



Department of Mechanical Engineering

**MODELING OF TRANSPORT PHENOMENA
IN POLYMER ELECTROLYTE FUEL CELL
STACKS**

Progress Report

Submitted by

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INTRODUCTION

Background

PEM fuel cell has become one of the most promising types of fuel cells, especially to replace the internal combustion engine at automotive applications. However, there are still many limitations in order to achieve the optimum performance. Thermal management couple with water management become a crucial factor to determine the performance of fuel cell especially at stack level.

Objectives

The main objective of this research is to address the fuel cell issues and further contribute to the fuel cell research and development for speeding up the progress to reach into commercialization. This research is dealing with two aspects related to the fuel cell which is fundamental and applications:

- Fundamental research, including:
 - Mathematical modeling of transport phenomena in fuel cell
 - Model development and validation against experimental data
 - Two-phase transport modeling in PEMFC
 - Thermal characteristic in stack PEMFC
- Applied research, addressing:
 - Gas management
 - Predicting and optimizing mass transport limitation for electrochemical reaction due to agglomerate catalyst particle.
 - Thermal management
 - Study several cooling mechanism to enhanced heat removal rate while keeping stack at high performance
 - Water management
 - investigating liquid water behavior inside porous backing and gas channel to get better liquid water removal.

RESEARCH PERFORMED TO DATE

Continuing previous semester's work, an advanced agglomerate catalyst model, comprise of correction factor due to: agglomerate particle, thin film polymer, thin film liquid water and catalyst (Platinum) loading, has been implemented and solved. The

agglomerate model could predict better mass transport limitation which is O_2 transport inside catalyst to investigate the limiting current density. Good agreement between model predictions and the experimental data are achieved, in terms of the local current density distributions, global polarization curve and temperature increase inside the fuel cell.

Continuing previous semester's work on forced convection air cooling, stack level modeling base on the validated model is then developed to get better insight on the thermal management. Various type of fan power are implemented into the fuel cell model to numerically cool down the stack. The fan is modeled as boundary condition, where the characteristic fan curve is captured with a polynomial for the pressure drop of the system *vis-a-vis* the flow velocity. The overall velocity that is achieved by fan is thus not known *a priori* but needs to be iterated. The results show that there is strong correlation between fan power and amount of heat can be removed with the stack performance. As the fan power increased, the stack temperature can be maintained at minimum and uniform temperature distribution can be achieved. In addition, increasing fan power could sustain fuel cell run at high current density and more uniform current density distribution. However, care should be taken on the stack operating condition since high fan power will consume high parasitic load which reduce the overall/net power produced by stack especially at low current density.

In order to optimize the stack performance, cost and space requirement, geometry configuration become an important part to achieved good stack performance and heat removal rate. To study the impact of these, three cathode channel height, width and fuel cell length are investigated. The results show that there is strong correlation between stack characteristic curve, number of cell can be placed in stack, total stack power and heat removal rate. For limiting case of the thinnest cathode channel height, the system characteristic curve switch to the left means that higher pressure drop is needed to drive the flow, the average current density is lower and the average temperature is higher. However, in term of total stack power, the thinnest cathode channel height could produce highest net power since more cell can be placed at the same stack dimension.

In parallel, a micro simulation for two-phase flow in the cathode channel is carried out since liquid water transport is one of the key challenges for water management in PEMFC. A transient 2D micro scale porous gas diffusion layer and cathode channel are

modeled and simulated by employing Volume of Fluid theory for interface gas-liquid tracking. Several parameter are investigated in order to understand gas-liquid flow behavior such as: gravitational effect, contact angle (hydrophobicity/hydrophilicity of the gas diffusion layer material), liquid water volume fraction, liquid water velocity and air velocity. Results show that the liquid water flow behavior is directly linked to above parameter. Higher air velocity could flush more liquid water in the surface of gas diffusion layer, gravitational orientation also affect the ability to remove amount of liquid water.

FUTURE WORK

So far, several model development and numerical investigations have been conducted for both single cell and stack fuel cells. Furthermore, continuation studies will be carried out constituting both fundamental and applied research. For fundamental research, extension on the model development of two-phase flow using Volume of Fluid (VOF) theory accounting for interface mass transfer due to condensation or evaporation and electrochemistry. This will be done by employing a series of User Define Functions into current model.

Applied research will deal with thermal management issues couple with water management, and then some possible new design based on the model will also be developed. The applied research planned for the next phase study is as follows:

- Forced convection air cooling in stack:
An extension investigation from present study will be conducted. An transient fan cooling simulation with several mechanism including blowing and suction mode to avoid the present of hot spot along the fuel cell region will be conducted. Moreover, an additional cooling channel will be considered in order to enhanced heat removal rate to improve the stack performance.
- Wick design for water management:
Wicking action for the PEMFC can be used to control the amount of water inside the cell. This employs a hydrophobic bipolar plate with an electro-osmotic pump to control water at proper humidification level.

PUBLICATION

1. A.P. Sasmito, E Birgersson, A.S. Mujumdar, *Quantitative Comparison On the Effect of Net-Type Flow Gas Distributor on PEMFC Performance*, 10th AUN/SEED-Net Field Wise Seminar on Mechanical Engineering - New and Renewable Energy, Bandung 13-14 December 2007, Indonesia
2. A.P. Sasmito, E Birgersson, A.S. Mujumdar, *Implementation and Validation of a CFD Model for PEMFC with a Net-Type Flow Field*, 6th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics (HEFAT 2008), Pretoria South Africa. (presented)
3. A.P. Sasmito, E Birgersson, A.S. Mujumdar, *Numerical Investigation of PEMFC Stack Cooling*, 6th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics (HEFAT2 008), Pretoria South Africa. (presented – selected as invitation for journal publication)
4. K.W. Lum, E Birgersson, A.P. Sasmito, H.J. Poh, A.S. Mujumdar, *Numerical Study of Forced Air Convection for Polymer Electrolyte Fuel Cell Stacks*, 213 Electrochemical Society Meeting 2008, Phoenix Arizona United States of America. (presented)
5. A.P. Sasmito, E Birgersson, A.S. Mujumdar, *Framework for Modelling and Design of PEMFC Stacks with FLUENT*, 7th ASEAN ANSYS Conference, Singapore 2008 (presented)
6. A.P. Sasmito, E. Birgersson, A.S. Mujumdar, *Fuel Cell Stack: Thermal Management*, Workshop on Mathematical Modeling on Minerals, Metals, and Materials Processing, Singapore 14 March 2009
7. A.P. Sasmito, E. Birgersson, A.S. Mujumdar, *Numerical Investigation of Liquid Water Cooling for a PEMFC Stack*, Heat Transfer Engineering - An International Journal, Submitted (Selected paper from HEFAT 2008 conference)
8. K.W. Lum, A.P. Sasmito, E. Birgersson, A.S. Mujumdar, *Numerical Study of Forced Convection Air Cooling for PEMFC Stack*, manuscript in preparation
9. A.P. Sasmito, E. Birgersson, A.S. Mujumdar, *Analysis of Fan Performance for PEMFC Stack Cooling*, manuscript in preparation
10. A.P. Sasmito, E. Birgersson, A.S. Mujumdar, *Geometry Analysis for PEMFC Stack with forced convection air cooling*, manuscript in preparation