Permeability and p_c-S_w relationship for gas diffusion layers of a PEMFC

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Motivation

During two decades the polymer electrolyte membrane fuel cell (PEMFC) as one promising power source has been investigated in detailed experiments as well as in modelling studies. Most of the transport models were based on pore network models or on model types like the dusty gas model. Acosta et al. [1] used a Darcy-flow based approach to model the processes in the electrodes of a PEMFC.

The electrodes (cf. fig. 1a/b) consist of a flow field, a catalyst and a hydrophobic thin material, which is called gas diffusion layer (GDL).

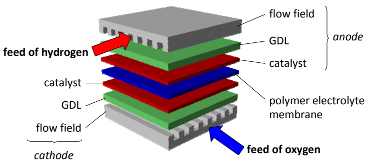

Figure 1a: Sketch of a PEMFC

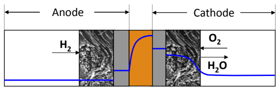

Figure 1b: Cross section with profile of water content

As a crucial point for modelling the counter-current transport processes of gas, water and electrical current occurring in the GDL of a PEMFC were identified. The knowledge of constitutive relationships as well as permeabilities as intrinsic parameters for the model of GDL is essential.

The properties and tasks of the gas diffusion layer are:

- 200-500 µm thickness
- Enabling diffusion of gas to the catalytic layer
- Formation of an electrical connection between bipolar plate/flow field and catalyst layer
- Carrying out of the produced water
- Providing a protective layer over the catalyst layer
- It is sometimes covered with micro porous layer (MPL) to enhance performance

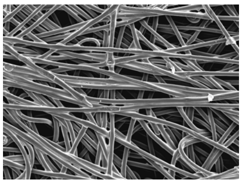

Figure 2: GDL 200x, SEM micrograph

While assembling the fuel cell stack the different layers are compressed due to sealing purposes, which leads to pore deformation and has a strong influence on capillary pressure - saturation relationship.

In the following sections experimental methods for the direct determination of permeabilities and pc-Sw relationships under well-defined compression levels for thin hydrophobic layers, such as GDLs, are presented.

Experimental setup

Capillary Pressure - Saturation Relationship

Capillary pressure on macro-scale (Darcy-flow based REV-models):

$$p_c = p_n - p_w = f(S_w) \quad \text{with} \quad S_w = \frac{\Phi_\alpha}{\Phi}$$

where p_n denotes the pressure of the non-wetting phase, p_w for the wetting phase. For hydrophobic GDLs p_n is the pressure of the water phase, p_w the pressure of the gas phase.

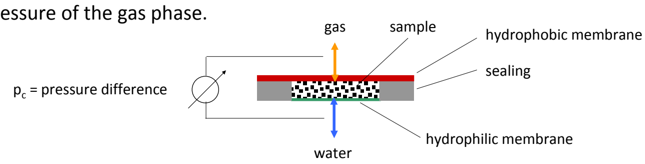

Figure 3: Schematic diagram of sample and membranes

Operation mode:

- Purging of lower part with water to remove trapped air
- Assembling stack consisting of membranes and sample (cf. figure 3)
- Sealing of cell and adjusting desired compression level with stamp
- Continuous imbibition and drainage cycles till pressure response is repeatable in the range of -30.000 Pa up to 30.000 Pa
- Starting stepwise injection of small portions of water via a syringe pump
- Pausing to enable relaxation of pressure (cf. figure 5/6)
- Withdrawing gradually small amounts of water followed by relaxation periods to gain the drainage curve

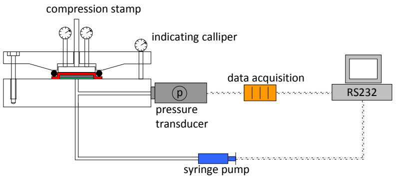

Figure 4: Experimental setup for p_c-S_w measurements

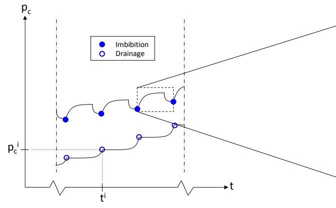

Figure 5: Measured pressure curve for evaluation of capillary pressure p_c^i at known saturation S_w^i

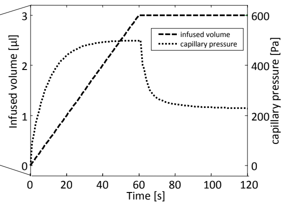

Figure 6: Pumping strategy and pressure response exemplarily shown for one period

Permeability Measurement

The permeability as one key parameter for modelling the processes in the electrodes of a PEMFC was determined for several materials. In-plane (IP) and through-plane (TP) permeabilities (cf. figure 7) were measured with the following framework:

- Accurate flow of air ensured by mass flow controller (MKS 1179) and accounting for actual temperature by a thermocouple (type K)
- Differential pressure manometer (Furness FCO 12 micro manometer, range of 0-2 mbar or 0-20 mbar, accuracy ~0.001 mbar)

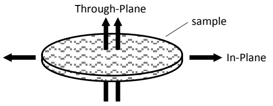

Figure 7: In- / through-plane permeability

In-Plane measurement

$$K = \frac{R \cdot T}{\pi \cdot V_0 \cdot d} \cdot \frac{Q}{(p_{amb} + \Delta p)^2 - p_{amb}^2} \cdot ln(\frac{r_2}{r_1})$$

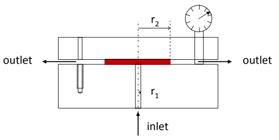

Figure 8: In-Plane permeability measurement cell

Through-Plane measurement

$$K = \frac{Q \cdot \eta \cdot d}{\Delta p \cdot A}$$

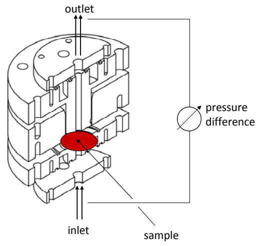

Figure 9: Through-Plane permeability measurement cell

Results

Capillary pressure - saturation relationship measurement

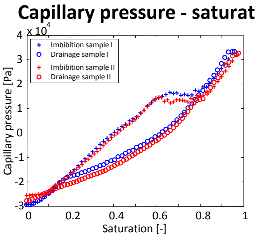

Figure 10a: Samples of SGL Carbon 24 BA @ 0% Compression

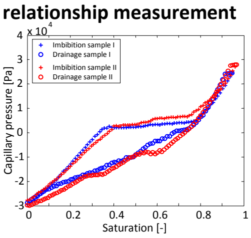

Figure 10b: Samples of Freudenberg H2315 T10A @ 0% Compression

- Results show hysteresis
- Accounted for dynamic effects
- Residual saturation negligible

Permeability measurement

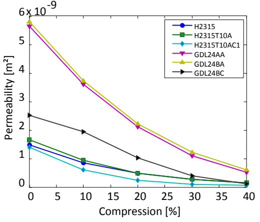

Figure 11a: In-Plane (IP) permeabilities

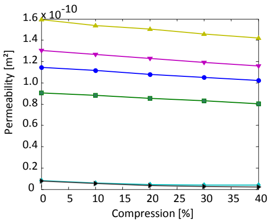

Figure 11b: Through-Plane (TP) permeabilities

GDL compression leads to:

- Linear decrease of TP-permeability and
- Exponential decrease of IP-permeability due to the fiber orientation (cf. fig. 2)

Outlook

➔ Examination of hysteresis behaviour of p_c-S_w function in detail

➔ Combination of capillary pressure - saturation relationship with permeability measurements within a new device, where:

- capillary pressure (i. e. amount of water inside sample) is kept constant, while
- low-flow permeability measurements or/and
- counter-current diffusion experiments will be conducted

to obtain relative permeability - saturation relationships in axial and radial direction for gas diffusion layers.

References:

[1] *Acosta, M.; Merten, C.; Eigenberger, G.; Class, H.; Helmig, R.; Thoben, B. and Müller-Steinhagen, H.:* Modeling non-isothermal two-phase multicomponent flow in the cathode of PEM fuel cells. *Journal of Power Sources* 159 (2006), p. 1123-1141

[2] *Gostick, J. T.; Ioannidis, M. A.; Fowler, M. W. and Pritzker, M. D. :* Direct measurement of the capillary pressure characteristics of water–air–gas diffusion layer systems for PEM fuel cells. Electrochemistry Communications 10 (2008), p. 1520-1523

[3] *Fairweather, J. D.; Cheung, P.; St-Pierre, J. and Schwartz, D. T. :* A microfluidic approach for measuring capillary pressure in PEMFC gas diffusion layers. Electrochemistry Communications, 2007, 9, p. 2340-2345