Behavioural Patterns of LT PEMFC and HT PEMFC over 1200 hours of operation

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1. Introduction

- Studies related to long term performance of PEMFCs are of paramount importance to make the fuel cell based systems commercially viable. Here, performance of a LT PEMFC (containing a PFSA based membrane) and a HT PEMFC (containing a PBI-H_3PO_4 based membrane), both containing commercially available MEAs are presented.
- Although, operating PEMFCs with low fuel humidification is desired to reduce peripheral losses in fuel cell based systems, their long term performance should not be compromised with. LT PEMFC single cell and a HT PEMFC single cell, both containing ~ 50 cm² of active area were fed with H_2 and air without any active humidification. The fuel cell voltage degradation curves, bipolar plate properties and fuel cell exhaust water were examined to observe degradation patterns.

2. Cell architecture

The LT PEMFC and the HT PEMFC cells employed in the current study have the following cell architecture

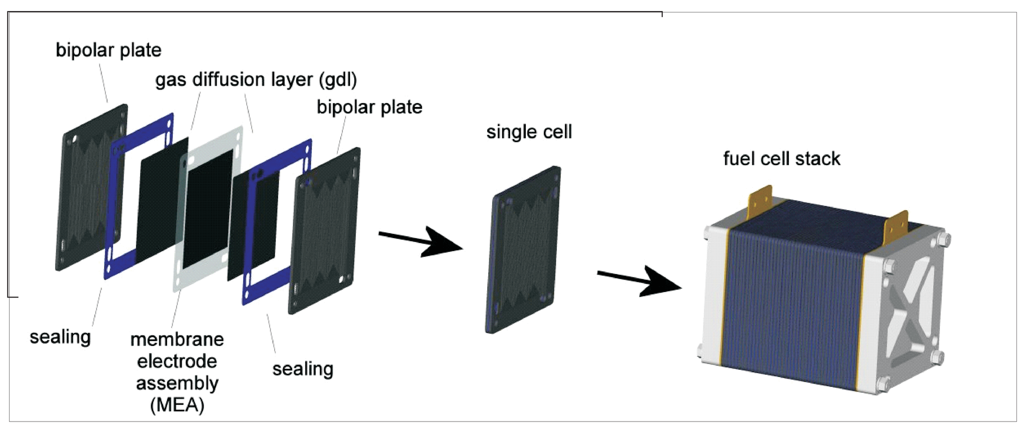

Fig.1

3. Experimental Part I: LT PEMFC Performance (Cell Temp: 40°C)

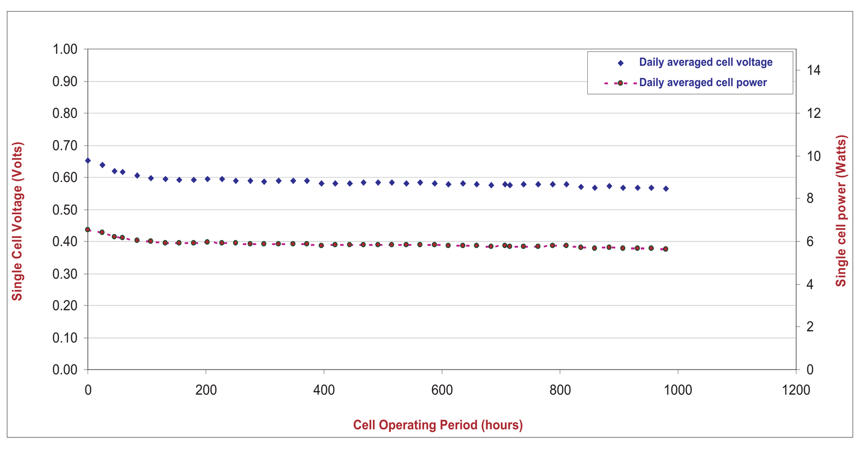

Fig.2 Voltage and power degradation curves at a load current of 200 mA.cm^{-2} Vs. Cell operating period. Cell active area : 50 cm^2; Fuel feed : H2/Air: 1.2/2.0 {no active humidification}; Bipolar plates used: Our own graphite based 3 mm thick plates containing a 6 channel serpentine flow field. MEA: 425 microns. Catalyst loading: 0.4 mg.cm^{-2}

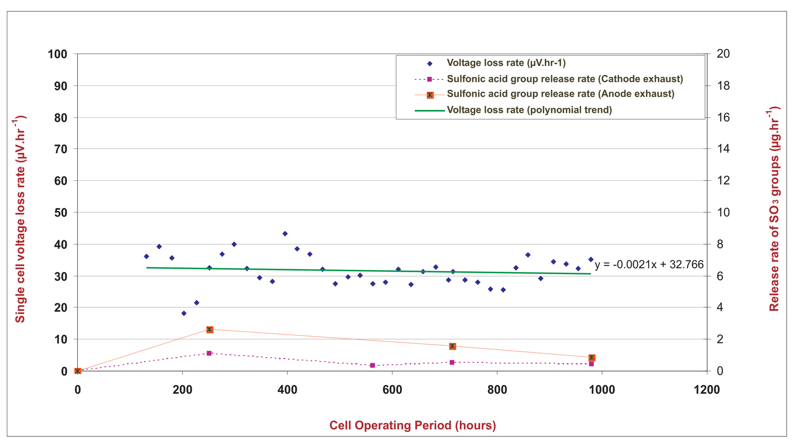

Fig.3 After a100 hour cell conditioning period, the voltage degradation rate at 200 mA.cm^{-2} Vs operating period. The voltage degradation had shown a polynomial fall at an average rate of ~33 μV.hr^{-1} as shown here. The membrane was self-humidified. However, the anode exhaust water (orange squares) had shown that rate of release of SO_3 groups was much higher when compared to the cathode exhaust (brown squares) water: Elemental analysis was made using ICP-OES .

4. Conclusions for Experimental Part I

- It is possible for the LT PEMFC to operate at 0.2 A.cm^{-2} for about 1000 hours with self-humidification with a modest voltage degradation rate.
- There was virtually no degradation on the part of the graphite-compound based bipolar plates employed in this study.
- But a higher release rate of sulfonic acid groups from the anode side was observed compared to the cathode side exhaust. The amount of carbon present in the anodic exhaust was also concurrently higher, which might be due the water concentration gradient formed across the cross section of the MEA (from cathode catalyst layer to anode catalyst layer) in the absense of any active humidification.

5. Experimental Part II: HT PEMFC Performance (Cell Temp: 160°C)

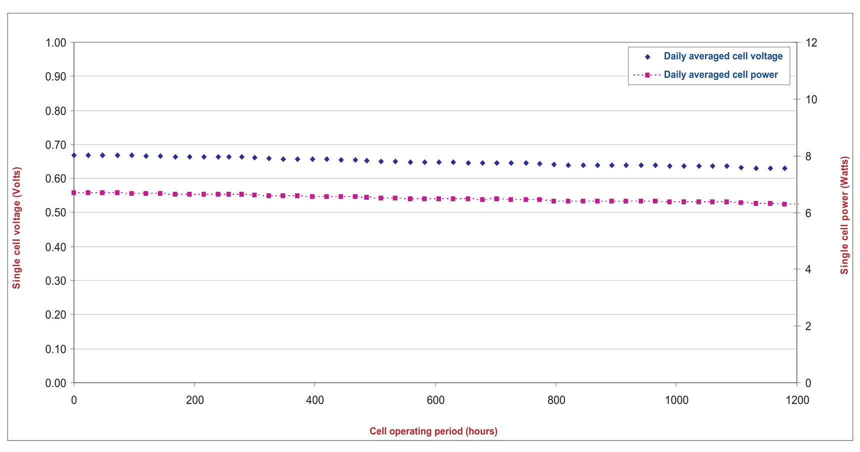

Fig.4 Voltage and power degradation curves of a HT PEMFC at a load current of 200 mA.cm^{-2} Vs. Cell operating period. Cell active area : ~50 cm^2; Fuel feed : H_2/Air: 1.35/2.5 {no active humidification}; Bipolar plates used: Our own graphite based 3 mm thick plates containing a 6 channel serpentine flow field. MEA: ~900 microns. Catalyst loading: 1.0 mg.cm^{-2} Cell temp: 160°C

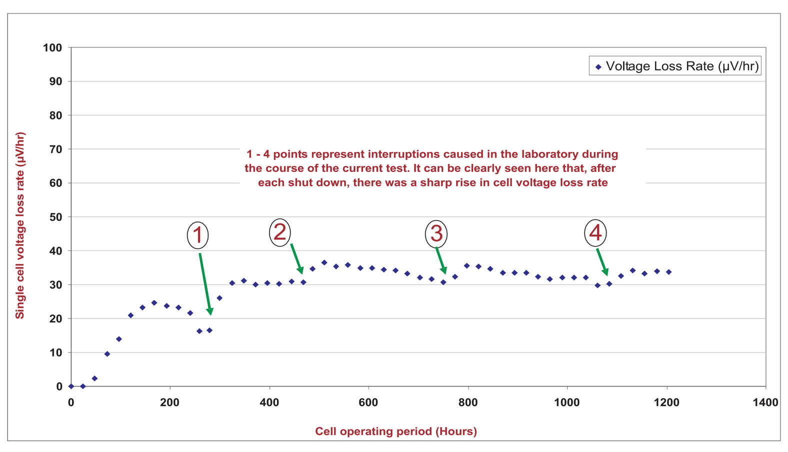

Fig.5 First 100 hour operation is the cell conditioning period. 1-4 points denote the interruptions to the life test. It can be seen that immediately after each shut down, there was a rise in cell voltage degradation and after sometime, the voltage degradation was almost flat. The current drawn from the cell was 200 mA.cm^{-2}.

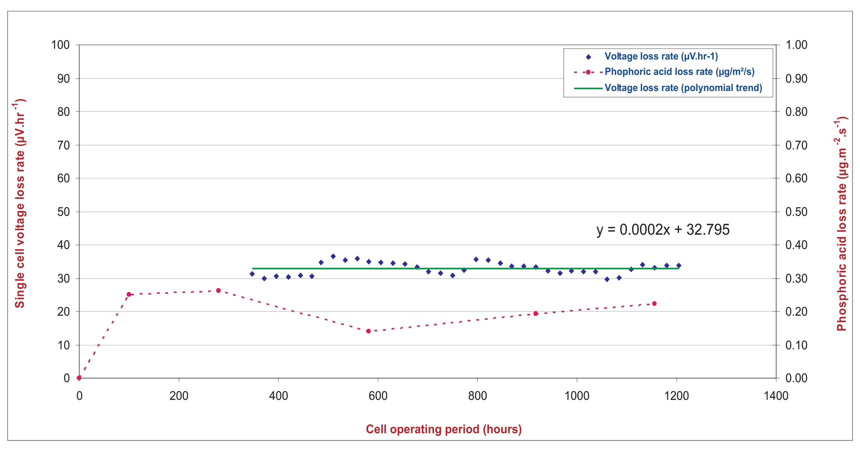

Fig.6 This figure is a sequel to fig.5. It can be seen here that the voltage degradation rate in the HT PEMFC was almost flat at around ~33 μV.hr^{-1} from around 300 to 1200 hours of cell operation. The degradation rate was exacerbated by the start stop phases encountered during cell operation as shown in fig.4. It can also be seen that the phosphoric acid (electrolyte) lost from the cathode side exhaust water (orange circles) also had exhibited a similar trend.

Exhaust water analysis :

The HT PEMFC fuel cell exhaust water was analysed employing ICP-MS and ICP-OES for elements such as phosphor and the amount of phosphate (PO_4) and phosphoric acid (H_3PO_4) per litre of water collected was calculated employing the correpsonding molecular weight.

6. Conclusions for Experimental Part II

- Performance curves show that the HT PEMFCs can be operated with virtually no fuel gas humidification. However, they require special protocols during start stop cycling to keep the degradation low.
- The electrolyte or phosphoric acid (H_3PO_4) management is crucial for the satisfactory operation of a HT PEMFC. Whereas water management is crucial for LT PEMFCs.
- When operated with a load current of 200 mA.cm^{-2}, the voltage degradation rate was similiar to that of a comparable LT PEMFC operated with fuel gases which were fed without any active humidification.
- Materials employed in a HT PEMFC have to be carefully chosen to withstand a chemically challenging environment.

7. Bipolar Plates for HT PEMFCs

- Material needs of a HT PEMFC stacks are typically challenging considering even the state-of-the art material technologies. ZBT gGmbH, together with the University of Duisburg-Essen in Germany have been researching materials for use in bipolar plates suited for HT PEMFCs. We had produced compression moulded bipolar plates successfully till date and the injection moulding of bipolar plates for HT PEMFCs is actively pursued. A few details of these HT-BPPs are presented here.

A compression moulded bipolar plate specimen with a 6 channel serpentine flow field being machined on it is shown in fig.7

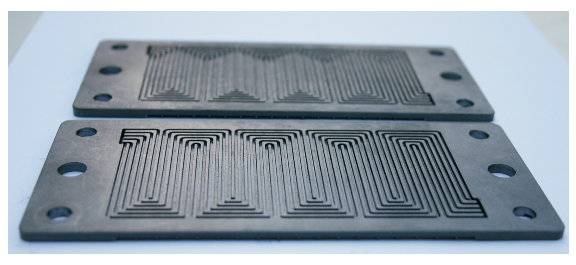

Fig.7

8. Analysis of Bipolar Plate material

- Graphite compound based bipolar plates, with Poly (Phenylene Sulfide) or PPS being used as a binder have been compression moulded and were examined for their behaviour. Fig.8 shows a raw HT-BPP. Accelerated ageing test was performed on this bipolar plate in an enclosure containing 85% phosphoric acid at 160°C with oxygen being supplied to it. The solution was constantly stirred during the course of the test. Fig.9 depicts the SEM image of the bipolar plate after the accelerated ageing test. It can be seen that deposits of phosphoric acid are present on the BPP material. No material degradation was observed.

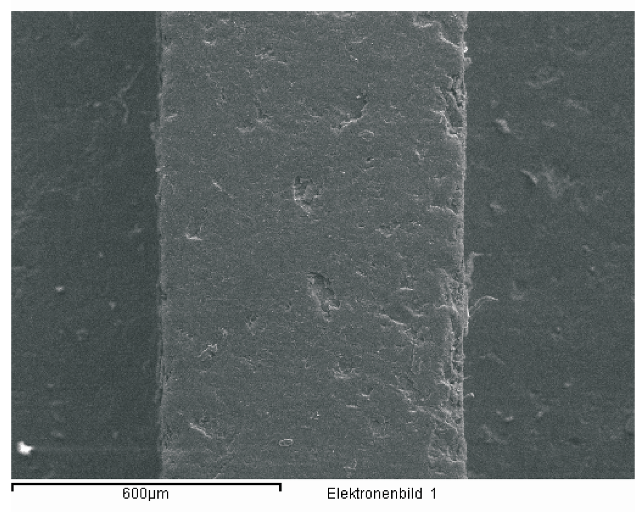

Fig.8 SEM image of the HT BPP before the accelerated ageing test

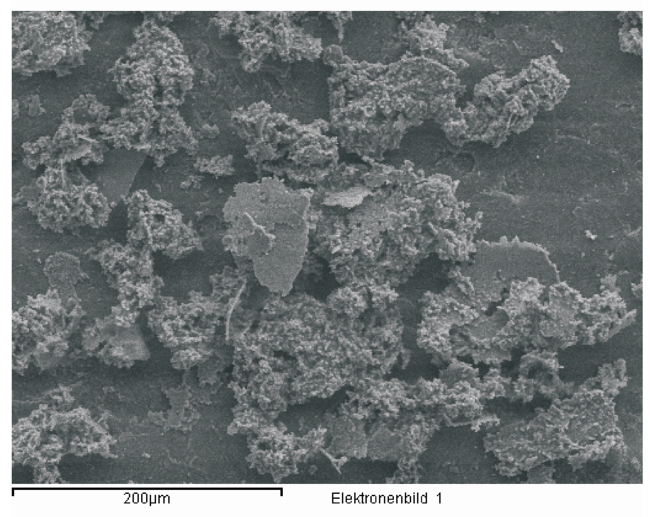

Fig.9 SEM image of the HT BPP after the accelerated ageing test

9. In-Cell testing of the Bipolar Plate material

- The HT BPPs were also tested in an operating HT PEMFC. This cell was run at 160°C for about 3000 hours. The fuel gases supplied were hydrogen and air. The current drawn was 200 mA.cm^{-2}. After the life test was completed, The bipolar plates were analysed using SEM microscopy. The results show that these bipolar plates were stable in the HT PEM cell environment. Fig.10 shows the centre part of the bipolar plate where the graphite grains are enlarged. Fig.11 shows the surface of the bipolar plate close to the cathode outlet where large deposits of phosphoric acid are clearly seen. The bipolar plates had proven to be stable.

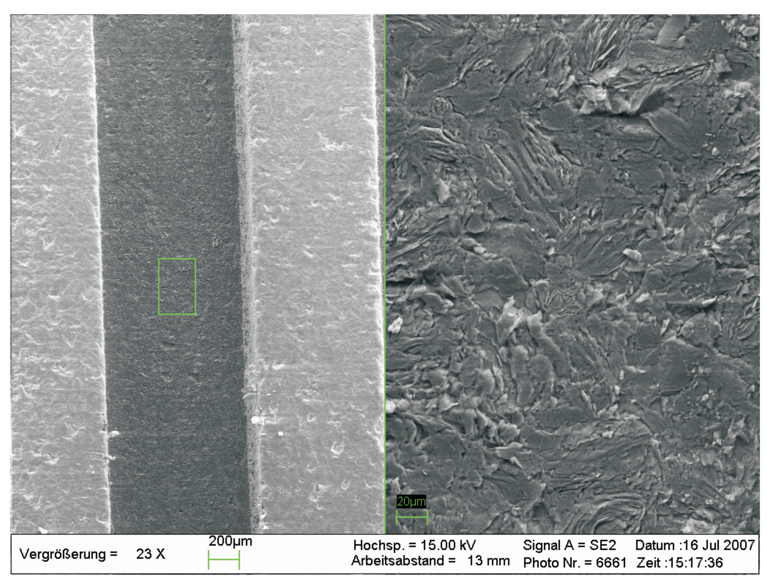

Fig.10 SEM image of the HT BPP after the in-cell testing (at centre of the cathode side channel)

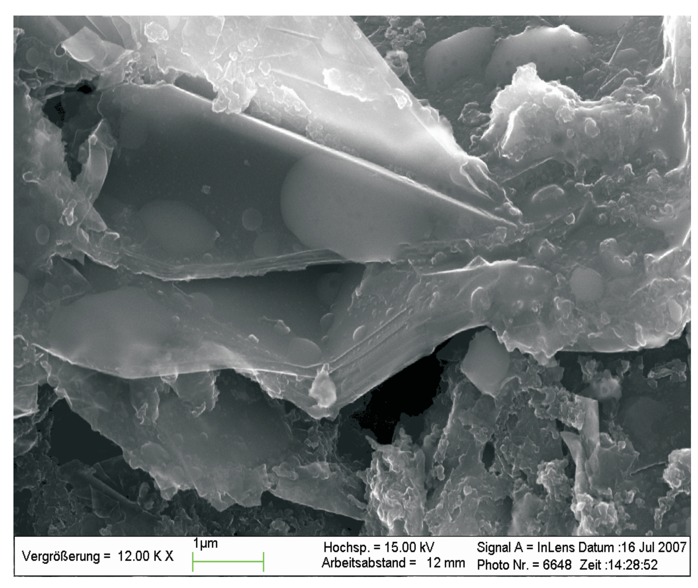

Fig.11 SEM image of the HT BPP after the in-cell testing (close to the cathode exit)

10. BPP material properties

The PPS based HT BPPs developed by our group have the following characteristics:

Electrical Characteristics (with an applied pressure of 2.5 Mpa)		Mechanical Characteristics	
Volume conductivity (S/cm) (through plane):	38	E-Modulus (Mpa) (DIN EN ISO 178):	127.6
Bulk conductivity (S/cm) (through plane):	139	Flexural strength (Mpa) (DIN EN ISO 178):	55.8
Contact resistivity (ohm-cm²) to GDL :	2.59	Density (g/cm³) (DIN 51913):	1.97

11. Conclusions

- HT PEMFCs seem to hold a great promise.
- The HT BPPs have proven to be stable during the in-cell testing & accelerated ageing test.
- Affordable HT BPP manufacturing needs to be addressed.
- Analysis of the electrical, physical, mechanical and chemical properties of the PPS based HT bipolar plates developed at ZBT gGmbH, together with the University of Duisburg-Essen, Germany appear to be promising.
- Further tests are necessary to estimate the projected life of the bipolar plate materials.
- Further research is under way to injection mould the HT BPPs.

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