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Liquid water quantification in the cathode side gas channels of a proton exchange membrane fuel cell through two-phase flow visualization

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HIGHLIGHTS

- Liquid water in the cathode side channels of PEM fuel cell is quantified.
- Algorithm developed in MATLAB® to quantify liquid water in two-phase flow.
- Dominant flow patterns detected and quantified for each condition.
- The variation of liquid water in individual channels is compared.
- Correlation developed to predict ACR at different operating conditions.

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ABSTRACT

Water management is crucial to the performance of PEM fuel cells. Water is generated as part of the electrochemical reaction, and is removed through the reactant channels. This results in two-phase flow in the reactant channels. Increased understanding of the behavior of the liquid water in the channels allows us to devise better strategies for managing the water content inside the fuel cell. Most previous work has been focused on qualitative information regarding flow pattern maps. The current work presents new algorithms developed in MATLAB® to quantify the liquid water and to identify the flow patterns in the cathode side reactant channels. Parallel channels with dimensions matching those of commercial stacks have been used in this study. The liquid water present in the reactant channels is quantified for different temperature, inlet RH and current density conditions, and the results are presented in terms of area coverage ratio. The dominant flow patterns for the different conditions have been mapped, and trends interpreted on the basis of air flow velocities and saturation conditions within the channels.

1. Introduction

1.1. Overview

PEM fuel cells generate electrical energy from the electrochemical reaction of hydrogen and oxygen. Water is a by-product of the reaction. Water management remains a crucial limiting factor in the performance enhancement of proton exchange membrane fuel cells (PEMFCs) [1–8]. Understanding the two-phase flow of water and reactants in the flow field channels (of PEMFCs) has received significant attention in the past few years [1,5,7,9–14]. Most of the work has focused on the two-phase pressure drop in the reactant channels as the method for defining effectiveness of water management within the cell [5,9,10]. It has been identified as an important diagnostic tool for PEMFC performance [15].

The liquid water present in the gas channels affects the performance in two ways. Increased flow resistance decreases the reactant flow and causes localized starvation down the channel from the liquid water features. It also reduces the area available for diffusive mass transport into the GDL and increases the diffusion resistance for the reactants. Therefore it is important to quantify the liquid water present in the gas channels.

Transparent fuel cells have been used by different researchers to understand the behavior of liquid water in the reactant channels of

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an operating PEMFC [16–21]. However, most studies have focused on the qualitative evaluation of the liquid water features, such as identification of flow patterns, without providing quantitative information.

1.2. Literature review

The product water from the electrochemical reaction emerges into the channels, and is then removed from the cell. Water is removed in the form of vapor carried in the gas stream, and also as liquid water in the reactant channels. Various visualization techniques have been used to investigate the liquid water present in the reactant channels [15,16,18].

Neutron imaging has been used successfully while studying the presence of water in PEMFCs [19,22–25]. The water has high interaction with the neutrons, while PEMFC materials have low interactions. Kramer et al. [24] used neutron imaging to investigate liquid water in the flow fields, achieving a spatial resolution of 115 μm/pixel and a temporal resolution of 2 frames per second (fps). Access to neutron sources remains limited and expensive. Additionally, the temporal resolution is too low to observe changes in water flow patterns in the flow fields. Rapidly moving water features may travel at up to 1 m s^{-1} which would display as a thin film, leading to incorrect conclusions [19]. Therefore, neutron imaging, although well-suited to measuring saturation of the GDL or the MEA, would not be as accurate for quantifying liquid water in the flow fields.

X-rays have also been used for imaging of fuel cells [26–28]. However, as metals attenuate the high energy waves, modifications must be made to enable the X-rays to penetrate. Manke et al. [26] utilized high spatial resolution to study formation of liquid water inside individual pores of GDL. Although high temporal resolution can be obtained, it comes at the cost of spatial resolution. Thus, high temporal and spatial resolutions cannot be obtained simultaneously. Lee et al. [28] also used X-rays to visualize the temporal change in liquid water quantity within the cell. The study observed the cell from the in-plane direction: the thickness of the liquid water features was their focus.

Dunbar and Masel [29] used magnetic resonance imaging to study water distribution. They reported a 3D water concentration profile for the operational fuel cell. They successfully demonstrated that the majority of the water content was present on the cathode side.

Optical imaging systems have been around for centuries. They are easy to operate, accessible and cost effective. The maximum resolution is limited by the Rayleigh criterion at about 200 nm. However, the operating region for water management research in the flow fields is only limited by the quality of camera being used. Typical PEMFCs do not use optically transparent materials, and therefore require modifications and inclusion of optically transparent windows. One of the concerns with introducing this modification is the effect it has on the parameter being studied: in this case, the two-phase flow in reactant channels [30].

Optical imaging has been used to study water management in PEMFCs using in situ studies [17,19,20,31–36] as well as ex-situ investigations [37–41]. Various imaging techniques have been used to obtain qualitative data pertinent to liquid water within the reactant channels. Hussaini and Wang [33] quantified liquid water in the cathode channels for the first time in 2009. However, the focus of their work remained spatial quantification: they recorded static images after 30 min of operation, assuming that steady state condition had been achieved. Nirunsin and Khunatorn [34] used optical imaging to quantify the water in a single serpentine channel PEMFC. They investigated the change in liquid water coverage of the channel area with temperature and stoichiometry.

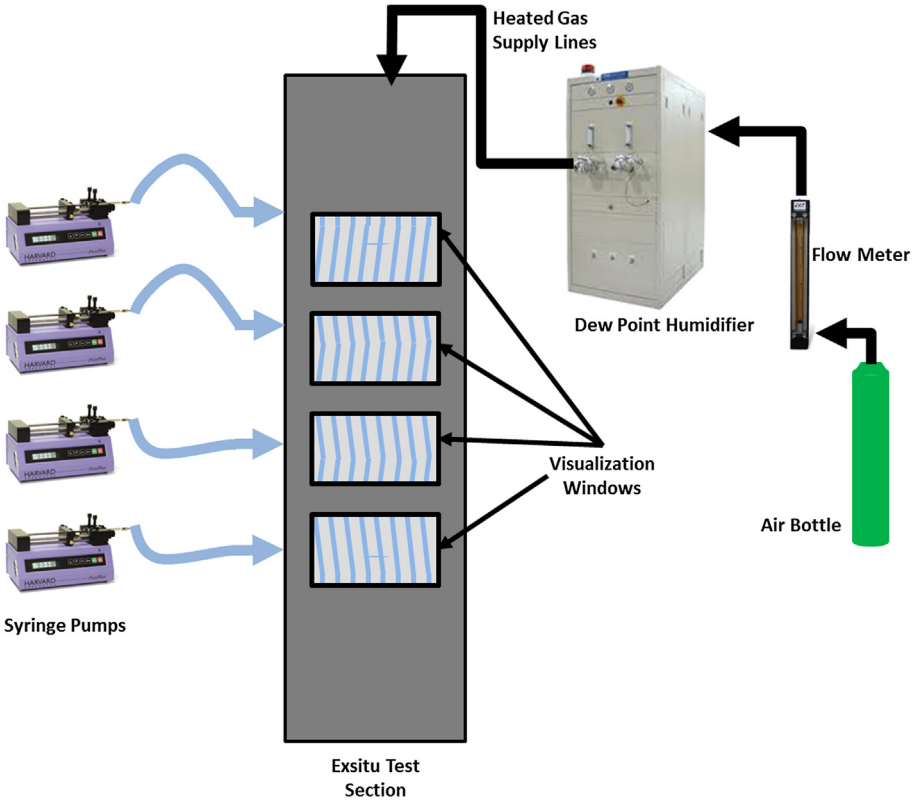

Fig. 1. Schematic of the ex-situ test setup used in this work.