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Theoretical and Experimental Study of SOFC Gas Diffusion Using Impedance

Y. FU[1], Y. Jiang[2], G. V. Pattarkine[2], L. Sun[2], A. Dutta[2], A. Mohanram[2], J. D. Pietras[2], M. Z. Bazant[1];

[1] Dept. of Chemical Engineering, MIT, Cambridge, MA, [2]Saint-Gobain R&D Center, Northboro, MA.

In this research, we used zero current impedance spectrums to study multi-component gas transport in porous electrodes of solid oxide fuel cells. An anode supported single cell was used, where the anode was 1.5mm thick and the cathode was 0.1mm thick. The cell was glass sealed at the circumference and was put into a spring loaded single cell testing fixture with the anode facing up. A mixture of hydrogen, water vapor, and nitrogen was provided to the anode from a top feeding tube and air was fed from the bottom, carrying oxygen to the cathode.

Impedance spectra of the anode supported cell at zero current were measured with the temperature and pressure fixed at 800^{O}C and 1 atm, respectively. The partial pressure of hydrogen in the anode feeding gas was varied from 10% to 100% of the total pressure. The theoretical comparison predicts that diffusion resistance from anode side of the cell dominates. Therefore, the low frequency arc in the impedance was fit with a finite-length Warburg in a Randles circuit (Figure 1) to extract the anode diffusion resistance (Rb), which was then compared to predictions from three analytical models, including Fick's Law, the Stefan-Maxwell model, and the Dusty gas model.

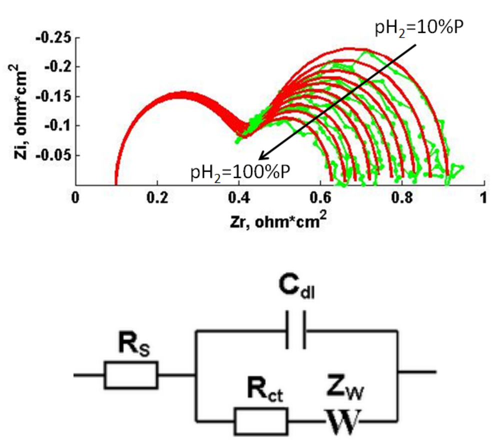

Fig.1 (Above) Fitting of low frequency arc with Randles circuit. (Below) The Randles circuit used to fit the zero impedance spectra.

We found that the Dusty gas formula is intrinsically inconsistent with the isobaric assumption. So pressure effects on the Dusty gas model were studied. Comparing gas composition profiles from full numerical simulations with pressure variations and analytical results in isobaric case, the deviation is very small. We also computed the diffusion resistances (Rb) allowing for variations in pressure. The computed values are almost the same as what were obtained from analytical results under isobaric conditions, allowing pressure variations to be neglected. Thus, we were able to derive diffusion resistances expressions apparently for the first time for the Stefan-Maxwell model and the Dusty gas model.

Figure 2 shows the structural factor values (porosity/tortuosity) from fitting the data with the analytical diffusion resistances (Rb). It is noteworthy that the Dusty gas model gives a constant structural factor, independent of hydrogen partial pressure. This is consistent with real physics, where the microstructure of the porous media does not change with testing conditions. Moreover, with the anode porosity known to be 46%, the tortuosity fitted from the Dusty gas model is 2.3, which matches both theoretical expectations and experimental measurements.

Figure 3 shows the comparison between diffusion resistances derived from the aforementioned models and the values extracted from experimental data after taking into account the structural factor. The Dusty gas model best describes the gas diffusion, while the Stefan-Maxwell model shows some deviations, and Fick's law cannot capture the performance at all.

In summary, our work shows that zero current impedance spectra are useful for studying multi-component gas diffusion in porous electrodes. Instead of invoking high tortuosity values to explain the limiting current in IV curves, the tortuosity fitted from impedance measurements using the Dusty gas model is physically reasonable, and does not vary with gas pressure.

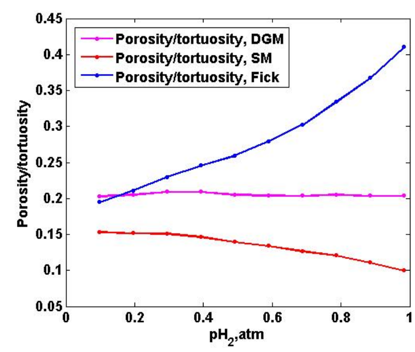

Fig.2 Structural factor (porosity/tortuosity) values fitted from three different models.

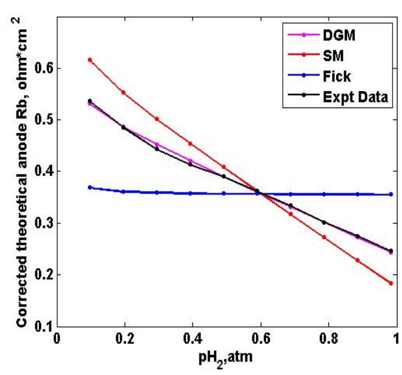

Fig.3 Comparison between diffusion resistances derived from models and the values extracted from experimental data after taking into account the structural factor (porosity/tortuosity).

Reference

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