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Effect of inhomogeneous compression of gas diffusion layer on the performance of PEMFC with interdigitated flow field

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ABSTRACT

In this paper, effects of inhomogeneous compression of GDL at the cathode side of proton-exchange membrane (PEM) fuel cell with interdigitated flow field on water management and cell performance has been numerically investigated.A 2D, isothermal, two-phase and multi-component transport model has been used in order to simulate the transport phenomena. The model consists the gas diffusion layer and an ultra- thin layer as catalyst. The model results were in good agreement with the published data found in the literature. The results of this study prove the effects of considering GDL deformation on decreasing water removal from cell and also on decreasing reactants diffusion transports to the reaction sites, and thus dropping the cell performance as expressed by a drop in the cell limiting current density and maximum output power. Also, it has been proven that the compression level of 35% has no significant effects on the performance of the cell in single-phase regions, but effects of this level of compression are very considerable on the performance of the cell in the two-phase region. As a result, limiting current density and maximum out power of the cell were dropped by approximately 25%. Moreover, increasing the compression level from 10% to 35% led to an increase in the flooding of GDL and reactant transport was limited and performance loss increased (even in single-phase regions). At high compression level of 35%, the limiting current density and maximum output power had a very considerable drop of 25.1%, which indicates the importance of considering the effects of high clamping pressures in PEMFC modelling.

1. Introduction

In recent years, Proton- exchange membrane fuel cells (PEMFCs) have gained increasingly high interests because they are pollution free and highly efficient. Most of these interests are focused on optimizing the PEMFC's performance in order to commercialize these stationary and automotive power sources. One of the crucial problems which affect the cell performance is "water flooding" of the cell; in fact, the water flooding is a performance limiting issue which may cause cell degradation. The water flooding problem can be reduced by proper flow field design in bipolar plates. Among various flow fields suggested by the researchers, interdigitated gas distributors seem to be the most effective design in water removal from cell because this flow field design changes the reactants transport mechanism from diffusion dominated to forced convection dominated mechanism which leads to major water removal capacity and high electrochemical reaction rates, and consequently high cell performance.

For the first time, Nguyen [1] presented the interdigitated gas distributor for the cathode side of proton exchange membrane fuel cell in order to reduce mass-transport limitations and flooding problems. The results of his study indicated that this new flow field design was able to achieve a higher cell performance. Kazim and Liu [2] also presented a mathematical model to show the advantages of interdigitated flow fields over conventional flow fields in terms of limited current density and maximum output power density. They found that the power density and current density of the cell with interdigitated flow field are two and three times more than conventional flow field respectively.

Mathematical modelling provides a tool for evaluation, optimization and further development of fuel cells. Yi and Nguyen [3] developed a two-dimensional, steady- state, multi-component transport model to simulate the transports of gases in the cathode side of PEMFCs with interdigitated gas distributors, and predicted the effects of differential pressure between the inlet and outlet channels of interdigitated gas distributor, and cathode structure

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Nomenclature

C	molar concentration (mol/cm^3)
D	mass diffusivity (cm/s)
P	pressure (pa)
P_{ref}	reference pressure 1.013×10^5 pa
R	universal gas constant 8.3145 J mol^{-1} K^{-1}
s	saturation of liquid
T_{ref}	reference temperature 25 °C
$\mathbf{u}$	velocity vector (cm/s)
u	velocity in x-direction (m/s)
v	velocity in y-direction (m/s)
T	time period (s)

Greek symbols

ρ	density (kg/m^3)
ε	porosity
α	species (O_2, N_2, H_2O)
α_c	transfer coefficient of oxygen reduction
γ	advection correction factor
σ	surface tension (N/m)
η	over potential (V)

parameters like electrode height and shoulder width on the performance of the cell with interdigitated gas distributor. He et al. [4] also presented a two-dimensional, two-phase, and multi-component transport model to investigate the influence of hydrodynamics of gas and liquid water on the performance of PEMFC with interdigitated gas distributors. The model was then employed to determine the effects of various electrode parameters on the performance of PEMFC. A good review of the on-going research in the field of modelling PEMFCs was provided by Sigel [5], Ryan Anderson et al. [6] and Djilali [7]. A wide researches had been done in the literature on improving mathematical modelling of fuel cells for the purpose of optimization and performance evaluation of fuel cell systems (especially PEMFCs) ([8–20]).

Kazim and Liu [21] used a two-dimensional mathematical model for the cathode of proton exchange membrane fuel cell with interdigitated flow field to study the effects of increasing the porosity of electrode, mole fraction of oxygen, operating pressure and temperature on its performance. Tao et al. [22] developed a hybrid single- and two-phase, two-dimensional and multi-component model for the cathode side of proton exchange membrane fuel cell with interdigitated flow field to simulate transport of species and the effects of operating conditions and cathode structural parameters on cell performance. Lum and McGurick [23] presented two and three dimensional models for the cathode of proton exchange membrane fuel cell to conduct parametric study of the cell and to simulate and compare the flow distribution between conventional and interdigitated flow fields. Acosta et al. [24] formulated a two-dimensional, non-isothermal, two-phase, and multi-component model with capability to be used for proton exchange membrane fuel cell with both interdigitated and conventional flow fields, and then used the model to predict the effect of inlet stream humidity and capillary, on liquid water distribution and cell performance. Cheng et al. [25] proposed a two dimensional, isothermal, steady state water management model considering both cathode and anode of gas diffusion layers and a proton exchange membrane for the fuel cell. Also, their model included a pseudo- homogeneous model for catalyst layer in the cathode side. They investigated the effects of various parameters such as rib size, interdigitated flow field design, and operating conditions including gas flow rate, gas temperature and pressure, humidification and inlet relative humidity. Wang et al. [26] used a three-dimensional model for the cathode of proton exchange membrane fuel cell to explore the effects of flow channel configuration on cell performance for fuel cells with interdigitated and parallel flow channels. Yu et al. [27] numerically studied proton exchange membrane fuel cell and used a three dimensional, two-phase transport model to simulate the transport phenomena in both anode and cathode. Then, the model was used to investigate the effects of operating and geometrical parameters on cell performance. Berning et al. [28] presented a multi-fluid model to simulate the multi-phase flow in the cathode side of proton exchange membrane fuel cell with interdigitated flow field. With the aid of this model, they studied the effect of various parameters such as irreducible saturation, in- and through plane permeability on results. Abdollahzadeh et al. [29] investigated the performance of polymer electrolyte membrane fuel cell with parallel and interdigitated flow field designs for the cathode side by employing a two-dimensional, multi-component mixture model. They conducted a wide parametric study on the effects of operating conditions such as pressure difference, operating temperature and geometrical parameters including diffusion layer thickness and material parameters like electrode porosity, on the performance of PEM fuel cell with interdigitated flow field. They proved the validity of their simulation through qualities and comparison of the results of the parametric study with experimental results found in the literature.

Ramiar et al. [30], developed a dynamic unsteady two dimensional, two-phase, isothermal, multi-component model for the porous electrode of the cathode for simulating the PEMFC with interdigitated flow fields. The model was used to study the effect of pulsation amplitude and frequency on the water management, reactant distributions and effect of mean inlet pressure on the performance of the fuel cell.

Gas diffusion layers (GDLs) are one of the most important components in fuel cell assembly. GDLs make a path for reactants and products to/from catalyst layer's reaction sites. For this purpose, GDLs are made of high porous fibres and this high porosity makes them deformable and once the fuel cell components are assembled together, GDL will be compressed and this compression causes a non-uniform deformation on it. In fact, the clamping force in fuel cell assembly applies the most compression on GDL in comparison with other components because it has the lowest Young's modulus among cell components. This deformation changes the mass transport properties in GDL and affects the cell performance. Lee et al. [31] and Ge et al. [32] used different types of gas diffusion layers in their experiments and reported that change in GDL properties made by compression significantly dropped the cell performance. Ihonan et al. [33] concluded that using high pressure clamping forces increase flooding of cell which is the result of simultaneous effects of decrease in porosity and temperature gradient between GDL and current collector. Sue et al. [34] performed an experiment to obtain porosity and permeability of compressed GDLs and used the obtained data in a numerical simulation. Nitta et al. [35] investigated the effects of inhomogeneous compression of GDL on performance of fuel cell. In another study Hottinen et al. [36], concluded that modelling and using an empirical geometry for compressed GDL presented a relation for porosity, permeability and electrical conductivity as a function of deformation investigated the effects of GDL compression on the performance of cell.