Water Transport in PEM Fuel cells

D.S. Falcão[1], [2]C. M. Rangel, C.Pinho[1] and A.M.F.R. Pinto[1*]

[1]Centro de Estudos de Fenómenos de Transporte (CEFT), Faculdade de Engenharia da Universidade do Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal

[2]Instituto Nacional de Engenharia, Tecnologia e Inovação, Portugal

(*) corr. author: apinto@fe.up.pt

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1 Introduction

The potential of fuel cells for clean and efficient energy conversion is generally recognized. Proton-exchange membrane (PEM) Fuel Cells are among the different types of fuel cells one of the most promising. Several coupled fluid flow, heat and mass transport processes occur in a fuel cell in conjunction with the electrochemical reactions. One of the most important operational issues of PEMFC is the water management in the cell.

Water content of the membrane is determined by the balance between water production and three water transport processes: electro-osmotic drag of water (EOD), associated with proton migration through the membrane; back diffusion from the cathode to anode; and diffusion of water to/from the oxidant/fuel gas streams. Understanding the water transport in the PEM [1, 2] is a key issue to avoid cathode flooding and membrane dehydration and can also serve as a guide for materials optimization and development of new MEAs.

To improve the system performance, design optimization and analysis of fuel cell systems are important. Mathematical modelling and simulation are needed as tools for design optimization of fuel cells, stacks and fuel cells power systems. Different models were developed in the last decade to describe several water transport mechanisms through the membrane such as Springer et al. [3] using a diffusion model, Bernardi and Verbrugge [4] considering a hydraulic permeation model and Kulikovsky [5] developing a semi analytical model 1D+1D.

To achieve optimal fuel cell performance, it is critical to have an adequate water balance to ensure that the membrane remains hydrated for sufficient proton conductivity while cathode flooding and anode dehydration are avoided.

In a previous work, Falcão et al [6] developed a semi-analytical one-dimensional model considering the effects of coupled heat and mass transfer, along with the electrochemical reactions occurring in PEMFC. The model was validated with published experimental data.

The influence of the membrane thickness on the water content through the membrane and on the cell performance was simulated using the developed model.

2 Analytical Model

In In the development of the model, the fuel cell is assumed as composed by different layers represented in Figure 1.

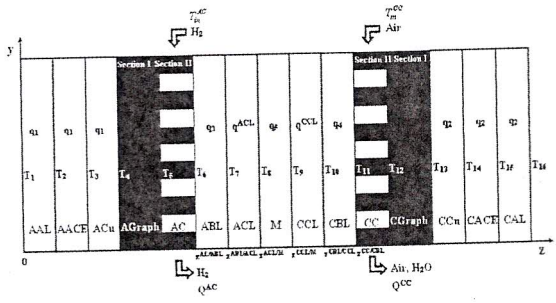

Figure 1. Schematic representation of a PEM fuel cell.

The cell consists in an aluminum plate (AL), an acetate sheet (ACE), a cupper current collector (Cu) and a flow channel (C), at the anode and cathode sides and a MEA. The MEA includes the backing layers (BL), the catalytic layers (CL) and the membrane (M). The acetate sheet isolates the end plate (aluminum), from the current collector plate.

The model developed relies on the following assumptions:

- mass and heat transport are steady-state and one-dimensional (direction z in Figure 1);
- heat and mass transport through the gas diffusion and catalyst layers assumed to be a diffusion-predominated process (negligible convection effects);
- effective Fick models for the mass transport in the diffusion layers and membrane are considered;
- the thermal energy model is based on the differential thermal energy conservation equation (Fourier's law);
- the thermal conductivity for all the materials is assumed to be constant;
- heat generation or consumption is considered in the catalyst layers;
- water transport through the membrane assumed to be a combined effect of diffusion and electro-osmotic drag;
- membrane proton conductivity is a function of λ, the number of water molecules per ionic group;

- local equilibrium at interfaces is represented by partition functions;
- kinetics of the cathode and cathode is described by a Tafel expression;
- anode and cathode flow channels are treated as a continuous stirred tank reactor (CSTR), so, the composition and temperature inside the channels are uniform;
- anode and cathode streams act as heat transfer fluids removing heat from the cell at the exit temperatures.

The development of the model is explained in detail in a previous work [6]. All the model equations and the parameters values used to obtain the results presented in the next section can be found in a previous work, with only one change in kinetics. The expressions for anode and cathode kinetics are updated and presented below:

$$\eta_a = \ln\left(\frac{I_{cell}(C_{H_2}^{ref})^{\gamma^a}}{i_0^{ref}(C_{H_2}^{CCL})^{\gamma^a}}\right)\frac{RT}{\alpha_a F} \quad (1)$$

$$\eta_c = \ln\left(\frac{I_{cell}(C_{O_2}^{ref})^{\gamma^c}}{i_0^{ref}(C_{O_2}^{CCL})^{\gamma^c}}\right)\frac{RT}{\alpha_c F} \quad (2)$$

3 Results and Discussion

The model predictions for the I-V curve for a cell of 25 cm^2 active area are presented in Fig.3 for four values of membrane thickness. Anode and cathode pressures are 1 atm, cell temperature and reactant (fully humidified) temperatures are 333 K and flowrates are calculated using ζ_a=1 and ζ_c=2 at 1 A/cm^2. As can be seen from the plots, better performances are obtained for Nafion 112 and Gore Select, the thinner membranes. Thicker membranes with higher transfer resistances retain less water and provide lower proton conductivities. It is therefore useful to calculate the water contain retained at each membrane. Simulation results for the water content are presented in Fig. 3.

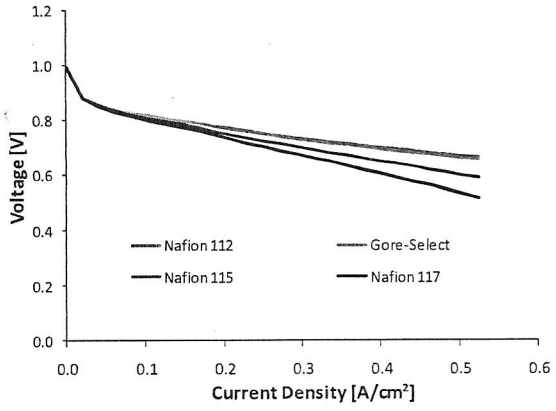

Figure 2 – Voltage vs. Current density for differents membrane thicknesses: Nafion 112 (0.0051 cm), Nafion 115 (0.0127 cm), Nafion 117 (0.0178 cm) and Gore-Select (0.003 cm).

As expected, the membrane water content values are lower for thicker membranes. Thinner membranes with lower mass transfer resistances generate higher water fluxes increasing fuel cell performance.

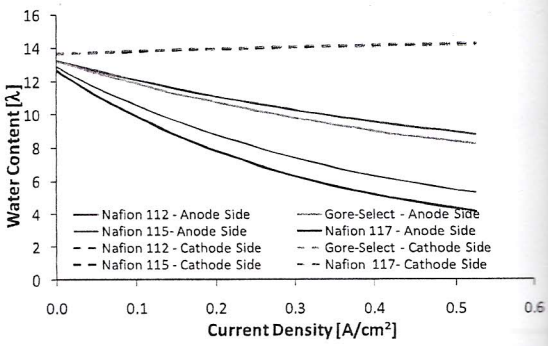

Figure 3 – Menbrane water content vs. Current density for differents membrane thicknesses: Nafion 112, Nafion 115, Nafion 117 and Gore-Select.

The cathode side water content is almost the same for all membranes, due to water production at this side of the cell. Concerning the two thinner membranes, although Gore-Select is more thin than Nafion 112, the water diffusivity in Gore- Select membrane is half than in Nafion 112 resulting in a slight lower performance and water content.

4 Conclusions

In the present study, a previous developed model is used to predict the influence of the different parameter/material properties such as membrane thickness (reported here) on the cell performance. The use of thinner membranes generating higher water fluxes through membrane (lower mass transfer resistances) lead to improved performances. For all the conditions studied, a better fuel cell performance corresponds to higher water contents in the membrane. This easy to implement model is useful to achieve optimized and tailored MEAS and adequate operating conditions to different applications.

5 References

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