Two-phase Flow Through the PTL of PEM Water Electrolyzer: MRI Experiments and Numerical Modeling Using Phase-Field Theory

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Résumé

Proton Exchange Membrane (PEM) electrolyzers are a promising technology for large industrial-scale hydrogen production, but they face limitations in terms of efficiency and durability due to mass transport and electrical transfer issues in the anode Porous Transport Layer (PTL). The optimal porosity and pore size of the PTL contributes to efficient water, gas, and electron transport. This work used a combination of modeling and experiments to determine the optimal porous layer morphology. Magnetic Resonance Imaging (MRI) was utilized to quantify water content within the porous layer during two-phase flow, using borosilicate filters instead of real paramagnetic titanium PTL. The saturation profiles within the porous material depend on gas flow rate variation, resulting in a semi-dry sample having minimum stable water content trapped between pores. The water flow rate variation in the channel does not affect saturation, but a higher gas flow rate is needed to reach a minimum stable water content for a higher water flow rate. *Measurement of* gas pressure drop through the porous medium and bubble formation analysis revealed that pressure drops and flow types depend on the water channel's orientation, flow direction, and gas and water flow rates. The dynamic characteristics of water and oxygen transport (two-phase flow) over the PTL were studied using a phase-field model based on the Cahn-Hilliard theory. The modified Navier-Stokes equations for two phases were coupled with a phase field equation for describing the diffuse interface. Numerical simulations performed in the COMSOL® Multiphysics software were carried out on 2D geometries composed of spherical solid grains of different sizes, similar to the PTL used in experiments. Gas was injected into one side of an initially saturated porous medium and evacuated from the other side in contact with the water channel. The study investigated gas flow and bubble formation in the water channel by varying gas and water flow rates. Simulation results provide information on gas pathways and saturation profiles over time based on flow rates, to be compared with experimental data.

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