Available at www.sciencedirect.com

ScienceDirect

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

Three-dimensional computational fluid dynamics modeling of anode-supported planar SOFC

Zuopeng Qu [a,*], *P.V. Aravind* [a], *S.Z. Boksteen* [a], *N.J.J. Dekker* [b], *A.H.H. Janssen* [b], *N. Woudstra* [a], *A.H.M. Verkooijen* [a]

[a] *Department of Process & Energy, Delft University of Technology, The Netherlands*
[b] *Energy Research Centre of the Netherlands (ECN), The Netherlands*

ARTICLE INFO

Article history:
Received 1 March 2010
Received in revised form
7 November 2010
Accepted 9 November 2010
Available online 21 December 2010

Keywords:
Three-dimensional
Anode-supported
Planar
SOFC
CFD model

ABSTRACT

Modeling plays a very important role in the development of fuel cells and fuel cell systems. The aim of this work is to investigate the electrochemical processes of a Solid Oxide Fuel Cell (SOFC) and to evaluate the performance of the proposed SOFC design. For this aim a three-dimensional Computational Fluid Dynamics (CFD) model has been developed for an anode-supported planar SOFC with corrugated bipolar plates serving as gas channels and current collector. The conservation of mass, momentum, energy and species is solved by using the commercial CFD code FLUENT in the developed model. The add-on FLUENT SOFC module is implemented for modeling the electrochemical reactions, loss mechanisms and related electric parameters throughout the cell. The distributions of temperature, flow velocity, pressure and gaseous (fuel and air) concentrations through the cell structure and gas channels is investigated. The relevant fuel cell variables such as the potential and current distribution over the cell and fuel utilization are calculated and studied. The modeling results indicate that, for the proposed SOFC design, reasonably uniform distributions of current density over the active cell area can be achieved. The geometry of the cathode gas channel has a substantial effect on the oxygen distribution and thus the overall cell performance. Methods for arriving at improved cell designs are discussed.

1. Introduction

The Solid Oxide Fuel Cell (SOFC) is considered to be a promising and environment-friendly energy conversion device with high efficiency, low emission level of pollutants and multi-fuel flexibility. However, its development still faces challenges towards its large-scale commercialization. To solve the problems encountered in the development of SOFC, a detailed understanding of the internal processes and an accurate prediction of operating parameters inside the fuel cell are essential. Such detailed understanding of the internal processes is also required for optimizing the SOFC design. Due to the costly and difficult experimental investigation, the mathematical modeling becomes an important tool [1,2].

A number of theoretical models have been developed to predict the temperature profile of SOFC. Studies of one, two or three-dimensional models with various configurations and geometries have been published for either tubular or planar types of SOFCs [7,16–25]. Many SOFC models so far published have all kinds of deficiencies, such as either simply ignoring the electrochemical reaction happening in the fuel cell, or assuming the cell as a single solid phase without considering the effect of the diffusion of gases through the porous

* *Corresponding author.*
E-mail address: z.qu@tudelft.nl (Z. Qu).
0360-3199/$ – see front matter
doi:10.1016/j.ijhydene.2010.11.018

electrodes. The resistance used in the electrochemical model is treated as constant, etc. The proposed model tries to avoid or minimize the deficiencies and inaccuracies by carefully dealing with the electrochemical reactions, diffusion phenomena and the cell resistance.

A research program is under way at the Energy research Centre of the Netherlands (ECN) cooperating with Delft University of Technology (TUD) and some other industrial partners to develop a 20 kW SOFC stack. TUD focuses on the development of models of the proposed SOFC design, which should enable the analysis of the internal processes of the SOFC, such as the fluid dynamic behavior of gases, temperature profiles, species concentrations and current density distributions, etc. and ultimately will be used as a tool to optimize the proposed SOFC design.

The aim of the work presented in this paper is to investigate the electrochemical processes inside an SOFC single cell fed with hydrogen as the fuel and to evaluate its overall performance. For this aim a three-dimensional Computational Fluid Dynamics (CFD) model has been developed for an anode-supported planar SOFC with corrugated bipolar plates serving as gas channels and current collector. With the modeling results, the distribution of temperature, flow velocity, pressure and the gas concentrations (fuel and air) through the cell structure and gas channels is investigated. Potential and current distributions over the cell and fuel utilization are computed. For this aim, the commercial CFD code FLUENT is used to solve the mass, momentum, energy and species conservation. The electrochemical reactions, loss mechanisms and related electric parameters throughout the cell are calculated using the add-on FLUENT SOFC module.

2. SOFC model development

2.1. Model specifications

The geometric model developed and described in this paper is based on an anode-supported planar SOFC with corrugated bipolar plates serving as gas channels and current collector above and below the active area of the cell. Fig. 1 shows the cross section of a single repeated channel in the cell. Fig. 2 shows the fuel flow and the configuration of the SOFC and Fig. 3 presents the dimensions of the full cell. Compared with the most common channel configurations such as the parallel, serpentine and interdigitated and their combinations, the proposed design can be easily manufactured and achieve a relatively lower resistance and then a less pressure loss of gases. The corrugated configuration of the separate plate can help to make fuel more evenly distributed over the cell [26]. The model developed and described in this work considers a single cell in the stack. The simulation of the single cell is supposed to be representative for the behavior of the whole stack, except the cells at the top and bottom of the stack where boundary conditions could be different.

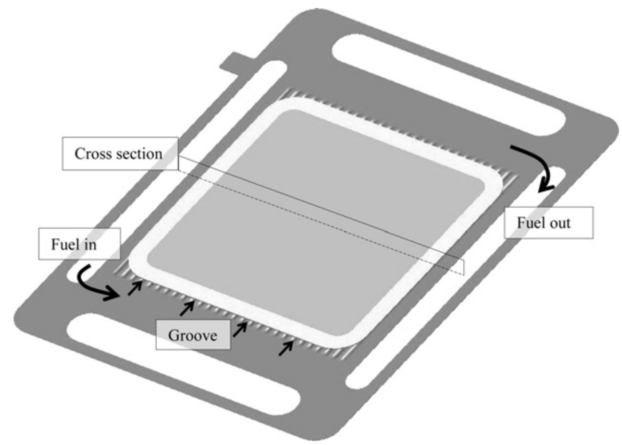

Fig. 2 – Schematic drawing of the fuel flow and configuration of SOFC.

Fig. 2 illustrates that a single repeating unit starts from a separator plate, with which the porous anode is in contact. The separator plate is corrugated in the central region so that the gases can flow in between the plate and the cell. Because of the anode-supported cell, a thin electrolyte is placed on top of the thick anode. The electrolyte is solid and ideally impermeable to gases. On top of the electrolyte is the porous cathode and another separator plate will be placed above the cathode to form a complete single repeated SOFC. The activation input parameters and material properties of the developed model are summarized in Table 1.

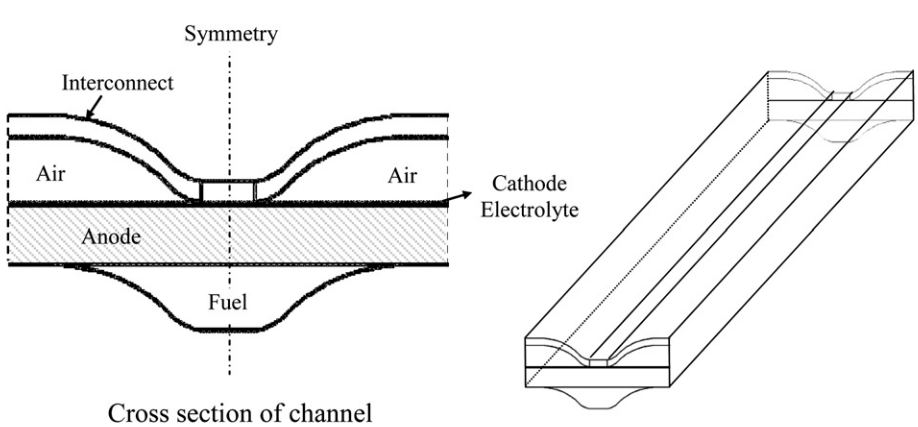

Fig. 1 – Geometric model of a single repeated channel.