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The dynamic behavior of pressure during purge process in the anode of a PEM fuel cell

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Abstract

A one-dimensional mathematic computational fluid dynamics model of a proton exchange membrane (PEM) fuel cell is presented in this paper to simulate the transient behavior of hydrogen pressure in the flow field during a typical dynamic process—the purge process. This model accounts for the mechanism of pressure wave transmission in the channels by employing the characteristic line method. A unique parameter—pressure swing, which represents the top value of pressure variation at certain point in the channel during the purge process, is brought up and studied as well as the pressure drop. The pressure distribution along the channel and the pressure drop during the purge process for different operating pressures, lengths of purge time, stoichiometric ratios and current densities are studied. The results indicate that the distributed pressure, pressure drop and pressure swing all increase with the increment of operating pressure. With a high operating pressure a second-falling stage can be seen in the pressure drop profile while with a relatively low operating pressure, a homogeneous distribution of pressure swing can be attained. A long purge time will provide enough time to show the whole part of the pressure drop curve, while only a part of the curve can be attained if a short purge time is adopted, but a relatively uniform distribution of pressure swing will show up at the moment. Compared with the condition of stoichiometric ratio 1, the pressure drop curve decreases more sharply after the top value and the pressure swing displays a more uniform distribution when the ratio is set beyond 1. Different current densities have no apparent influence on the pressure drop and the pressure swing during this transient process. All the distribution rules of related parameters deducted from this study will be helpful for optimizing the purging strategies on vehicles.

Keywords: PEM fuel cell; Purge; Dynamic pressure; Simulation

1. Introduction

PEM fuel cells are considered as one of the most promising alternative power devices for both stationary and mobile applications. However, with regard to the longevity, the fuel cells for vehicle use inevitably cannot survive as a long period as for the stationary application. The reason may lie in the fact that the fuel cells for vehicle use frequently experience dynamic conditions which accelerate the aging process of the fuel cells [1]. Pressure wave transmission generated in the flow channels during the dynamic processes may lead to mechanical vibrations of the membrane electrode assembly (MEA) and accelerate its damaging. [2]. Early dynamic model by Amphlett et al. [3] based on coupling the steady state electrochemical model with an unsteady thermal model predicted the transient electrical response of start-up, load-step and slow-down operating conditions. Most of the following dynamic models [1,4–6] in the past were also set up to simulate the transient behaviors of current–voltage relation polarization curve, or develop modeling methods and experimental techniques for the study of current distribution under transient conditions [7,8], whereas few calculations have concentrated on the dynamics of pressure and flow conditions or specially modeling the transient response of pressure distribution in the flow channels. Though there had been many excellent models through CFD approach to simulate the flow and the along-channel pressure drop [9,10], most of them were limited to the pressure characteristics under steady state. Pathapati et al. [11] proposed a transient mathematical model incorporating the effects of dynamics of flow and pressure in both anode and cathode side and charge double layer to simulate the dynamic response of pressure as well as voltage output. However, the dynamic properties of pressure presented by

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them only characterize the average pressure in channels, while the pressure wave at certain point or non-uniformity of pressure distribution could not be caught since uniform pressure in the flow field has been assumed. Um et al. [12] developed a multidimensional model through CFD approach to simulate the transient details of electrochemical kinetic, current distribution, hydrodynamics and multicomponent transport in PEMFC. They studied the non-uniformity in the flow field during transient processes, but as mentioned above, this study also focused on the dynamic behaviors of polarization relation and local current distribution. Although the along-channel distribution of reactant and water vapor fraction had been presented simultaneously, the concentration of this study was still on the basis of performance output, other than the potential damages from the pressure dynamics in channels. Since the membrane electrode assembly (MEA) of fuel cell suffers from frequent pressure fluctuations generating in the channels during dynamic processes, a comprehensive understanding about the phenomena and regularity of pressure distribution is indispensable to improve the controlling strategies for various transient processes. Another important point that should be mentioned is that numerous dynamic simulations have been proposed while experimental data about the dynamic processes are scarce in the present. This work is to pursuit the dynamic characteristic of pressure in the flow field during a typical dynamic process—the purge process based on one-dimensional non-steady fluid simulation and experiments.

2. Model development

The PEM fuel cell model presented here is a one-dimensional, transient, computational model providing a detailed description of the following phenomena during the purge process on different operating conditions:

1. transient distribution of pressure along the channel in the anode;
2. pressure drop of the gas flow in the anode.

The equations governing the purge process include the mass and momentum conversion equation governing fluid flow, procedure equations governing the assumed isentropic process and the ideal gas state equation.

The governing equations and appropriate boundary conditions were implemented and solved in MATLAB environment based on the characteristic line method which has been classified as an excellent solution for the one-dimensional unsteady flow condition solving [13].

2.1. Assumptions

A complete computational fluid dynamics model of the flow field in fuel cell will involve many complex factors and related equations, which make the model complicated. Therefore, some assumptions should be made to simplify the model.

From a typical profile of pressure curve during the purge process shown in Fig. 1, the pressure variation can be divided into three stages: trailing edge, wave hollow and rising edge. According to numerous wave forms collected from the tests, consistent with the curves in Fig. 1, it can be concluded that the rising stage has to take relatively long time to recovery the initial pressure, compared with the other two stages. Since the recovery process proceeds smoothly and no fluctuations of pressure has been observed, the rising stage is ignored in this simulation to save the computational resource and improve the efficiency of calculation.

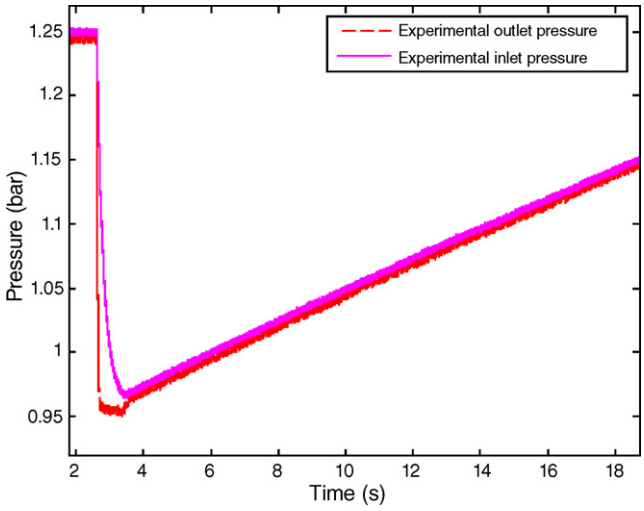

Fig. 1. A typical pressure curve of the purge process.

The modeled period including the trailing edge and the wave hollow lasts a very short time, usually less than 2 s, so the heat transfer between the gas flow and outside during this period can be ignored and an isentropic flow condition is assumed here. Thus, the energy equation can be neglected in the model. The adiabatic index k is assumed to be a constant and k is only related to the diatomic gas H_2.

The effect of the channel bends on the pressure drop is ignored here and the frictional is taken as the total pressure drop in the channel. The discrete pressure drop due to the bends in the channel is much less than the frictional pressure drop due to the viscosity of gas flow, and a calculated frictional pressure drop can be very near to the experimental data [14].

In the channels, water is assumed to exist in the vapor phase. This assumption is made to eliminate the two-phase flow condition in the model. While the liquid water may exist in practice, this is beyond the scope of this work.

Other assumptions used in this model are:

1. The hydrogen gas is assumed to be fully saturated by water vapor and the mixture of hydrogen gas and water vapor behaves as compressible ideal gas in the anode channels.
2. The flow is assumed laminar due to the low characteristic Reynolds number. The entrance and exit effect are neglected due to the length of channel.
3. Similar flow conditions are assumed in all of the channels.