



**University
of Victoria**

Graduate Studies

Notice of the Final Oral Examination
for the Degree of Doctor of Philosophy

of

TE-CHUN WU

BSc (Chung Yuan Christian University, 1993)

MSc (National Cheng Kung University, 1995)

PhD (National Cheng Kung University, 2000)

“Two-Phase Flow in Microchannels with Application to PEM Fuel Cells”

Department of Mechanical Engineering

Thursday, April 9, 2015

10:00 A.M.

Engineering Office Wing

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Supervisory Committee:

Dr. Ned Djilali, Department of Mechanical Engineering, University of Victoria (Supervisor)

Dr. Rustom Bhiladvala, Department of Mechanical Engineering, UVic (Member)

Dr. Alexandra Branzan Albu, Department of Electrical and Computer Engineering, UVic (Non-Unit Member)

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Abstract

The performance of PEM fuel cells (PEMFC) relies on the proper control and management of the liquid water that forms as a result of the electrochemical process, especially at high current densities. The liquid water transport and removal process in the gas flow channel is highly dynamic and many of its fundamental features are not well understood. This thesis presents an experimental and theoretical investigation of the emergence of water droplets from a single pore into a microchannel. The experiments are performed in a $250\text{ }\mu\text{m} \times 250\text{ }\mu\text{m}$ air channel geometry with a single $50\text{ }\mu\text{m}$ pore that replicates a PEMFC cathode gas channel. A droplet manipulation platform is constructed using a microfluidics soft lithographic process to allow observation of the dynamic nature of the water droplets. Flow conditions that correspond to typical operating conditions in a PEMFC are selected. A test matrix of experiments comprised of different water injection velocities and air velocities in the gas microchannel is studied. Emergence, detachment and subsequent dynamic evolution of water droplets are analyzed, both qualitatively and quantitatively. Quantitative image analysis tools are implemented and applied to the time-resolved images to document the time evolution of the shape and location of the droplets, characteristic frequencies, dynamic contact angles, flow regime and stability maps. Three different flow regimes are identified, slug, droplet, and film flow. The effects of the air flow rate and droplet size on the critical detachment conditions are also investigated.

Numerical simulations using Volume-of-Fluid method are presented to investigate the water dynamics in the droplet flow. The focus of the modeling is on methods that account for the dynamic nature of the contact line evolution. Results of different approaches of dynamic contact angle formulations derived from empirically and using the theoretically based Hoffmann function are compared with the static contact angle models used to date. The importance of the dynamic formulation as well as the necessity for high numerical resolution is highlighted. The Hoffmann function implementation is found to better capture the salient droplet motion dynamics in terms of advancing and receding contact angle and periodicity of the emergence process.

To explore the possibility of using the pressure drop signal as a diagnostic tool in operational fuel cells that are not optically accessible, a flow diagnostic tool was developed based on pressure drop measurements in a custom designed two-phase flow fixture with commercial flow channel designs. Water accumulation at the channel outlet was found to be the primary cause of a low-frequency periodic oscillation of pressure drop signal. It is shown that the flow regimes can be characterized using the power spectrum density of the normalized pressure drop signal. This is used to construct a flow map correlating pressure drop signals to the flow regimes, and opens the possibility for practical flow diagnostics in operating fuel cells.