SELECTION CRITERIA FOR GAS DIFFUSION LAYERS FOR PEM FUEL CELLS

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Abstract

Gas Diffusion Layers (GDL) are affecting fuel cell performance besides the membrane and catalyst components. Their role of providing the correct balance of water transport (vapor and liquid) while providing access for gases to the reaction sites is becoming appreciated by the scientific community. This paper gives a study of the interaction of GDL materials properties such as density, thickness, hydrophobicity, and fuel cell operating conditions such as humidification, gas stoichiometry and temperature. The gained results are contributions to better understanding of governing materials properties and an aide for selecting the best fitting materials grades for the chosen operating conditions. The study comprises results from designed experiments of a vast variety of GDL parameters used in single cell experiments. State of the art understanding obtained empirically is a relationship between porosity of the GDL substrate and its tendency to influence membrane hydration. More open substrates are beneficial where electrode flooding phenomena are noted whereas denser materials are advantageous where membrane dehydration is the performance limiting factor. This study provides a tool set to select the best GDL option for most operating conditions.

Introduction

A polymer electrolyte membrane (PEM) fuel cell consists of a stacked series of planar layered components: The polymer electrolyte membrane which is coated with a thin catalyst layer on both sides. This catalyst layer represents the area of the two individual electrochemical partial reactions of the oxidation at the anode and reduction at the cathode, respectively. This catalyst layer must provide a best fitting porosity and electrical conductivity, to allow the reactants flow into and the products flow out of the reaction layer. The reactant gases and reaction products are distributed across the active area of a single cell by means of a flow field channel structure, typically embedded into the plate material which separates two adjacent cells within the fuel cell stack. The mediating component between the coarse channel structures and the very fine porosity of the catalyst layer is the GDL. It must also comprise a fair degree of open porosities to provide gas transport pathways from the flow field channel to the catalyst particle and back. The products from the electrochemical reaction comprise water in liquid and vapor form. It is this two phase flow which makes the GDL a key component in PEM fuel cells.
It is easy to see that the liquid product water must not accumulate in the open porosity of the GDL. It would block the reactant pathways and lead to mass transport limitations. Especially at conditions where much product water is generated, this phenomenon must be avoided. On the other hand, if water transport is facilitated too much, the membrane conductivity might suffer. Membrane conductivity in most systems, depends on full humidification of the membrane. Membrane dehydration is a state which must be avoided during fuel cell operation. Besides the direct influence on water handling, the GDL must fulfill further functions, only to mention the key ones: the mechanical tolerances of the adjacent separator plate component must be compensated. The cross section of the flow field channel must not be reduced when the fuel cell stack is compressed. Furthermore, the area between the lands must be contacted well enough to provide the catalyst layer with the required electronic conductivity. Therefore, the material must provide a minimum stiffness. The base material is available in a variety of thicknesses and porosities. Such base material may be treated with agents affecting the surface energy with the objective to tailor a desired degree of hydrophobicity. This is usually done by applying a thin film of PTFE on the inner pore surfaces in varying amounts. Lastly, it has been shown that adding a microporous layer on top of the GDL is beneficial for fuel cell performance, especially the handling of liquid water (see Qi and Kaufman 2002).

Aims and Objectives

It is the aim of this paper to establish relationships of material properties such as thickness and porosity, operating parameters such as relative humidity (RH) and resulting fuel cell performance. The following key points of performance are used as evaluation criteria responses:

- Voltage at 300 mA/cm² (this is the high efficiency region)
- Voltage at 800 mA/cm² (this is a typical maximum power region)
- Internal resistance at 1 A/cm² (IR)
- Current density at 300 mV (this is the ability to avoid mass transport limitation, MX)

Using initial input parameters, a model and an evaluation tool set should be developed which enables answers for selecting the best fitting GDL configuration within the anticipated set of operating conditions and the intended performance functions. In the end, the developed tool set is used to confirm the predictions of previous studies (see Wood 2002 and Wilde 2004) where the benefit of using denser materials at low humidification conditions was noted as well as the benefit of more open substrates to enable high current densities.
For this study, the GDL PTFE content was kept constant at 5 wt.-% and all samples under investigation were coated with an industry standard microporous layer.

Experimental

Experimental Procedure
In-situ testing in single cells was used to obtain performance data of the cell configurations under investigation. A commercial standard catalyst coated membrane was used for the entire study. The parameters used in this study are listed in Table 1.

Table 1: Experimental parameters (kept constant for all experiments)

Cell temperature	75 °C
Utilization of hydrogen	70 %*
Utilization of air	40 %*
Back pressure	0 kPa
Active area of MEA (PRIMEA®5570)	4.2 cm^2

* Constant gas flow rate below 0.2A/cm^2

Design of Experiments
A set of experiments was designed to systematically approach and analyze the relationship between the materials properties and the fuel cell data at various operating condition parameters. For analysis, Modde version 8 software (Umetrics) was used.

Parameter settings
The parameters for this study were chosen as listed in Table 2.

Table 2: Parameters for the investigation

Property	Abbreviation	Type	Use	Settings
Porosity	Por	Qualitative	Controlled	Low; High
Thickness	Thi	Qualitative	Controlled	t200; t300
Anode RH	RH_a	Multilevel	Controlled	79; 100
Cathode RH	RH_c	Multilevel	Controlled	41; 65; 100

The corresponding materials having different thicknesses and porosities are listed in Table 3.

Table 3: Materials used in the investigation

	Low Porosity	High Porosity
200 microns thickness	SIGRACET® GDL24BC	SIGRACET® GDL25BC
300 microns thickness	SIGRACET® GDL34BC	SIGRACET® GDL35BC

Results

Polarisation (I-V) curves were obtained using the parameters listed above. From these I-V curves, the resulting performance data were evaluated and entered into the statistical evaluation software system. An example set of I-V curves is shown in Figure 1.

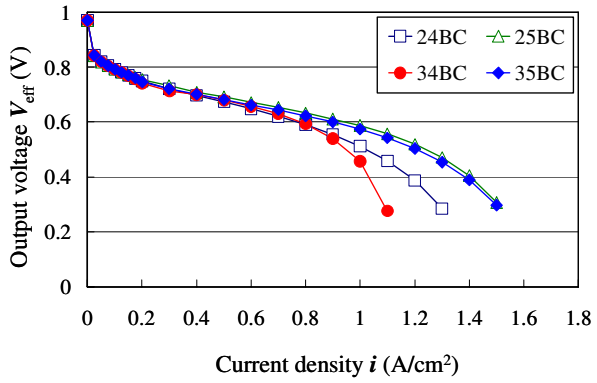

Figure 1: Polarisation curves of different GDL materials at $RH_a = RH_c = 100\%$

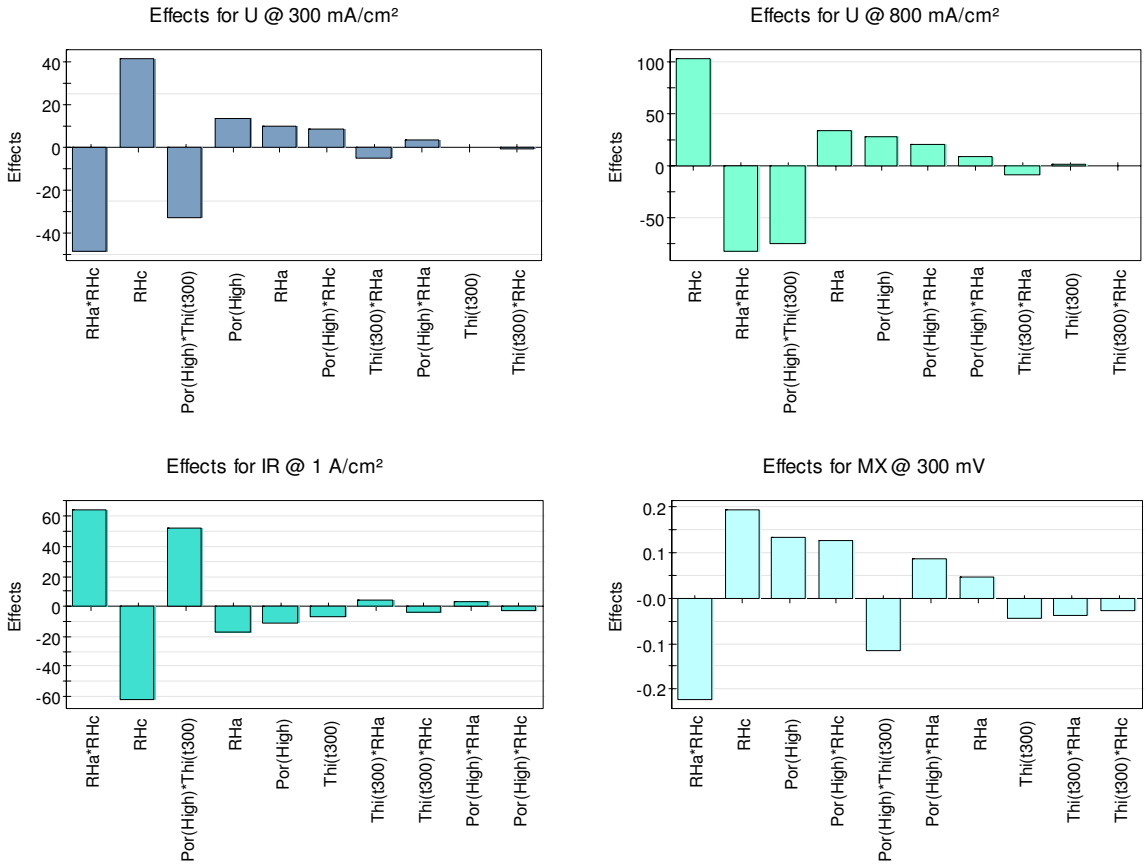

Figure 2: Main effects of input parameters on output results

The main effects are displayed in Figure 2. For process factors the values of the effects (computed as twice the MLR coefficients) are plotted sorted (in absolute value) in descending order. The ± 95% confidence interval is shown as error bars. This effect represents the change in the response values when component k varies over its range, all other mixture factors kept in the same proportion as in the reference mixture.

Analysis and Discussion

As a general observation, the humidity content within the cell imposed by external humidification of the fuel and oxidant gases has the greatest effect on every fuel cell performance response used in this study.

The resistance against humidity transport is a function of porosity, pore size distribution and pore length and tortuosity. Both porosity and pore length are direct input factors which can be selected by choosing the best fitting materials option. The GDL materials compared on the micro scale are of similar structure (see Figure 3), which makes the pore sizes no real determining factor. The remaining factors to select for optimum performance are porosity and thickness of the base materials.

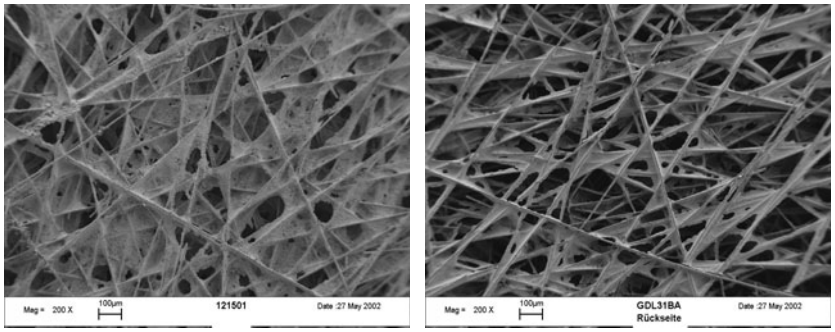

Figure 3: SEM micrographs of denser (left) and more open (right) GDL pore structure

The data show a clear influence of the relative humidities on the FC performance. The material parameter with the next largest effect on the fuel cell performance (U@300 mA/cm²) is porosity in combination with thickness. This means that to achieve optimum results, one had to choose a material with lowest possible product of thickness and porosity. If the particular fuel cell design required a predefined thickness, then the porosity selection would give an alternative to optimize performance.

The product of thickness and porosity is key effect for all selected responses. This implies that the responses are related as well.

It is to be noted that low porosity and low thickness are not listed as having a profound influence on the selected responses. Clearly, the selection of the responses is guiding the study towards an anticipated direction. The high power density is a function of external humidification and the ability to transport water effectively to and from the reaction sites. By selecting other responses – e.g. membrane conductivity – the tool set can be adapted. It is able to quantify the effects of materials properties on the selected response. The fuel cell designer can choose the best fitting materials options to optimize the cell configuration with respect to the selected performance target.

Conclusions

The present study gives a starting point for systematical analysis and understanding of the interaction of material properties and operating conditions on fuel cell performance. A DOE based tool set has been used to evaluate the experimental data. This tool set is suitable not only for processing but also for generating statistically reliable interrelations of the parameters. Initial semi quantitative results confirm the empirical results of previous studies: High amounts of humidity – either generated at high current density regions or by external humidification of the reactant gases – are handled best with high porosity GDL materials. At the same time, membrane dehydration phenomena are successfully prevented when a GDL material is employed with a high resistance against humidity transport, represented by high thickness and/or low porosity. Understanding these interrelations assists the fuel cell designer to work towards the “sweet spot” of components selection and system robustness.

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