Characterization and modeling of mass transport effects in gas diffusion layer and catalyst layer of PEM fuel cells

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Cost and power density of the PEM fuel cell are critical aspects for its application in the automotive power train. A broad commercialization of this technology requires its cost to be lowered to a competitive level compared to internal combustion engines. The required price reduction cannot be achieved by economies of scale alone, significant advances in material cost and material consumption are also necessary. A major lever in this direction is the optimization of areal power density of the fuel cell stack to minimize material consumption as well as stack volume and weight at a given required power output.

As will be shown in this study, one of the major limiting factor in regards to further increasing the areal power density is the limitation in the oxygen transport from the flowfield channels to the catalyst site. To improve power density, it is key to understand and break down the contributions to mass transport limitation that arise from different effects between channel and catalyst layer.

In this study we will present different ex-situ and in-situ characterization methods, that allow the determination of mass transport characteristics for the different layers.
For the characterization of molecular diffusion in the gas diffusion layer in the through-plane and in-plane direction, an ex-situ flow cell has been developed, that in contrast to published methods [1-2] allows for direct measurement of oxygen diffusivity, even for wet samples. A similar, slightly modified method can be applied to characterize gas diffusivity inside the catalyst layer ex-situ. This method however only accounts for bulk diffusivity inside the catalyst layer, and diffusion through ionomer or water layers surrounding the catalyst particles cannot be accounted for.

Therefore, the results of this ex-situ studies are compared to in-situ results generated with limiting current methods [3-5], that allow characterization and break-down of mass transport effects by applying different oxygen concentrations, pressures and temperatures. In addition to the ex-situ methods, these in-situ measurements can also access the contribution of mass transport through ionomer and water films around the catalyst agglomerates.

Although conditions are not totally comparable between in-situ and ex-situ measurements, it becomes clear that the correlation between both is very straight-forward.
The major contribution to oxygen concentration loss is thus following the results of this study the molecular diffusion inside the cathode gas diffusion layer. However, another significant mass transfer effect, that is often not accounted for, is the concentration drop inside the gas flow channel. Simulation results show that this effect becomes especially critical if landings have a rounded shape instead of a rectangular profile.

Based on the results of this study, different approaches for improvement of PEM fuel cell areal power density can be derived. Improving the oxygen diffusivity inside the gas diffusion layer is one of the key levers. Optimizations of the flowfield structure and shape however can also have a significant impact.

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