Analysing the effects of Oxygen diffusion on a HT PEMFC Stack Performance

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1. Introduction

- High temperature proton exchange membrane fuel cells (HT PEMFCs) which can be operated in the temperature range between 150 °C and 200 °C have drawn significant attention during the current decade. This is due to the fact that HT PEMFCs can be easily coupled to reformers which produce hydrogen (H_2) rich gases as opposed to the LT PEMFCs which are operated upto about 80 °C. HT PEMFCs can tolerate carbon monoxide (CO) concentrations in the % range and there exists a possibility to recycle the heat generated in the fuel cell stack to the other system components such as metal hydrides, evaporators and the like. Further, they can be operated with low or almost no fuel gas humidification, thus offering a possibility to reduce the peripheral parts. PEMFC stack development is one of the thrust areas at the Zentrum für Brennstoffzellen Technik gGmbH (ZBT) along with the University of Duisburg-Essen, Germany during the past few years. Optimizing stack design parameters is pivotal to a satisfactory long term performance.
- ***The primary aim of the current work is to have a closer look at the HT PEMFC stack performance under different conditions of Oxygen diffusion into reactions sites. Poor oxygen dissolution and diffusion and its subsequent impact on poor cathode kinetics has to be addressed to achieve satisfactory performance.***
- ***EIS (Electrochemical Impedance Spectroscopy) was employed to understand HT PEMFC stack performance under different conditions of temperature, humidity and under different fuel compositions. By looking at the charge transfer resistance, it was observed that there exist enormous possibilities to enhance the stack performance, by carefully engineering Oxygen diffusion.***

2. Measured performance curves of a HT PEMFC at 150°C – 180°C

- Measured current voltage curves of a HT PEMFC operating at 150 °C – 180 °C are depicted in Fig.1.

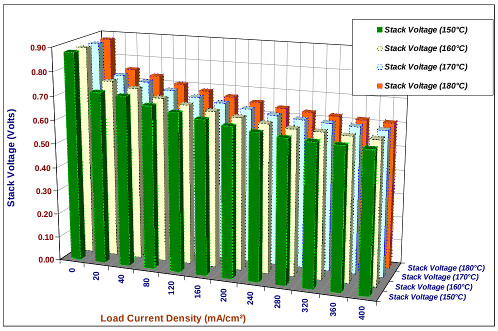

Fig.1: Measured polarisation curves of a single HT PEMFC. Fuel feed: H_2/Air : 1.2/2.5. Fuel hydrogen was fed at 22 °C with 10% r.h. and air was supplied at 22 °C with 35% r.h. at ambient pressure. Commercially available MEA and bipolar plates manufactured by ZBT gGmbH were used in this cell assembly.

3. EIS test results of a single cell operated at 170°C

- Figure 2 depicts the analysis made using electrochemical impedance spectroscopy. A single cell was tested at 170 °C, first with Hydrogen/Air and later with Hydrogen/Oxygen. An analysis was made using simplified equivalent circuit models to assertain the value of Rchem (chemical resistance, which represents oxygen diffusion or the non-charge transfer process. A qualitative view of Rchem which represents oxygen diffusion into porous reaction sites is portrayed in Fig.2. The green arrows represent the curves, when the cell was operated with Hydrogen/Air and the red arrows represent their respective curves when the cell was operated with Hydrogen/Oxygen.

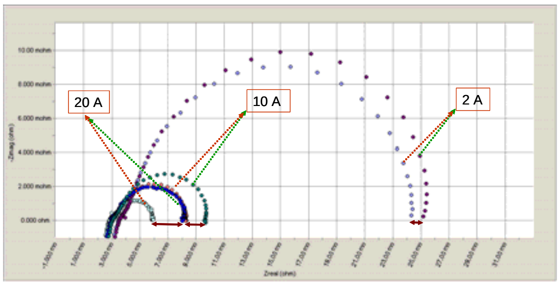

Fig 2: Nyquist curves of a single HT PEMFC, operated at 170°C, with H2/Air (green arrwos) and H_2/Oxygen (red arrows) at 2 amps, 10 amps and 20 amps. The active area of the cell is : ~ 50 cm². A commerically available MEA with ZBT's PPS based bipolar plates were used in the cell. H2/Air stoichs: 1.2/2.0. EIS: Galvanostatic mode, with 100 mA signal from 100 mHz to 100 kHz scanning frequencies.

4. Equivalent Circuit Models used to analyse the EIS test results

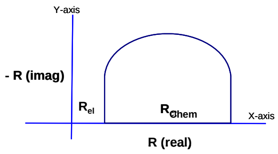

Fig 3 : Nyquist plots obtained by EIS spectra were analysed using the simplified equivalent circuit model shown in Fig 3.

5. Performance characteristics of a 5 Cell Stack at 170°C

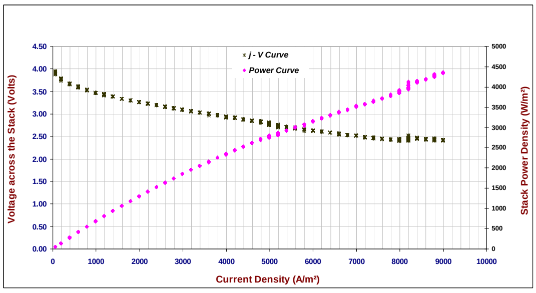

Fig 5: Typical performance curves of a 5 Cell stack, operated at 170°C, with H_2/Air: 1.2/2.0 stoichiometries.

6. EIS test results: 5 Cell Stack operated at 170°C (comparing the effects of Oxygen and Air)

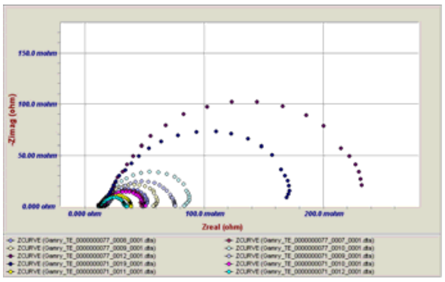

Fig 5: Typical performance curves of a 5 Cell stack, operated at 170°C, with H_2/Air: 1.2/2.0 stoichiometries. 0077 series represent Hydrogen/Air and 0071 series represent Hydrogen/Oxygen. EIS from Gamry Instruments was used for this study. Scanning frequency: 100 mHz to 100 kHz. EIS was operated in galvanostatic mode with a probing signal of ~100 mA.

H_2/Air				
Series No.	Load (I) amps	Cell (V)	Rel (mohm)	Rchem (ohm-cm²)
0077_13	0	4.19	17.517	41.62415
0077_12	1	3.939	14.388	10.8961
0077_10	5	3.3	12.895	3.50845
0077_09	10	3.02	12.537	2.2395
0077_08	15	2.8144	11.833	1.83925
0077_07	20	2.445	11.111	1.8323

Table 1

H_2/Oxygen				
Series No.	Load (I) amps	Cell (V)	Rel (mohm)	Rchem (ohm-cm²)
0071_07	0	4.32	14.594	10.0203
0071_19	1	4.1	13.713	7.7743
0071_09	5	3.6	16.844	2.9414
0071_10	10	3.37	14.75	1.79555
0071_11	15	3.2	12.691	1.27765
0071_12	20	3	12.367	1.1303

Table 2

7. Analysis of EIS results: A closer look at R_{chem}

- As explained earlier, the non-charge transfer resistance, R_{chem} could be attributed to the resistance to oxygen diffusion. After fitting the EIS test results into the equivalent circuits shown in Fig.3, the non-charge transfer resistance values were evaluated and are presented in Fig.6 as a comparison. It can be seen that the reciprocal of R_{chem} increases (when the stack was operated with H_2/O_2) gradually as the load current increases, whereas the same shows a different trend when operated with Air.

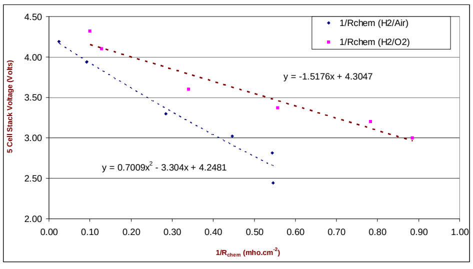

Fig 6: Reciprocal of Rchem is showing a steady trend, when the 5 cell stack was operated with Oxygen as the fuel, whereas the same exhibits a different trend when operated with Air. These results are based on the nyquist plots shown in Fig.5

8. Conclusions

- Oxygen diffusion (caused due to dissolution and diffusion) into the reaction sites should be improved to achieve satisfactory cell performance. Flow field design, stack operating regimes, should be carefully designed to achieve better oxygen diffusion.
- It has also been observed that the oxygen diffusion into the reaction sites is a function of stack operating temperature.
- Local electrolyte composition and acid concentration, electrode thickness will have their significant impact on the oxygen diffusion properties of a HT PEMFC – Membrane Electrode Assemblies.

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