INTERFACIAL DROPLET PHENOMENA IN PEM FUEL CELLS – MODELING AND VISUALIZATION

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A visualization study of liquid water transport and distribution has been performed using an optical H_2/air PEM fuel cell. The mechanics of liquid water transport, starting from droplet emergence on the carbon paper gas diffusion layer (GDL) surface, droplet growth and departure, to the two-phase flow in gas channels, is characterized under automotive cell conditions of 0.82 A/cm^2, 70^{o}C and 2 atm. It is observed that water droplets emerge from the GDL surface only under over-saturation of water vapor in the gas phase, appear only at preferential locations (perhaps structural irregularities), and can grow to a size comparable to the channel dimension under the influence of surface adhesion. Both the gravitational force and drag from the core airflow are found to be inadequate to detach water droplets from the GDL surface under the test conditions. Growing into a sufficiently large size, the water droplets then touch more hydrophilic channel walls and quickly spread over them to form an annular film flow. When the liquid film on channel walls grows sufficiently thick to become unstable, a liquid water bridge forms and hence channel clogging takes place.

Based on these experimental observations, a new model for two-phase flow and flooding dynamics in PEM fuel cells has been developed. This three-dimensional electrochemical and transport fully coupled PEM fuel cell model contains four submodels to account for two-phase effects, including liquid coverage model in the catalyst layer, liquid water transport model through hydrophobic GDL, interfacial droplet model at the GDL interface, and two-phase flow model in the gas channel. The M^2 model has been adopted to study liquid water transport in the porous GDL while the liquid transport in the gas channel is treated using either mist flow or annular film flow model. A new interfacial droplet submodel at the GDL interface is developed, for the first time, to account for profound effects of GDL interfacial liquid coverage on flooding. The inclusion of this submodel at the GDL interface not only provides the present two-phase model with a capability to truly reveal the cathode flooding effect on cell performance, but also overcomes the disadvantages of previous two-phase models in the literature in that it is now capable of discerning vastly distinctive effects of the hydrophilic and hydrophobic porous media as well as capturing the air flowrate (or air stoichiometry) effect on cathode flooding.

Figure 1 compares the polarization curves at single- and two-phase conditions. The two-phase results reach a maximum current density around 1.2A/cm^2, which is 20% lower than the mass-transfer-limited current density of 1.5A/cm^2 in the single-phase calculation. The difference is caused entirely by the cathode flooding effect. Figure 2 presents two polarization curves obtained at two different liquid saturations at the GDL/GC interface. Decreasing the liquid saturation (S_0) to 0.1, the cathode flooding effect on the maximum current density decreases to less than 8%. This clearly shows the significant effect of air flowrate (or air stoichiometry) on cell performance.

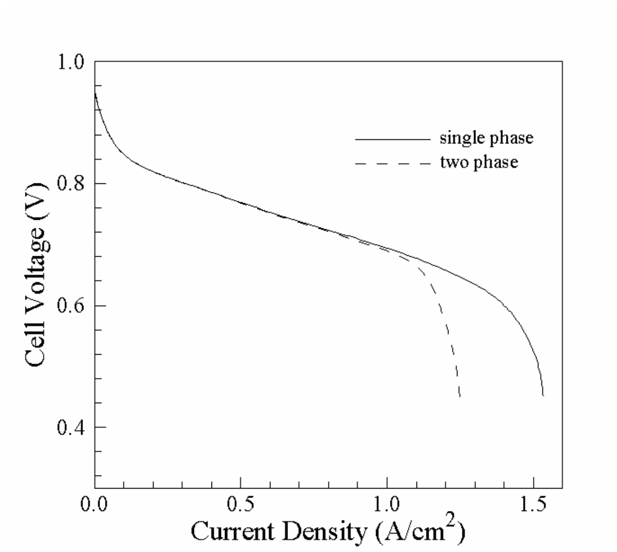

Figure 1. Polarization curves from both single- and two-phase calculations

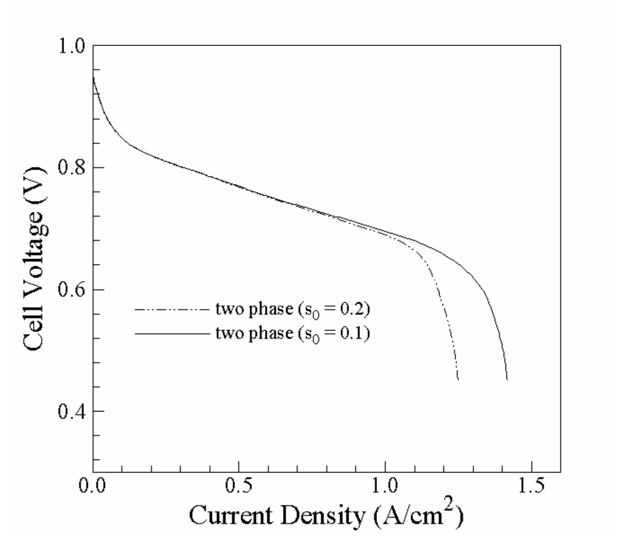

Figure 2. Polarization curves with different saturation values at the GDL/GC interface