Towards a model concept for coupling porous gas diffusion layer and gas distributor in PEM fuel cells

Nowadays, the development of new alternative, more effective power sources becomes more and more important, since a further increase of the worldwide energy demand is still expected in the next years. Fuel cells are good alternatives to combustion engines due to the high efficiency combined with low emissions. Especially Polymer-Electrolyte-Membrane fuel cells (PEMFC) could replace the less effective combustion engines in automobiles.

The performance of a PEMFC is highly dependent on the water management in the fuel cell. The reaction gases are transported through a porous gas diffusion media. If the emerging water in the reaction zone isn't well removed to the channel on the cathode side, the pores in the gas diffusion layer and the reaction layer can be blocked and the supply of reaction gases will be inhibited or reaction zones can be covered by water. Otherwise, water is needed for the transportation of the protons through the membrane. The risk of membrane drying out, mainly on the anode side but also on the cathode side can occur. On the cathode side the risk is lower, since water is produced but it has to be assured that not too much water is removed. Therefore, the constituent parts such as the membrane, the gas diffusion layer, and the reaction layer have to be carefully constructed and the inlet gas has to contain a certain amount of water vapour. For this reason the gas diffusion layer consists of a hydrophobic material.

The investigation of the material used in fuel cells by experimental studies is difficult, due to the small geometry and the expensive material. For the hydrophobic material of the gas diffusion layer no exact data is available. Therefore, numerical models can help to improve the material and the performance of the fuel cell. With the help of numerical models, relations between the different properties can be found out to improve the performance.

In this thesis, the water management of the cathode is investigated. Different parameters are varied to find out how they influence the water distribution and the performance of the PEMFC.

A three dimensional, numerical model is derived for the gas diffusion layer (GDL) and the gas channel of the cathode of a PEMFC to investigate the water management. The flow is modelled as a liquid-gas two-phase, three-component flow (Acosta et al., 2006). The gas channel is added to the model for investigating the influence of the flow in the channel on the water distribution in the GDL and the reaction layer, and the performance of the fuel cell. The expansion to three dimensions allows representing the flow through
the gas channel parallel to the GDL. Different approaches for coupling of the GDL and the gas channel are discussed in detail and the coupling with Darcy's law in both domains is chosen for simulation. The permeability of the gas channel is assessed with Hagen-Poiseuille's law by assuming flow through a small gap (Silberhorn-Hemminger, 2002). The model is implemented in MUFTE-UG, a numerical simulator developed at the Department for Hydromechanics and Modelling of Hydrosystems of the University of Stuttgart.

Variations of different parameters in the gas channel are carried out to identify their influence on the water management in the GDL and the performance of the fuel cell. Following conclusions can be derived: The pressure gradient between channel inlet and outlet highly influences the amount of water accumulated in the reaction layer and in the GDL. The higher the pressure gradient, the lower the saturation in the GDL and the higher the current density. To test the real influence of the flow in the channel, the permeability is varied. If a higher permeability prevails in the channel, the saturation in the GDL decreases and the performance is improved. Moreover the influence of the water vapour content at the channel inlet is tested. More water accumulates in the GDL, if a higher water vapour mole fraction is assumed in the channel (see figure below). Consequently, the current density decreases with increasing water vapour content in the channel.

Additionally, the capillary pressure-saturation relation is varied, since only few data exists for capillary pressure of the hydrophobic GDL. It is found that the capillary pressure, the saturation and the current density are highly coupled and that the capillary pressure relation highly influences the water management in the GDL. If the capillary pressure is too low, a high amount of water accumulates in the reaction zone and the reaction is highly inhibited. This is due to the fact that the capillary forces aren't high enough to sufficiently distribute the water over the whole GDL and to transport enough water to the gas channel. Therefore, liquid water covers several catalyst sites and inhibits the transport of the reaction gases through the GDL to the reaction layer.

Summing up, the main physical behaviour can be well demonstrated with the presented model. The model provides important information how the conditions in the channel influence the water management in the GDL and the overall performance of the fuel cell. Therefore, the model helps to improve the performance by choosing the right parameters in the channel to avoid the covering effect of reaction sites and a blocking of the GDL by
water. Moreover, it can contribute to assure a good distribution of the reaction gases. Additionally, the investigations of the capillary pressure-saturation relation show a high influence on the overall performance and the importance of further experimental investigations to assess the right parameters of the relation.

References

