Polymer Electrolyte Membrane Fuel Cell – Single Cell Model

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A three dimensional steady-state numerical heat and mass transfer model for polymer electrolyte membrane prototype fuel cell is developed for multi-parallel flow field channel design of SS-316 bipolar plates. The model focuses on determining the local distribution of temperature, pressure, reactants, and humidification level, which are important parameters for determination of average net current density from the cell. The flow domain consists of flow field channels, diffusion layers and catalyst layer on both the anode and cathode sides. Four species *viz.* H_2, O_2, N_2 and H_2O (vapor) were considered for the simulation. The basic transport equations were solved over the domain using the commercial computation fluid dynamics software, Fluent 5.5 with Gambit as preprocessor. The equation of continuity has a source term, which corresponds to the consumption of hydrogen and oxygen on anode and cathode side respectively along with the production of water on both the sides. The transport of water across the membrane depends on the hydration level of the membrane and is simulated through the source terms. The momentum conservation is given by classical Navier-Strokes equation and also has source terms over the porous electrodes zones as given by Darcy's law. Similarly the species transport equations for each of the species has a source term, which corresponds to consumption or production of that species in the catalyst layer. The species diffusion coefficients were calculated using the kinetic theory of gases. The kinetics of the electrochemical equations were also incorporated in the source terms. Fluent software was customized to incorporate these source terms by the introduction of User Defined Function (UDF's) written in C language. Two simulations were performed corresponding to low and high humidification conditions as given in table 1. The results indicate a significant effect of humidification of reactant gases on the current density levels in the cell (Table 2). Also the flow patterns for H_2 and O_2 at the electrode/ electrolyte interface were obtained, which helps in the prediction of any reactant starved areas on the interface. The model results as shown in figure 1 are in good agreement with the experimental results.

Gas Species	Low Humidification (mass frac.)		High Humidification (mass frac.)	
	Anode	**Cathode**	**Anode**	**Cathode**
H_2	0.730	0.000	0.406	0.000
O_2	0.000	0.225	0.000	0.210
N_2	0.000	0.751	0.000	0.700
H_2O vap	0.270	0.024	0.594	0.090

Table 1. Simulating conditions corresponding to low and high humidification of reactant gases.

Humidification Level		Comments	Reference
Low	**High**		
2062	7209	Using Multi-Parallel design in bipolar plate with active area = 58 cm^2	Present Work
2246	6348	Using serpentine flow-field in bipolar plate with active area = 10.2 cm^2	[Dutta, etal]*

Table 2. Comparison of average current density values for low and high humidification. (Values in A/m^2).
*Dutta, S., etal., "Numerical Prediction of mass-exchange between cathode and anode channels in PEM Fuel Cell", International Journal of Heat and Mass Transfer, 44, (2001) 2029-2042
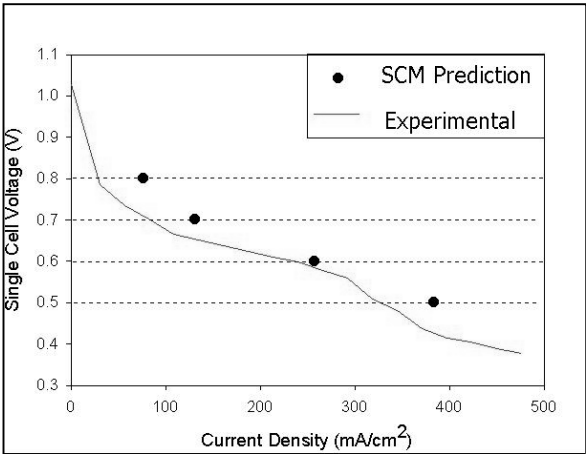

Fig 1. Validation of the Single Cell Model with our Experimental Data (T = 350 K, P = 240 kPa abs)