrical and thermal output.

4 Conclusion

A HT-PEMFC short stack was assembled based on BASF Celtec – P-2100 MEAs. In the construction and evaluation of the stack, an external thermal oil based cooling system was applied. Experiments showed that the optimal anode and cathode utilization of gases was 80% and 50% respectively. The electrical power density generated by the stack reached 0.31 W/cm^2, and an overall power output of 150 W was measured at 0.625 A/cm^2 and 0.5 V of average cell voltage. Further test on extended version, up to 1 kW power fuel cell stack construction is underway with the aim to validate the stack for CHP applications in terms of both thermal and electrical and combined efficiency.

Acknowledgements

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