Available at www.sciencedirect.com

ScienceDirect

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

A key geometric parameter for the flow uniformity in planar solid oxide fuel cell stacks

Wuxi Bi[a], *Daifen Chen*[a], *Zijing Lin*[a,b,*]

[a]*Hefei National Laboratory For Physical Sciences at the Microscale, University of Science and Technology of China, Hefei, Anhui 230026, China*
[b]*Department of Physics, University of Science and Technology of China, Hefei, Anhui 230026, China*

ARTICLE INFO

Article history:
Received 23 July 2008
Received in revised form
8 February 2009
Accepted 14 February 2009
Available online 26 March 2009

Keywords:
Flow distribution
SOFC stack
CFD calculations
Geometric parameter
Design optimization

ABSTRACT

Intensive CFD calculations are performed for the flow distribution in planar solid oxide fuel cell (SOFC) stacks with different number of cells. The calculations are based on 3D models with realistic geometric and operational parameters. The effects of design parameters, such as the channel height and length, the height of the repeating cell unit and the manifold width, on the flow uniformity are examined. The CFD results demonstrate that the ratio of the outlet manifold width to the inlet manifold width (α) is a key design parameter that affects the flow uniformity. The physical origin for the effect of α on the flow distribution is discussed and a simplified 2D model with the critical details of the flow physics is developed. The 2D model provides quality result for the optimal value of α and is easy to use for the broad engineering society.

1. Introduction

Planar solid oxide fuel cells (SOFCs) are emerging as a practical technology for high efficiency, high power density electric-power generation. One of the engineering problems in the design of planar SOFC stacks is the geometrical gas-flow configuration that should lead to uniform flow distribution and stable stack operation. It is possible to have a uniform flow distribution among cells piled in a stack by ensuring in the stack design that the pressure change in inlet/outlet manifolds is much lower than that in the gas channels in interconnect between individual cells. However, an important consideration is that the overall net pressure drop should be as low as possible to reduce parasitic power needed to drive pump or compressor. So high flow uniformity with relatively low net pressure drop is beneficial for the overall system efficiency and should be a goal of engineering design for the fuel cell stack. As the experimental test is expensive, time-consuming and difficult to explore combinations of various design parameters, theoretical approaches are favored in the engineering design of the SOFC gas-flow configuration.

There have been numerous studies in recent years on the flow distribution inside the individual cell [1–12]. A number of other studies have been focused on the flow distribution among the individual cells in a stack [13–22]. Boersma and Sammes [13] viewed the flow in an SOFC stack as a network of hydraulic resistance. Their model included the main energy loss terms and was able to point out the ratio of cells receiving less than the average mass flow to those getting more than the average in the stack. Based on the energy loss analysis, they

* *Corresponding author at*: Department of Physics, University of Science and Technology of China, Hefei, Anhui 230026, China. Tel.: +86 551 3606345; fax: +86 551 3606348.
E-mail address: zjlin@ustc.edu.cn (Z. Lin).
0360-3199/$ – see front matter © 2009 International Association for Hydrogen Energy. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijhydene.2009.02.071

also presented a 2D numerical approach to predict the stack flow distribution [14]. However, the two papers did not provide us any measure to improve the stack flow uniformity. Kee et al. [15] adopted a 2D model with laminar flow in cells and mass and momentum conservation equations for flow in stack inlet/outlet manifolds. They presented a flow uniformity design space map that showed the relationship between the flow distribution uniformity and the design parameters. The results, however, involve several design parameters and the key parameters responsible for the flow uniformity have not been clearly pointed out. Koh et al. studied the effects of pressure losses from different origins and presented an algorithm to solve the stack pressure and flow distribution with a 2D model [16]. Their theoretical analysis showed that the local energy loss in stack manifolds played an important role in determining the pressure and flow distributions in stacks. Chen et al. presented a 2D model analysis for PEM fuel cell stacks which was partially applicable to SOFC stacks [17]. They pointed out that larger channel resistance and manifold width and lower air feeding rate could enhance the uniformity of flow distribution.

Generally speaking, almost all of the studies on the fuel cell stack flow distributions were based on simplified model analyses. These model analyses are helpful for providing the overall characteristics of the flow distributions and certain guidelines for the flow uniformity design. However, these simplified models usually involve numerous approximations that may or may not be applicable to the realistic 3D stack configurations. Consequently, there are intrinsic uncertainties in the results given by simplified model analyses and they should be assessed by the computational fluid dynamics (CFD) calculation on realistic SOFC stacks.

In this work, realistic planar SOFC stack models were constructed and the CFD calculations were performed to provide the detailed flow distribution. Geometric parameters influencing the stack flow distributions were systematically varied in order to obtain the optimal flow uniformity. The ratio of the inlet manifold width to the outlet manifold width is found to be a key geometric parameter influencing the stack flow uniformity. The optimal value of the key parameter for the SOFC stack with a given number of single cells may be fitted with a simple expression. The CFD results are rationalized by the pressure energy loss analysis and a clear physical explanation for the flow distribution uniformity is obtained. Furthermore, an analytical model for determining the optimal value of the key parameter is provided that is easy to use for the broad engineering society.

2. Model descriptions

2.1. The planar SOFC stack model

The SOFC stack is composed of repeating single fuel cells connected in series. The core part of a single cell is a membrane electrode assembly (MEA) consisting of anode, electrolyte and cathode layers [23]. Another important component of a single cell is the interconnect with parallel channels dug in both sides to distribute the gas flow across the cell [24]. Sealing materials are also applied between the interconnect and the electrodes to avoid the gas leakage. The repeating single cells are enclosed by two ending plates to form a complete stack. A realistic planar SOFC stack with typical geometric parameters illustrated in the SECA core technology program [25] is constructed and illustrated in Fig. 1. The relevant geometric parameters for the gas flows in a reference cell are indicated in Table 1.

2.2. The gas model structure

As shown in Fig. 2a, the flow field in a unit cell may be divided into three parts: the inlet manifold, the cell gas channel and the outlet manifold. The inlet manifold for a single cell is a part of the stack inlet manifold. It leads the air (or fuel) into the single cell as well as transports the excess to the next cell. The overall manifold may be divided into different number of sub-manifolds for other design considerations. As shown in Fig. 2a, three parallel inlet or outlet manifolds were used in our stack model. The cell gas channel may be further divided into the feeding header, the channels between the interconnect ribs and the combining header. The air (or fuel) guided by the three parallel-inlet-manifolds is combined at the feeding header from which it is redistributed into each gas channel inside the interconnect plate. The rib and channel dimensions are shown in Table 1. The flows in cell gas channels meet at the combining header and then exhaust through the outlet manifolds. By connecting the single cell gas models in series, the overall stack flow structure is obtained and shown in Fig. 3.

For a stack with a given number of single cells, the geometric parameters that are influential to the stack flow uniformity are envisioned to be: the height of the repeating unit cell, H_{cell}, the height (h_{ch}) and length (L_{ch}) of the gas channels of the interconnect, the inlet manifold width (L_{in}) and the outlet manifold width (L_{out}). The five parameters are illustrated in Fig. 2b. For a given inlet manifold width, the outlet manifold width may also be represented by the ratio parameter, $\alpha = L_{out}/L_{in}$. As can be seen in Fig. 2a, α is also the

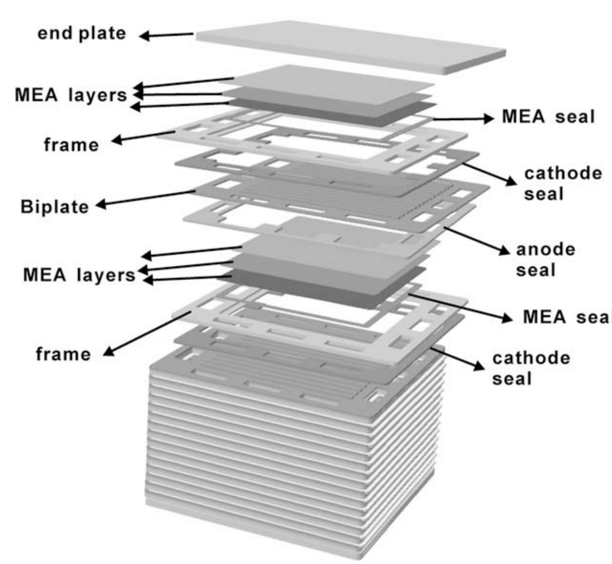

Fig. 1 – The structure of a realistic planar SOFC stack for our CFD studies.