International Journal of Heat and Mass Transfer 66 (2013) 90–100

Contents lists available at SciVerse ScienceDirect

International Journal of Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ijhmt

Gas–liquid two-phase flow in a mini-square-channel with a permeable wall (influence of surface characteristics of a permeable wall)

Jian Li [a,b], Jun Zhao [a], Shixue Wang [c,*]

[a] Key Laboratory of Efficient Utilization of Low and Medium Grade Energy, MOE, Tianjin University, Tianjin, China
[b] School of Vehicle & Motive Power Engineering, Henan University of Science and Technology, Luoyang, Henan, China
[c] State Key Laboratory of Engines, Tianjin University, Tianjin, China

ARTICLE INFO

Article history:
Received 16 December 2012
Received in revised form 18 June 2013
Accepted 19 June 2013
Available online 31 July 2013

Keywords:
Gas-liquid two-phase flow
Flow pattern
Surface characteristics
Pressure drop variation
Permeable wall

ABSTRACT

Characteristics of air–water two-phase flow in a mini-square-channel were investigated experimentally. One sidewall of the flow channel was made of permeable porous material (carbon paper). Air was fed into the channel from its inlet, while water was injected uniformly into the channel along the permeable wall. Based on the observed results, flow patterns of this special gas–liquid two-phase flow were classified, and different kinds of surface characteristics of the permeable wall were used, flow regime maps for specific flow parameters were drawn, and the influence of different combinations of gas flow rate and liquid infiltration amount on flow patterns were also analyzed. Meanwhile, the paper also provided a detailed analysis of the channel pressure drop characteristics in this kind of two-phase flow; with special focus on the influence of different kinds of permeable wall surface characteristics on pressure drop variation.

© 2013 Published by Elsevier Ltd.

1. Introduction

In the operation process, gas–liquid two-phase flow will be inevitably formed inside the cathode flow channel of a proton exchange membrane fuel cell (PEMFC). In this case, a clear understanding of the characteristics and the law of this kind of gas–liquid two-phase flow clear will be helpful to improve PEMFC's water management level, and has important scientific significance and application value. In a PEMFC, proton conductivity of the proton exchange membrane depends on water content of the film. The greater the water content, the higher the level of proton conductivity, while a deficiency of water content will seriously damage the battery's performance. Because water is generated in the cathode during the chemical reaction, water content increases along the gas flow direction gradually in the cathode flow channel. Therefore, during the operation of a PEMFC, a common phenomenon occurs at the inlet region of the flow channel: the water content of the proton exchange membrane is insufficient, while near the channel outlet, the increased water produced often leads to excessive water content in the channel. In serious cases, the lower water content of the membrane at the inlet of the channel will lead to a sharp voltage decline of the battery; we identify this as "dry-out phenomenon". While near the outlet, the air holes of the gas diffusion layer blocked by the produced water that cannot be discharged in time, and which also result in sharp voltage decreases, referred to as "flooding phenomenon". In the PEMFC's water management, a method to promptly eliminate reaction-generated water in the cathode channel is an important subject and research focus. In the PEMFC research, the influence of various operating parameters and channel geometry on the PEMFC's performance was studied [1–3]. Gasteiger et al. [4] studied voltage loss at high current density due to mass transport limitations. Owejan et al. [5] studied voltage instability at low current density. Rajalakshmi et al. [6] studied water transport characteristics of a PEMFC, and concluded that the major factor that affects the performance of the fuel cell when operated with dry gas is the product water transported to the anode and then back, which in turn depends on the area of the electrode, electrode preparation and flow field design.

For the past few years, the gas–liquid two-phase flow in a PEMFC's cathode flow channel has attracted increasing attention, and relevant theoretical studies and experimental studies have been gradually studied. Regarding early theoretical and numerical aspect simulation, one-dimensional models were dominant [7,8]. This type of model is relatively simple, but since the model only considered mass transfer perpendicular to the gas flow direction, there were large deviations when compared to gas–liquid two-phase flow in an actual PEMFC's flow channel. And a

* Corresponding author. Address: State Key Laboratory of Engines, School of Mechanical Engineering, Tianjin University, No. 92 Weijin Road, Tianjin 300072, China. Tel./fax: +86 22 27402567.

E-mail addresses: janlee127@tju.edu.cn (J. Li), zhaojun@tju.edu.cn (J. Zhao), wangshixue_64@tju.edu.cn (S. Wang).

0017-9310/$ - see front matter © 2013 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.ijheatmasstransfer.2013.06.045

Nomenclature

A_c	cross-sectional area of the channel, m^2
D_h	hydraulic diameter of the channel, m
J_L	velocity of liquid water infiltration, m/s
L_x	the axial distance, m
Q_L	liquid water infiltration amount, μL/ min
$x_{\max}$	the maximum value of liquid mass fraction
λ_e	experimental equivalent frictional drag coefficient
Q_G	volumetric flow rate of gas air, L/ min
d_e	equivalent diameter, mm
x	liquid mass fraction
A_p	area of the porous media sidewall, m^2
J_G	volumetric flux of gas air, m/s
L	the total length of the test section, m

Greek symbols

λ	equivalent frictional drag coefficient
ζ	local resistance coefficient
ρ	density, kg/m^3

Abbreviations

TH	temperature and humidity transmitter
FP	flow pattern

two-dimensional model has better applicability due to the mass transfer and reaction parallel to and perpendicular to gas flow direction considered simultaneously. Wang et al. [9] developed a two-phase model for channel flow in PEMFC, and studied water build-up and pressure drop in the flow channel. The results reveal that liquid water builds up quickly at the entrance region, followed by a slow increasing downstream under full-humidification inlet conditions. Basu et al. [10] indicated that the wetted area ratio on the cathode GDL surface, predicted by the model they established, matches quantitatively with experimental data over a range of current density, relative humidity and flow stoichiometry. Wang and Cheng [11], Wang et al. [12] established a two-phase flow and transfer model by using finite volume CFD technology and two-phase multicomponent mixture model, which can be used to describe transition states between the two phases. You and Liu [13] held the opinions that the threshold current density needed to form two-phase flow and the distribution of liquid saturation in the cathode side depends on the fuel cell operating temperature, cathode and anode humidification temperatures, and the characteristics of porous gas diffuser.

In experimental research, the commonly used method is to adopt visualization method to study the state of the gas–liquid two-phase flow in a PEMFC cathode flow channel. Chen [14] designed an assembly similar to the transparent PEMFC and studied air–water two-phase flow behavior experimentally. The results showed that the novel configuration featured less severe two phase flow mal-distribution and self-adjustment to water amount in channels. However, due to the porous media, pressure drop increased. And the dominant frequency of pressure drop signal was found to be a diagnostic tool for water behavior in channels. Hsieh et al. [15] studied the effect of pressure drop on water accumulation and current distribution in different flow channels at the cathode on water accumulation and current distribution for a micro PEMFC. The results showed that the total pressure drop was strongly influenced by the liquid volume fraction of the product water in the flow channels; and water formation, accumulation, and flooding are strongly dependent on the cathode air flow rate and channel type.

As can be seen from the above analysis, water management, as an important issue for fuel cell research and development studies, is widely developing both in numerical simulation and in experimental observation and measurement. However, the gas–liquid two-phase flow of PEMFC cathode flow channel is different from the traditional gas–liquid two-phase flow. The main difference is that during the process operation, the reaction generated water entering into the channel and the reactant gases are continuously consumed, and the gas–liquid ratio gradually changes. Due to the uniqueness of this kind of flow, basic research on the mechanism of this kind of gas–liquid two-phase flow is still relatively lacking. And this directly affects the accuracy of numerical simulation results and the development of an effective drainage method. Yang et al. [16] reported one kind of gas–liquid two-phase flow with a gas permeable sidewall. Gas infiltrates the flow channel uniformly along the direction of water flow, and the gas flow rate increases gradually along the channel. It is a peculiar flow phenomenon that belongs only to direct methanol fuel cell (DMFC). But this kind of flow also has many differences with the gas–liquid two-phase flow of a PEMFC cathode flow channel. In order to clarify the liquid generation and discharge mechanism of PEMFC cathode flow channel, and master the characteristics of this kind of gas–liquid ratio changing two-phase flow, the authors studied one kind of gas–liquid two-phase flow that was made of porous media (permeable wall made by carbon paper) on one side of the flow channel, where water infiltrates the flow channel along the gas flow direction, and the liquid infiltration amount increases gradually along the channel. In the previous study, the authors gave the experimental results of gas–liquid two-phase flow, where the cross-sectional area of the flow channel is 2×2 mm, and the material of permeable wall is ordinary carbon paper (TGP-120). The results showed that this kind of gas–liquid two-phase flow has special flow patterns and pressure drop characteristics compared to traditional ones. The authors made analytic study and gave the classification of flow patterns. Considering that the cross-sectional area of PEMFC cathode flow channel is often small, in this paper, the authors adopted a cross-sectional area of a 1×1 mm flow channel for further study. Meanwhile, the permeable wall used ordinary carbon paper and PTFE modification treatment carbon paper, and the experimental results were compared.

2. Experimental apparatus

2.1. Experimental system

The experimental system is shown in Fig. 1. It consists mainly of gas supply and water supply parts. The gas supply consists mainly of an air cleaner, air compressor, flow stabilizer, flow meter and flow controller etc. The water supply includes a micro-injection (peristaltic pump) and a water tank; this can ensure close contact between the surface of the liquid and the subsurface of carbon paper used as the permeable sidewall.

In the experiment, after the process of filtering, air was compressed by the air compressor, and then introduced into the flow stabilizer. After it was stabilized, it progressed through the flow controller, and was injected into the mini-flow-channel. Simultaneously, water was pumped to the water tank by a peristaltic pump, and then entered into the gas flow channel through the per-

Download English Version:

https://daneshyari.com/en/article/7057886

Download Persian Version:

https://daneshyari.com/article/7057886

Daneshyari.com