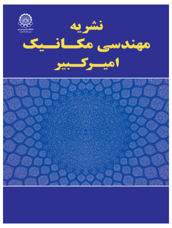

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Three-Dimensional Numerical Study of Solid Oxide Fuel Cell Performance with Converging Diverging Flow Field

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ABSTRACT: The main important roles of bipolar plates in solid oxide fuel cells are the uniform distribution of reactants to the reaction sites, the collection of current, and the separation of each cell from another. Therefore, the performance of a solid oxide fuel cell is highly dependent on air and fuel flow channel design. In order to investigate how the geometry of air and fuel flow channels affects performance, current, and power density, simulation results are discussed to evaluate the performance of two types of fuel cells with direct ducts and converging-diverging ducts. In this research, a three-dimensional model of an anode-supported hydrocarbon fueled solid oxide fuel cell is presented. The results show that the pressure difference between the converging diverging channels produces a transverse flow in the channels and ribs which is in favor of better distribution of the reactants in the fuel cell with the converging diverging channels. This transverse velocity causes a 6% increase in fuel consumption in the cell with converging diverging channels than the cell with direct channels at a voltage of 0.7V, but due to the reduction of the reaction area of this cell compared to the usual cell, the current density is 10% lower. At voltages above 0.55V, fuel cells with converging diverging channels have a higher fuel consumption than fuel cells with direct channels due to the presence of transverse flows.

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1- Introduction

Solid Oxide Fuel Cell (SOFC) is an effective energy conversion device that converts chemical energy into electrical energy and heat through electrochemical reactions of fuel and oxidant [1]. A planar SOFC consists of an ion-conducting cermet electrolyte that is sandwiched between two porous electrodes, which in turn are appended by bipolar-plate interconnectors that have flow channels etched in them to supply the fuel and oxidant [2]. The bipolar plate is a layer that is responsible for gas transfer, effective mass transfer, and uniform distribution of reactants and leads to the production of a uniform electric current to increase the power density of the cell. An important role of bipolar plates is the uniform distribution of reactants to reaction sites. These plates also help collect current, maintain a stable temperature, and separate each cell from the other. Gaseous species flow through gas channels. Channel walls collect current from the electrochemical reaction surface and direct it out of the fuel cell. In order to achieve a balance between a larger electrochemical reaction area and a shorter current collection pathway, one must answer the question of how bipolar plates should be designed and what kind of geometry is suitable for having the highest output power density and best cell performance.

A detailed literature review of various SOFC design and performance optimization has been carried out by Ramadhani et al. [3]. This review shows that studies that have investigated the effect of channel geometry on the performance of solid oxide fuel cells are rare. While many studies have been done on the design of bipolar plates in proton membrane fuel cells. Among the few studies on channel geometry [4-6], a study examining the three-dimensional effect of channel convergence and divergence on solid oxide fuel cell performance has not yet been observed. Also, the fuel used in the anodic channel in all research is hydrogen. Therefore, in this study, in order to investigate the effect of converging diverging channels on the efficiency of solid oxide fuel cells, the performance of two types of fuel cells fed with a modified natural gas mixture including direct channels and converging diverging channels have been compared.

2- Modeling

In this study, two types of cells with normal channels (including three straight channels with a width of 2 mm and a height of 1 mm) and converging diverging channels (including two converging channels and one diverging channel) have been investigated. Fig. 1 shows the top view of both types of fuel cells. Details of cell geometry with normal channels are listed in Table 1. The three dimensional steady-state model for an anode-supported SOFC is used to analyze

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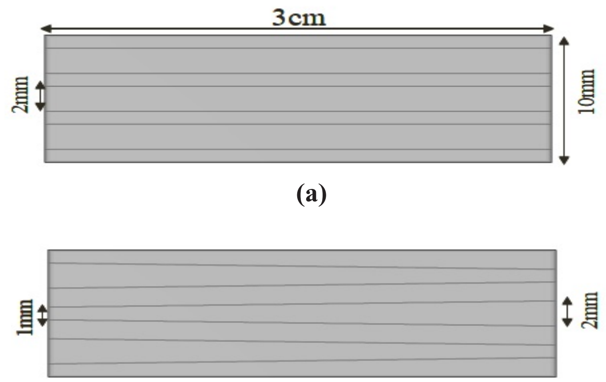

(a)

(b)

Fig. 1. Top view of fuel cells with a / direct channels b / converging diverging channels

Table 1. Geometric details of simulated fuel cells

Cell geometry parameters	units	Value
Channel length	mm	30
Fuel/Air channel height	mm	1
cell width	mm	10
Interconnect thickness	µm	300
Electrolyte thickness	µm	10
Cathode active layer thickness	µm	20
Cathode support layer thickness	µm	50
Anode active layer thickness	µm	15
Anode support layer thickness	µm	400

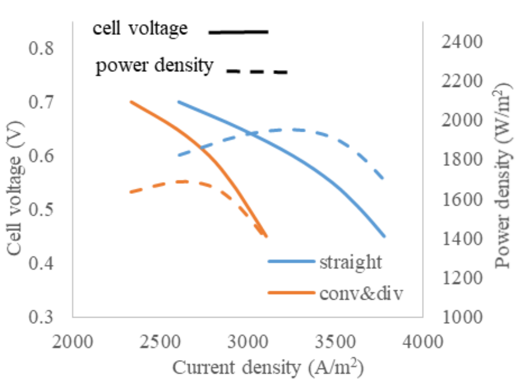

Fig. 2. Polarization and cell power diagrams for both types of channel geometry

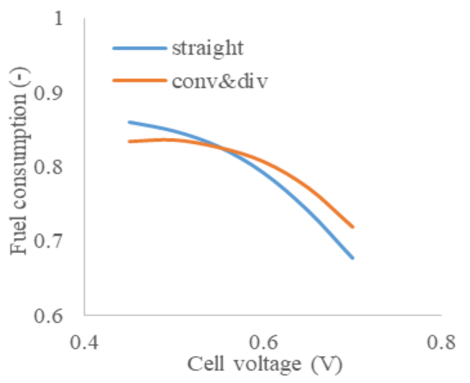

Fig. 3. The effect of convergence and divergence of channels on fuel consumption

the electrochemical reaction coupled with conservation of gaseous species mass, momentum, energy, and charge. The governing equations are solved by the commercial software COMSOL Multiphysics (version 5.4). The computational domain includes interconnecting, fuel and air flow channels, electrodes active and support layer, and electrolyte dividing the total cell into the nine zone. The temperature dependence of thermal conductivity and heat capacity of gas species are taken into account. It is assumed that the gas flow within the channel and electrode is laminar due to the low velocity. Also, in order to reduce the calculation time, local thermal equilibrium between gas and solid phases within the porous electrodes is considered and co-flow configuration is modeled in all channel designs. Finally, an ideal gas is applied for all gaseous species.

3- Results and Discussion

To study the effect of channel convergence and divergence on solid oxide fuel cell performance, simulations were performed for six different operating voltages (0.45, 0.5, 0.55, 0.6, 0.65, and 0.7 volts). Fig. 2 shows the polarization and power density diagrams for both converging diverging and straight channel geometries. For both channel geometries, the current density increases as the operating voltage decreases. As the current density increases, the power density first increases and then decreases due to the decrease in the cell voltage. This Figure also shows that the fuel cell with direct channels has a higher current and power density than the fuel cell with converging diverging channels. This difference is lower at higher voltages. The reason for the increase in current density in direct channels is a 33% increase in the area of direct channels (the interface between channels and electrodes) compared to converging diverging channels and an increase in the mass flow rate of fuel and air entering these channels. Therefore, a cell with direct channels has better performance than a cell with converging diverging channels, that means convergence and divergence of channels have a negative effect on current density and power. Fig. 3 shows the fuel consumption coefficient for different cell voltages for both types of cells with different channels. As can be seen, as the cell voltage increases, the fuel consumption coefficient for both types of cells decreases. This diagram also shows that these two curves have an intersection point, that is, up to an operating voltage of 0.55 V, the fuel cell with direct channels has a higher fuel consumption coefficient than the cell with converging diverging channels, however, for voltages higher than 0.55 volts, the fuel cell with converging diverging channels has a higher fuel consumption coefficient. Therefore, at operating voltages below 0.55 volts, the fuel cell with converging diverging ducts has a lower fuel consumption, current, and power density than the fuel cell with direct ducts. At an operating voltage of 0.7 volts, a fuel cell with converging diverging channels has a 6% higher fuel consumption coefficient but a 10% lower current density than a direct-channel fuel cell.

4- Conclusions

In this paper, a three-dimensional mathematical model of an internal reforming planar solid oxide fuel is presented. Numerical solution results are presented to evaluate the performance of two fuel cells with converging diverging channels and ordinary direct channels. The result of these simulations showed that the pressure difference between the converging diverging channels leads to the production of transverse flow in the channels and ribs for better oxygen distribution in the cathodic active layer. For voltages above 0.55 volts, the fuel cell with divergent ducts has a higher fuel consumption coefficient than the fuel cell with direct ducts due to the presence of transverse currents. Increasing the fuel consumption coefficient in the fuel cell with converging diverging channels improves the performance of this type of cell compared to the cell with normal direct channels in operating voltages higher than 0.55 volts.

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