Manifold design for flow uniformity in SOFC stack

Junhak Lee[1], Eunseop Yeom*[1,2]

1. Graduate School of Mechanical Engineering, Pusan National University

2. School of Mechanical Engineering, Pusan National University

2, Busandaehak-ro 63beon-gil, Geumjeong-gu, Busan, Republic of Korea

** E-mail: ljh5778@pusan.ac.kr*

ABSTRACT

The performance of solid oxide fuel cells (SOFC) is significantly influenced by the temperature and flow distribution within stack. In this study, computational fluid dynamics was used to design manifolds to improve the flow uniformity. Seven different sloped manifold designs were created for manifold widths of 5 mm, 10 mm, and 30 mm. The basic model is a manifold with an inlet-to-outlet length ratio of 9:9, while models with ratios of 3:15 and 6:12 were analyzed with varying slope directions, categorized as Outside, Inside, and Symmetric sloped. The analysis showed that the 3:15 ratio models exhibited low uniformity due to excessively narrow inlet, while the 6:12 ratio models showed higher uniformity than basic model. Among the 6:12 models, high uniformity was shown in the order of Symmetric, Inside, and Outside, depending on the slope direction. It was also confirmed that flow uniformity is proportional to manifold width in all seven models.

KEY WORDS

SOFC; Manifold; Flow uniformity

1. INTRODUCTION

A Solid Oxide Fuel Cell (SOFC) utilizes a solid oxide electrolyte to produce electricity through an electrochemical reaction between air and fuel. The SOFC consists of a unit cell composed of an anode, cathode, electrolyte, and bipolar plate, and achieves mass production of electricity by stacking these unit cells into a structure called a stack (1). Due to the high operating temperatures and associated costs of SOFCs, performance and flow analysis is often conducted via Computational Fluid Dynamics (CFD) rather than through experiments (2).

This study aims to improve flow uniformity in a planar SOFC by designing the manifold geometry through which fuel and air are distributed to the unit cells. A rectangular cross-section manifold is designed with varying width along the flow direction, and its performance is compared with that of a manifold with a constant cross-sectional area. Adjustments to the direction of cross-sectional changes and the width variation in the manifold are made to enhance flow uniformity.

2. SIMULATION PROCESS

2.1 Modeling and Analysis Conditions

The computational analysis was conducted on the air channels of a stack comprising 20 unit cells, with the representative configuration shown in Fig. 1(a). Each unit cell measures 110 mm × 130 mm × 5.76 mm, designed to accommodate a PEN layer area of 100 mm × 100 mm. The total manifold length is 164.2 mm, with a gradient applied over 114.2 mm, which connects the unit cells and excludes a 50 mm clearance below the inlet manifold. The air channel configuration in Fig. 1(a) depicts the "basic model," with a manifold of a constant 10 mm width. Fig. 1(b) visualizes the flow direction in the basic model. In this study, seven gradient models were applied to inlet manifolds with widths of 5 mm, 10 mm, and 30 mm, respectively. Fig. 1(c) illustrates examples of the Outside 3-15, Inside 3-15, and Symmetric 3-15 models with a 10 mm width inlet manifold, each showing the same 3-15 inlet-to-end ratio but with different gradient directions. The seven specific models and their nomenclature are detailed in Table 1, where the initial letters I (Inside), O (Outside), and S (Symmetric) indicate the gradient direction, while the following numbers denote the inlet and end lengths of the manifold.

The analysis was conducted with an air flow rate of 1e-4 kg/s, and the manifold uniformity was calculated using the standard deviation of flow rates across unit cells.

2.2 Results

Fig. 2(a, d) shows the results for manifold models with a width of 5 mm. In the uniformity graph of Fig. 2(d), models with an inlet-to-end ratio of 6-12

Table 1 Sloped manifold models for each width

Model	Basic	O3-15	I3-15	S3-15	O6-12	I6-12	S6-12
Inlet : End	1:1	1:5	1:5	1:5	1:2	1:2	1:2

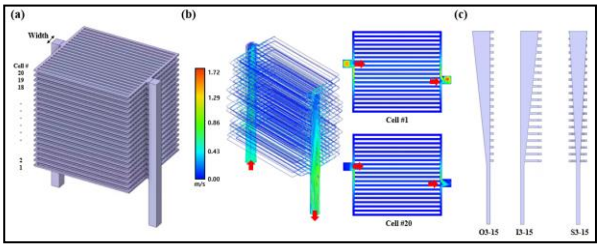

Fig. 1 Overall geometric shapes. (a) Air channel with 10mm width basic model. (b) Streamlines and flow direction. (c) Examples of the O3-15, I3-15, and S3-15 of inlet manifold models.

display higher uniformity compared to the basic model, with the order of uniformity being S6-12, I6-12, and O6-12. Models I3-15 and S3-15 show lower uniformity. The flow graph in Fig. 2(a) indicates low flow and backflow in the lower layer cells for these models. In S3-15 model, the narrow inlet creates high-speed flow, and the lower manifold pressure compared to the cells leads to backflow and vortices in the lower cells, resulting in reduced uniformity for S3-15 and I3-15 models with a width of 5 mm. The average uniformity for the 5 mm width models is 76%.

Fig. 2(b, e) shows the results for 10 mm width manifold models. As with the 5 mm models, models with an inlet-to-end ratio of 6-12 (S6-12, I6-12, and O6-12) show higher uniformity, while models with a ratio of 3-15 have lower uniformity, as observed in Fig. 2(b) due to low flow in the lower cells. However, with the increased width, all manifolds demonstrate uniformity exceeding 80%, with an average uniformity of 89.86% for the 10 mm models. Fig. 2(c, f) presents the results for 30 mm width manifold models, where uniformity exceeds 95% for all models. Even the lowest uniformity model, S3-15, achieves over 95%, confirming the dominance of width in manifold design, with an average uniformity of 98.24%.

2.3 CONCLUSION

A computational analysis was conducted to increase the uniformity of airflow channels in an SOFC stack composed of 20 unit cells. The manifold models were designed by varying the width, gradient ratio, and gradient direction, and flow uniformity to each unit cell was calculated at the same flow rate. The analysis results showed that uniformity varied with the gradient direction, even with identical gradient ratios. Models with an inlet-to-end ratio of 6-12 exhibited higher uniformity than 3-15 models, and avoiding excessively narrow inlets proved effective for flow uniformity. For the 6-12 ratio models, uniformity increased in the order of Symmetric, Outside, and Inside models, all of which outperformed the basic model. Additionally, as the manifold width increased, uniformity improved across all seven models, showing a proportional relationship between width and uniformity.

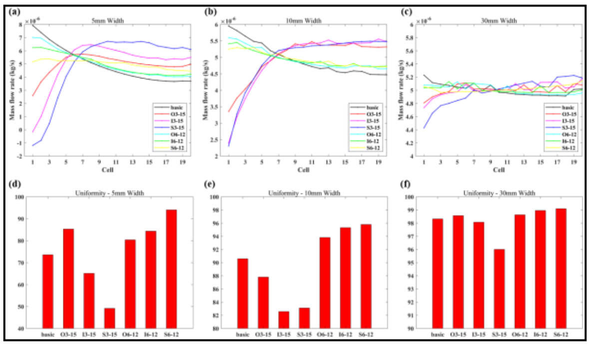

Fig. 2 (a-c) Mass flow rate and (d-f) uniformity depending on models

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