Energy xxx (2014) 1–9

Contents lists available at ScienceDirect

Energy

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

Numerical modeling of interconnect flow channel design and thermal stress analysis of a planar anode-supported solid oxide fuel cell stack

S.-S. Wei, T.-H. Wang, J.-S. Wu*

Department of Mechanical Engineering, National Chiao Tung University, Hsinchu, Taiwan

ARTICLE INFO

Article history:
Received 12 November 2013
Received in revised form
8 March 2014
Accepted 13 March 2014
Available online xxx

Keywords:
SOFC
CFD
thermal stress
stack
interconnect

ABSTRACT

In this paper, we propose a new design of flow channel and stack arrangement based on the numerical study considering the effect of the flow channel design on the stack performance and analyze the thermal stress of a planar anode-supported solid oxide fuel cell stack. We also attempt to simplify the cell stack design without affecting its performance and propose an easier sealing method of cell stacks through the study of the thermal stress distribution. The results indicate that the new design, created by changing the cathode flow channel to a porous current collector, with a 6.3% increase in power density, an 8.6% increase in electrical efficiency. Both more uniform flow and current density distribution can be obtained as compared with a conventional counter-flow design. In addition, we propose a new design direction of cell stack, which could be simpler and easier to fabricate, in which material can easily undertake the resulting stress based on the thermal stress analysis.

1. Introduction

A fuel cell is a device that converts chemical energy into electrical energy through an alternative, environmentally benign electro-chemical process. Compared to other renewable energy technologies, the non-renewable fuel cell is a relatively stable power generation device. In particular, fuel cell technology is gaining attention due to its high efficiency compared to combustion engines and its ability to address the depletion of natural resources and global environmental concerns by zero carbon dioxide emissions if hydrogen is used [1].

Among the different types of fuel cells, solid oxide fuel cell (SOFC) is an all-solid-state fuel cell that has been considered as one of the promising energy technologies for residential and distributed power plants due to its much higher efficiency in combination with combined heat and power (CHP), multi-fuel flexibility and potentially low production cost [2–4], even though other types of power systems have increasingly improved their efficiency over the years. Currently, there are two geometrical types of SOFCs depending on the cell structure, namely, planar and tubular. Compared to tubular cell, planar type SOFC has gained significant interest, since it can be easily produced and sealed [5]. In addition, planar SOFCs can operate at high temperatures (700–900 °C), which is particularly attractive for CHP (combined heat and power) applications, and its overall efficiency can reach up to 90% [6–8]. However, to improve the design of the SOFC–CHP system, fuel cell stacking is considered to be one of the key factors that affect the overall efficiency, in addition to the optimization of the CHP system itself.

Understanding the details of the internal processes occurring within the SOFC experimentally is an expensive and challenging procedure. Therefore, theoretical tools, such as simulation modeling, are very important in realizing the design process of an SOFC stack system. Accordingly, this study considers the detailed mass and heat transports, together with the electro-chemical reactions simultaneously, to obtain the distributions of power density, current density, fuel/oxidizer concentrations, and thermal stress, among others, under stack operation. Based on these, it is possible to optimize the stacking of fuel cells at a low cost compared to direct experiments based on a trial-and-error approach. This makes simulation as an inevitable tool in the iterative design process [9,10].

In the past, numerous numerical simulation models have been developed to predict the effects of various stack geometrical and operating parameters of SOFC. Based on these results, many designs have been reported for the planar SOFC stack, with an aim to maximize the power density and fuel utilization, and to minimize

* Corresponding author. Tel.: +886 3 573 1693; fax: +886 3 611 0023.
E-mail address: chongsin@faculty.nctu.edu.tw (J.-S. Wu).

http://dx.doi.org/10.1016/j.energy.2014.03.052
0360-5442/

the non-uniform current density distribution and temperature distribution that directly contribute to the thermal stress in different SOFC components [11–19]. Thermal stress analysis is a very important method to study systematically the performance of a system operating at high temperature, e.g., gas turbine [20], laser welding [21,22], and SOFC [23–26], to name a few, because it is generally difficult to measure the detailed properties in such harsh environment. SOFC is generally operated at high temperatures, it may have stress concentration problem, which may cause the damage of the cell stack for a long-term operation. In the past, several studies have employed the finite element method to predict the thermal stress distribution of the system which could lead to a better design of the system, which is also one of the major objectives of the current study.

For the flow channel design of a proton exchange membrane fuel cell (PEMFC), how to deal with condensed liquid water effectively is one of the critical issues. The liquid water, which is produced through chemical reactions, often easily plugs the flow channels. It results in performance deterioration of the fuel cell. In general, PEMFCs with single serpentine flow channel can easily remove liquid water by supplying enough pressure difference and also recreates a relatively uniform current density distribution (e.g., [27,28]). In contrast, the solid oxide fuel cell is operated at high temperatures. There are only gases flowing in the cell stack. Unlike the PEMFCs, the flow plates of an SOFC are used to make the temperature distribution more uniform. High-temperature gradient may lead to either fuel cell crack or failure of the sealant. Thus, the use of flow plates with parallel channels is very common in SOFC.

Recknagle et al. [29] have shown that a counter-flow channel design results in a higher power density than co-flow and cross-flow designs. However, it has been shown that the cell stack design using counter-flow channels has certain inherent disadvantages. These include non-uniform flow distribution and often very complex structures needed for coupling the fuel and air flow inlet and outlet. For efficient cell stack design, the uniform inlet flow is very important, which can decrease the temperature variation of the cell stack structure and increase the cell power density [30–32]. To circumvent these disadvantages, one may have to design a very complex geometrical configuration of inlet and outlet channels for fuel and oxidizer.

Thus, in this study we propose a new design of counter-flow channels in a cell stack for improving the uniformity of the thermal–fluid–electrical properties, based on extensive computational fluid dynamics (CFD) simulations, which not only retains the high power density characteristics but also maintains the simplicity of the design. Furthermore, we have performed the simulation of the thermal stress of the stack to verify the feasibility of the design.

Table 1
Material properties used in the benchmarked case.

Porous anode (NiO + YSZ)	Thickness	1.8 mm
	Density	6500 kg/m^3
	Specific heat	450 J/kg K
	Thermal conductivity	10 W/m K
	Electron conductivity	333,330 1/Ω-m
	Viscous resistance	1e + 13 1/m^2
	Porosity	0.24
	Tortuosity	3
	Anode transfer coeff.	0.7
	Cathode transfer coeff.	0.7
	Exchange current density	200,000
Porous cathode (LSM)	Thickness	0.03 mm
	Density	5620 kg/m^3
	Specific heat	450 J/kg K
	Thermal conductivity	11 W/m K
	Electron conductivity	7937 1/Ω-m
	Viscous resistance	1e + 13 1/m^2
	Porosity	0.375
	Tortuosity	3
	Anode transfer coeff.	0.7
	Cathode transfer coeff.	0.7
	Exchange current density	800
Electrolyte (YSZ)	Thickness	0.02 mm
	Density	5480 kg/m^3
	Specific heat	450 J/kg K
	Thermal conductivity	2 W/m K
	Resistivity	0.1
Interconnect (metal)	Density	8900
	Specific heat	446 J/kg K
	Thermal conductivity	72 W/m K
	Electron conductivity	1.5e + 07 1/Ω-m
	Anode contact resist.	1e−07 Ω-m^2
	Cathode contact resist.	1e−08 Ω-m^2

2. Numerical method

In the three-dimensional modeling work, commercial package, named ANSYS-FLUENT and ANSYS [33], which was, respectively, employed to simulate the thermal–fluid–electrical field and the thermal stress distribution within a cell stack. Initially, by using the CFD model, which includes an SOFC module, we solved the continuity, momentum, energy, and species continuity equations

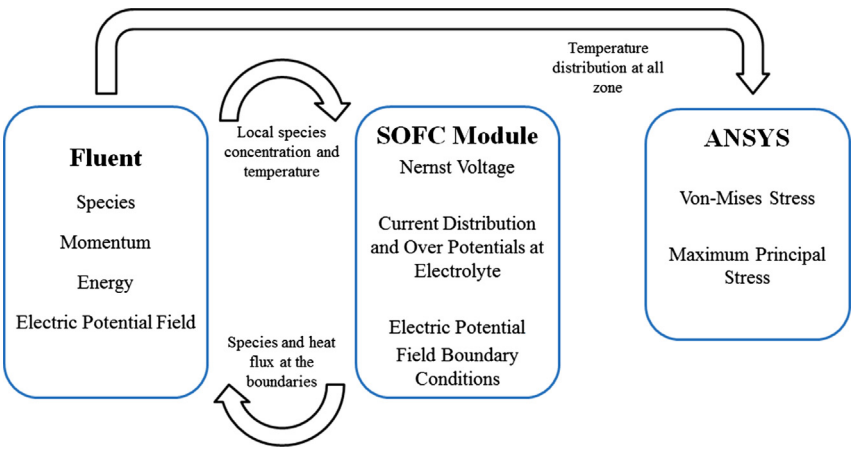

Fig. 1. Coupling of flow solver, SOFC module, and stress solver.

Please cite this article in press as: Wei S-S, et al., Numerical modeling of interconnect flow channel design and thermal stress analysis of a planar anode-supported solid oxide fuel cell stack, Energy (2014), http://dx.doi.org/10.1016/j.energy.2014.03.052