DETERMINATION OF OPTIMUM FLOW FIELD FOR SOLID OXIDE FUEL CELL (SOFC) INTERCONNECTS UNDER SPECIFIED CONDITIONS

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ABSTRACT

In a typical fuel cell system, hydrogen gas (as fuel) and oxidant gases should arrive and be separated homogeneously at the anode and cathode sides of cell for the purpose of increase efficiency in fuel cell systems. This study aimed to investigate optimum flow field for SOFC interconnects under specified conditions. Eight different flow field geometries, namely pin (grid), single serpentine, parallel serpentine, parallel (straight) and their variations were designed for the purpose to provide homogeneous hydrogen flow in the anode side. Flow fields were set as 1 mm gas channel width and height, 1 mm interconnect width and 40x40 mm^2 active areas for all designs. Superficial velocity distributions for the channel designs and the effects of gas flow geometry on velocity distributions were determined using COMSOL Multiphysics®. Results indicated that design # 8 yielded more homogenous gas flow compared to other channel designs.

1. INTRODUCTION

The humanity demands a sustainable supply of clean and economical energy due to environmental problems like global warming and greenhouse effects. The important of alternative energy resources increasing day by day due to detrimental effects to environment and depleting of fossil fuel resources. Fuel cells convert chemical energy directly into electricity without combustion and solid oxide fuel cells (SOFCs), in particular, have many advantages such as high efficiency, fuel flexibility, appropriate for cogeneration and independence of precious metal catalysts in the various fuel cell types [1,2]. SOFCs basically consist of mainly three components which are membrane electrode assembly (MEA), interconnect and sealant. The electrochemical reaction occurs in MEA., Interconnects, on the other hand, provide mechanical support to the stack and collect the current produced in the cells, and sealants prevent air/fuel leakages in between MEA and interconnects [3,4]. Interconnect is one of the key components of SOFCs stack through which multiple cells are connected in series [5]. Moreover, interconnects provide electrical contacts between cells, distribute reactive gases on both sides of cell (anode and cathode sides) and separate the anodes and cathodes of adjacent cells in the stack [5-7].

It is essential that interconnects fulfill the following conditions throughout the very wide range of temperatures (25–1000 °C) and chemical conditions that they are exposed to [7]:

- Excellent electrical conductivity, preferably in excess of 1 S/cm.
- Impermeable to both fuel and oxidizing gases, which is achievable through materials with low porosities (<6%) or high densities relative to the theoretical density (>94%).
- Stable as chemically, microstructurally and mechanically. Compatible thermal expansion coefficient with both electrodes and with the electrolyte.
- Good thermal conductivity (>5 W/mK) in order to transport heat produced in the anode to the cathode, increasing the efficiency of the latter.

- Easy and low-cost both in terms of materials and manufacturing.

Metal and ceramic materials are used for interconnect manufacturing, in general. Metallic interconnects perform better than ceramics in various aspects such as improved manufacturability, good mechanical properties, more cost-effective, easy fabrication as well as higher electrical and thermal conductivity [8-9].

Channel design on interconnects is important design factor that affects the fuel cell performance. There are many studies in the literature on interconnect design and analysis [10-19].

Danilov and Tade developed a new anode flow field design and compared conventional flow field design which has parallel flow field configuration and simulated using FLUENT software [10]. They indicated that the importance of the anode flow field design for planar SOFCs based on simulation results.

Duhn et al. [11] investigated the optimal design for a special gas distributor for solid oxide cell, numerically. In another study by Khazaee and Rava, numerical analyses were performed for different interconnect designs which includes rectangular, triangular and trapezoidal shapes for gas channels [12]. They indicated that higher performance was obtained by using rectangular geometry over triangular and trapezoidal geometries.

Huang et al. concluded flow uniformity in various interconnects and its influence on cell performance of a planar SOFC using a transparent hydraulic platform [14]. They concluded that numerical flow data are found in good agreement with experimental results; and Reynolds number (*Re*) has a strong influence on cell performance. They proposed that their new design can substantially improve the degree of flow uniformity in interconnects resulting in 11% increase of the peak power density.

Qu et al. studied the electrochemical process conditions of SOFC to evaluate the performance of proposed (parallel flow field geometry) SOFC design [15]. They investigated the distributions of temperature, flow velocity, pressure and gaseous concentrations through the cell structure and gas channels by using the commercial CFD code FLUENT, and implemented add-on FLUENT SOFC module for modelling the electrochemical reactions. They found that the geometry of the cathode gas channel has a substantial effect on the oxygen distribution and thus the overall cell performance.

Wei et al. expressed effects of flow channel geometries of interconnects, inlet and outlet port designs and stress distribution of the design on a counter-flow planar anode-supported SOFC stack, numerically [16]. It was found that porous media current collector at the cathode side increased the maximal power density, fuel utilization and electrical efficiency. The employed stack design provided more uniform flow and current density distribution when compared to a conventional counter-flow design.

In an another study Zhao et al., a 3-D FEA model was established to investigate the flow distribution and the pressure variations in a 40-cell SOFC stack using ANSYS FLUENT 13.0 with SIMPLE method [19]. The results showed that the flow uniformity strongly depends on geometric shapes of manifold. In addition, it was found that the flow distribution can be strongly influenced by the gas resistance of the stack, which is closely related to the configuration of interconnect channels.

This study aimed to investigate the effect of different channel geometries on the efficiency of the fuel cell, numerically. To this goal, eight different gas flow field geometries were investigated and superficial velocity distributions and flow profiles throughout channel were determined using COMSOL Multiphysics® computational fluid dynamics (CFD) software.

2. MODELING

Fuel and oxidant gases are transferred to the cell area through interconnect channels. Therefore, channel design of interconnect is very important.

Two-dimensional (2D) models were designed in SolidWorks software and than were integrated into the COMSOL Multiphysics® software. Geometrical parameters of cells are listed in Table 1. All dimensions were set as 1 mm and cell active area of 40 x 40 mm^2 was employed.

Table 1. Geometrical parameters

Parameter	Element	Value (mm)
Gas channel width	$W_{channel}$	1
Gas channel height	$l_{channel}$	1
Interconnect width	$W_{interconnect}$	1
Cell width	L_{cell}	40
Cell height	W_{cell}	40

Schematic figure of model and details of channel geometry is presented in Fig. 1. (Dimensions are not scaled)

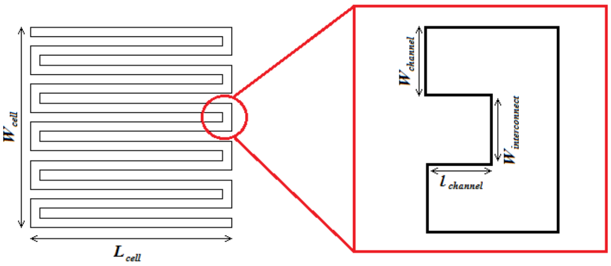

Fig. 1. Schematic figure and details of flow field

2.1. Model Designs

Eight flow channels were designed through SolidWorks software. Design and flow type configurations are presented in Table 2.

Table 2. Flow field designs and flow field types

Design #	Flow Type Configuration
1	Single serpentine
2	Single serpentine variation
3	Parallel serpentine
4	Pin (grid)
5	Parallel (straight)
6	Parallel (straight)
7	Parallel (straight) variation
8	Parallel (straight) variation

Flow type configurations which consist of single serpentine, parallel serpentine, pin (grid), parallel (straight) and their variations were investigated under same operating conditions. For this purpose, all flow field designs, inlet and outlet areas, gas inlet velocity and channel dimensions were kept as constant. Hydrogen gas inlet velocity was set as 2 m/s for all designs. Top views (x-y axis) of designed flow field geometries are shown in Fig. 2. Applied conditions, on the other hand, were listed in Table 3.

Table 3. Operating conditions for designs

Parameter	Value
Fluid type	H_2
Inlet velocity	2 m/s
Inlet pressure	1 atm
Channel width	Constant
Gas inlet area	Constant
Gas outlet area	Constant

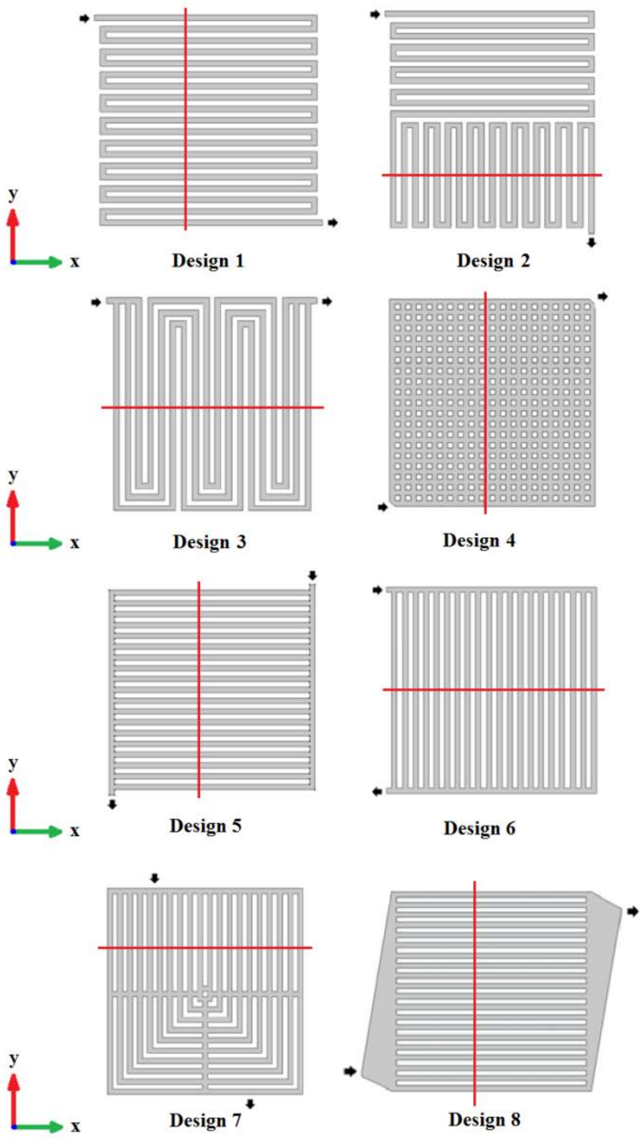

Fig. 2. Flow field designs

As the inlet velocity of hydrogen gas is low and velocity distribution is variable throughout the cell, velocity distributions were obtained throughout red lines to determine the average velocity variation on the cell surface. Red lines are shown in Fig. 2 for all designs.

2.2. Numerical Solution

Flow field velocity profiles were obtained through numerical solutions of Navier-Stokes (1) and Continuity (2) equations.

$$\rho\ (\partial u\ /\ \partial t)\ -\ \nabla.\ \mu\ (\ \nabla u\ +\ (\ \nabla u)^T)\ +\ \rho u.\ \ \nabla u + \nabla p=0 \qquad (1)$$

$$\nabla.u=0 \qquad (2)$$

where ρ denotes gas density (ρ=0,0899 kg/m^3), μ denotes dynamic viscosity (kg/m.s), u denotes velocity (m/s) and p denotes pressure (Pa).

3. RESULTS

Superficial velocity distributions for eight different flow field geometry designs are shown in Fig. 3. It was observed that more homogeneous distributions were obtained in Designs 1, 2 and 3 compared to the other designs. Fairly similar and homogeneous velocity profiles were obtained in Design 1 and Design 2, and it was determined that the velocity values were above 2 m/s in many points although gas inlet velocity was set as 2 m/s. It was understood that the flow velocity was maintained around 2 m/s in many fields in Design 3.

Water vapor, which is by product of electrochemical reaction of hydrogen and oxygen, exists in the same flow field with hydrogen (fuel) and bring about the decrease of hydrogen reaction surfaces acting like inert gas. For this reason, more of fresh hydrogen should be delivered in reaction fields and the water vapor should be homogenized as much as possible. Therefore, it was concluded that the flow field should have more hydrogen inlet and shorter circulation distance.

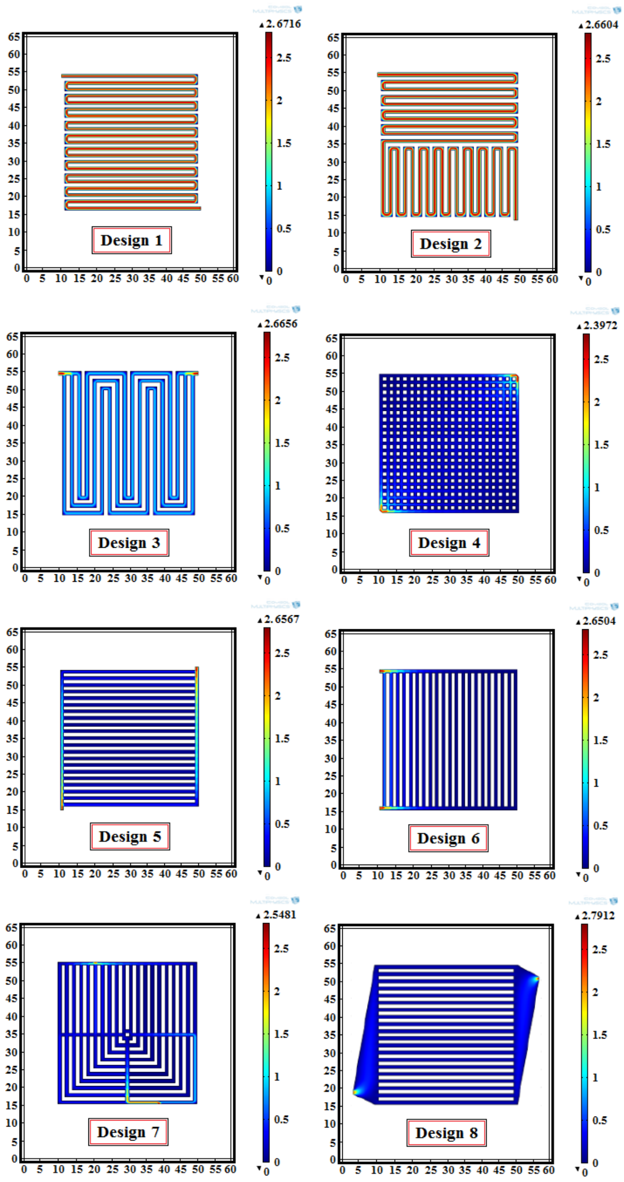

Fig. 3. Superficial velocity distributions of designed flow fields

Flow profile lines were presented in Fig. 4 throughout red lines to determine the average velocity changing on the cell surface. It was observed that flow profiles are quietly non-uniform in Designs 4, 5, 6 and 7 while those are mostly uniform in Designs 1, 2, 3 and 8. The least water vapor pressure should provide to increase the reaction efficiency of hydrogen. It was considered that Design 1, 2 and 3 can perform lower reaction performance of hydrogen due to their high vapor water pressure. Therefore, it was expected that Design 8 would perform high electrochemical efficiency in comparison to the others owing to its multi-channel system and low vapor water pressure.

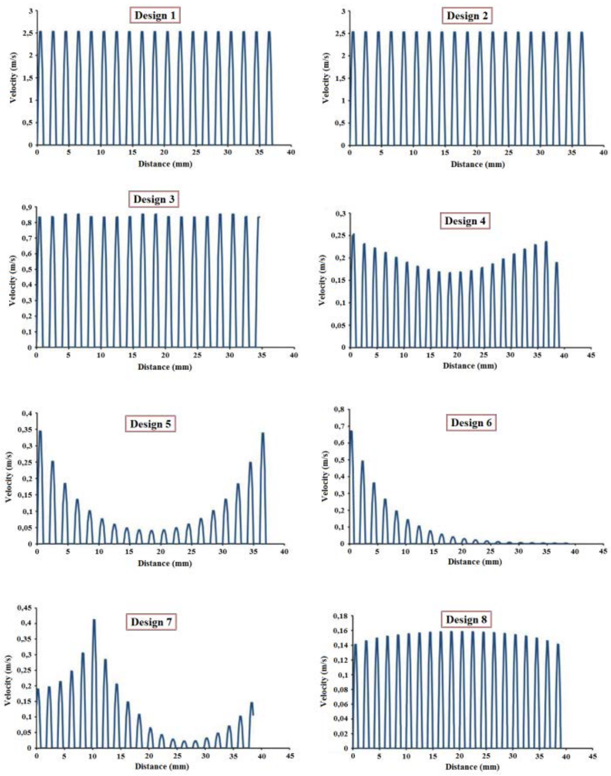

Fig. 4. Flow profile lines throughout red lines

4. CONCLUSION

Superficial velocity distributions for the channel designs and the effects of gas flow geometry on the velocity distributions of different SOFC interconnect channel designs were determined using COMSOL Multiphysics®. Results indicated that Design 8 yielded more homogenous gas flow compared to channel other designs.

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