Electrochemical Energy Conversion in Direct Methanol Fuel Cells: The effects of flow fields

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1 Introduction

Direct methanol fuel cells (DMFC´s) are promising candidates as portable power sources due to their lower weight, volume and high-energy density. They can potentially provide an energy content that exceeds current battery technology, with the possibility of instantaneous recharge. However, DMFC´s have several serious drawbacks such as slow methanol oxidation kinetics, poisoning by CO of the catalyst surface, the high methanol crossover through the polymer membrane, the high costs of the Nafion membrane and catalyst [1-3]. The flowing streams of fuel and oxidizer need to be evenly distributed over the entire surface of the catalyst layer in order to achieve a good performance together with an efficient removal of reaction products. This is achieved through the optimal design of the flow field [4-5].
In this work the effect of flow field design on cell performance is studied using polarization curves as a base technique.

2 Experimental

A fuel cell test station manufactured by Fideris Inc. was used, which includes a methanol and oxidant gas handling system and an electronic load, providing control over anode and cathode flow rates, cell operating temperature, oxygen/air pressure and methanol temperature.

An own built fuel cell was implemented, see figure 1a), using two aluminium end plates, two gold plated copper end connector plates, two graphite collector plates with different machined flow fields, see figure 1b-e): parallel (P), single serpentine (SS), parallel serpentine (PS) and interdigitated plates (ID), two carbon cloth (type A from E-TEK) as diffusion layers, two catalyst layers (Pt-Ru on the anode side with a loading of 4 mg/cm^2 and Pt-black on the cathode side with a loading of 4 mg/cm^2) and an electrolyte polymer membrane (Nafion 117). The active surface area of the cell is 25 cm^2. The effects of temperature, methanol concentration, feeding flow rates of fuel and flow field design on the cell performance were studied.

Typical cell operating conditions tested covers 0.5-5M methanol concentrations with a feeding flow rate up to 15 mL.min^{-1}; oxygen as a cathode reactant with feeding flow rates from 300 to 2000 mL.min^{-1} and temperatures between 25 and 70ºC.

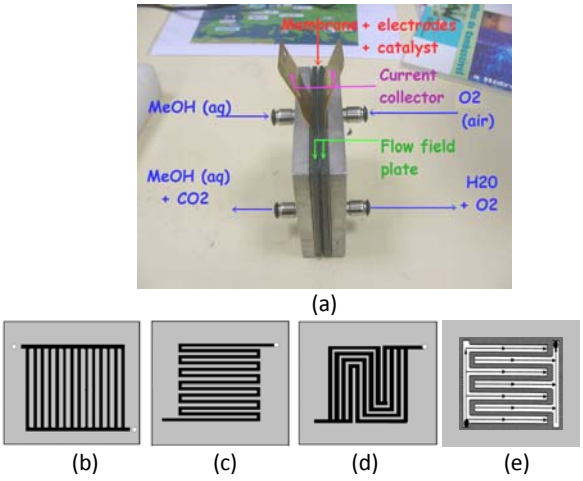

Fig 1. Own built fuel cell (a) and schematic flow field designs used in this work: parallel (b), single serpentine (c), parallel serpentine (d) and interdigitated plates (e).

3 Results

Results showed that the performance of the fuel cell increases with increase in cell temperature due to improvement in methanol oxidation kinetics, cathode kinetics as well as contributions from the ionic conductivity of the Nafion membrane, evident in the polarization curves (see figure 2 for results obtained with SS plates). Temperature has also its drawback effects on cell performance: the rate of methanol crossover increases with temperature, water transfer from anode to cathode through the membrane increases with temperature and the additional water increases the liquid water fraction in both the cathode catalyst and diffusion layers, thus causing an increase in concentration polarization.

Increase in methanol concentration affected the performance of the DMFC, due to crossover. The methanol transferred from anode to cathode is oxidized and causes a mixed potential, which lowers the cathode performance and thus the overall cell voltage output.

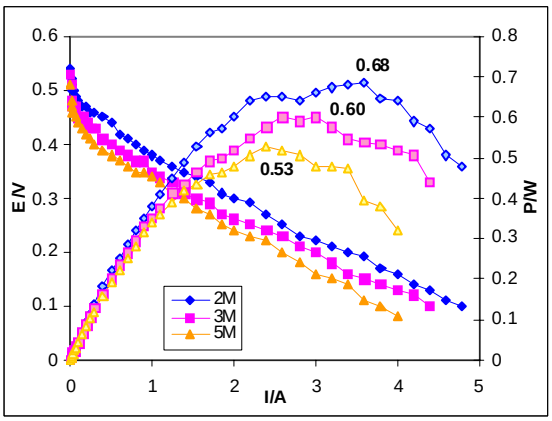

Fig. 2 Polarization curves for own-built DMFC at 60ºC, SS flow field design plates. [CH_3OH]=1M; flow rates: 5 $mLmin^{-1}$ for CH_3OH, 1000 $mLmin^{-1}$ for O_2.

The single serpentine flow field design resulted in overall better cell performance than the parallel serpentine and the parallel flow field design (SS>PS>P). The obtained results point towards an enhancement in the mass transfer of methanol. Another important issue is the eventual blocking of the flow channels, by CO_2, at high current densities. A reduction of the effective contact area between the fuel (methanol) and the gas diffusion layer is expected, as CO_2 gas bubbles accumulate in the channels, bearing implications in the continuous supply of methanol to the catalyst sites through the gas diffusion layer. This is less likely to occur with the serpentine design.

Performance was found to improve further with interdigitated flow fields (ID), which consists of dead end flow channels which are not continuous from inlet manifold to exit, so that the reactant is forced, under pressure, to go through the backing layers. The design provides convection velocities normal to the electrode surface, giving enhanced performance at high current densities as a result of better mass transfer and enhanced water removal from the backing layers. This is evident in figure 3, where the cell power is plotted as a function of methanol concentration for different current demands for a flow rate of 1$mLmin^{-1}$ and 1 $Lmin^{-1}$ for methanol and oxygen respectively and at a cell temperature of 47ºC.

Increasing the methanol feeding flow rate to 12 $mLmin^{-1}$, at which the highest cell power value was obtained for a 1000 $mLmin^{-1}$ O_2 flow rate, it was possible to use lower oxygen flow rate to 300 mLmin-1 and obtained the same results, over 1000 mW as seen in figure 4.

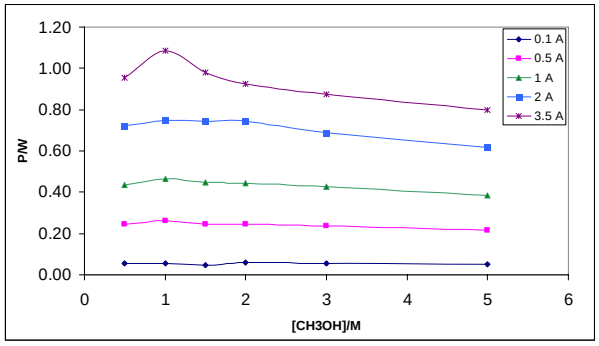

Fig. 3 Cell power as a function of methanol concentration at different loads, for an own built DMFC using interdigitated flow field design. Feeding flow rates: 1 $mLmin^{-1}$ and 1 $Lmin^{-1}$ for methanol and oxygen respectively at 47ºC.

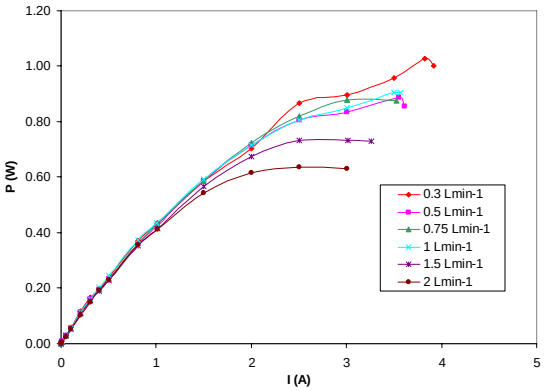

Fig. 4 Polarization curves for own-built DMFC at 47ºC, ID flow field design plates, at different oxygen flow rates. [CH_3OH] and flow rate: 1M; 12 $mLmin^{-1}$.

4 Conclusions

Cathode kinetics indicates much lower methanol crossover and better voltage efficiency for the single serpenttine (SS) design. It is a favorable design for avoiding blocking by CO_2 bubbles accumulation.

Interdigitated flow field design was found the best option (1122 mW) with the advantage of using reduced oxygen flow.

5 Acknowledgements

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6 References

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