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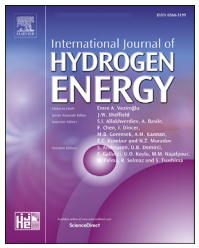

Mass transport limitation in inlet periphery of fuel cells: Studied on a planar Solid Oxide Fuel Cell

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ABSTRACT

It was recently clarified on a microtubular Solid Oxide Fuel Cell (SOFC) that the range of mass transport limitation might commence from the inlet periphery (inlet opening and inlet pipe), i.e., the concentration gradient of reactants may extend inward the inlet periphery. For demonstrating that this phenomenon occurs regardless of the form and type of the fuel cell operating at high reactant utilization rate, herein we investigate the mass transport in the anode side of a one-cell stack of a planar SOFC. The investigation leans upon experimental and numerical data analyzed from both conventional (non spatial) and spatial perspectives. The experimental data were spatially obtained in the lateral direction by applying the segmentation method. Regarding analyses let us to confirm that mass transport limitation occurs in the inlet periphery of the planar stack. Besides, the critical ratio of the consumed/supplied mass fluxes of hydrogen is valid for assessing whether the concentration gradient of hydrogen extends inward the inlet periphery. Furthermore, the virtual inlet opening is useful for accurately calculating the mass transport within the active field of the stack via hypothetically preventing the mass transport limitation in the inlet periphery. These findings are expected to help researchers and engineers for accurately designing and characterizing fuel cell systems at varying scales from cells to stacks.

Introduction

Although theoretical power capacity of a fuel cell is directly proportional to its active area, practical capacity of the cell can significantly differ depending on the distribution of reactants in the active area, provided that the cell components are isotropic and sufficiently stable [1,2]. At a high current density, the consumption of reactants by the electrochemical reactions may result in a remarkable drop in the reactant concentration toward downstream. Due to the uneven concentration distribution within the active area, current variations develop, which possibly give rise to performance and structure degradations [1,3–7].

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In a fuel cell module/stack, concentration variations develop also in the external manifold, i.e., the cells in the stack receive reactants at uneven conditions (pressure, rate, etc.) [2,8–11]. Combination of concentration variations in the external manifold with those in the single cells causes a substantial performance-loss in the system. To fully utilize the capacity of a fuel cell stack, related studies suggest optimization of the flow field of reactants at least at three levels: external manifold in the module/stack, internal manifold, and the flow patterns (e.g. parallel, serpentine, interdigitated, etc.) in the reactant distribution plates (i.e., separator, bipolar plate, interconnector) [2].

In addition, Aydın et al. recently disclosed that, at high reactant utilization rates, the concentration gradient of reactants extends inward the inlet periphery (inlet opening and inlet pipe) of a microtubular Solid Oxide Fuel Cell (SOFC) [12]. They deduced that the extension of the concentration gradient depends on the dimension of the inlet opening in the gas distribution plate. They proposed an evaluation method for fuel cell systems operating under similar conditions and also suggested a method for accurately simulating the regarding systems.

Having various types and forms (e.g. tubular, planar, etc.) of fuel cells, it is worth to investigate the mass transport limitation in the inlet periphery of other types and forms of fuel cells. In this regard, fuel cells in planar form deserve the highest attention, since they are widely adopted as the most promising form of fuel cells in terms of easier design/fabrication and higher power density, etc. In contrast to tubular cells, planar cells are basically sandwiched between separator plates which are responsible for distributing reactants over the active area in the both anode and cathode sides. Depending on the type of the fuel cell, (Polymer Electrolyte Membrane Fuel Cells (PEMFC), SOFC, etc.) and the electrode, separators accommodate specific flow patterns for maintaining effective transport of species within the active part [2]. For instance, for the cathode side of PEMFCs various flow patterns, e.g. parallel, serpentine, and cascade, etc., were developed to overcome the mass transport limitations stemming from combination due to product water and low concentration of oxygen in air.

Regarding the mass transport limitation in planar fuel cells, numerical tools are widely employed where they are applied on various domains: single channels, cells, and modules/stacks [2,9,10,13–20]. Although the flow fields in the external manifold (in modules/stacks), internal manifolds (in separators), and in the flow channels are carefully studied, the inlet boundary conditions are usually defined based on the assumption that reactants are effectively transported until the entry of the regarding domain. According to the recent findings by Aydın et al., at high fuel utilization rates reactants might not be effectively transported to the entrance of the domain. Thus, it is worth of investigating the role of the inlet periphery in the related models for accurately simulating the flow fields in the system.

In order primarily to demonstrate that mass transport limitation in the inlet periphery occurs regardless of the form, type, and scale (cell, module, stack, etc.) of fuel cells, and it affects the accuracy of the regarding modeling works, we carried out this study. Besides, we devoted a special effort to the demonstration of the evaluation method for other fuel systems operating under similar conditions [12], and to the method for accurately simulating the fuel cells systems [12]. For the aforementioned demonstration works, a numerical model was built leaning upon spatial current distributions in situ acquired by applying segmentation method to the stack [21].

Experimental

Segmented planar SOFC stack

For optimizing the width of the rib in the anode separator of a one-cell stack of a planar SOFC, we investigated current distribution in the lateral direction within the stack. The current distribution was in situ measured by applying segmentation method that refers to division of the total active area into subfields called "segments" [1,3–7,21]. As displayed in Fig. 1, the stack was composed of two separator plates made of SUS (AISI) 430 that were in charge of reactant distribution by parallel channels in the anode and cathode sides separately.

Although there were only two channels in dimension of 3/1/25 *mm* (width/depth/length) and a rib in the anode separator, in the cathode side multi-channels were designed. In other words, the focus of the investigation was on the single rib of the anode side. The dimension (width and depth) of the inlet and outlet manifolds of the anode separator were the same as that of the channels. The SOFC was electrolyte-supported provided by TOHO GAS (Japan) where the thickness of the anode, electrolyte, and cathode were ca. 40 μm, 200 μm, and 40 μm. Materials of the cell components were NiO – 10Sc1CeSZ, 10Sc1CeSZ (ZrO_2 stabilized with 10 mol $\%Sc_2O_3$ and 1 mol $\%CeO_2$), and LSCF-GDC for the anode, electrolyte, and cathode, respectively. In addition, an interlayer of GDC was present between the electrolyte and cathode layers. Current was collected by silver meshes placed among the separator plates and respective electrodes of the anode and cathode. To avoid disturbance in the anode side, the segmentation was applied only to the cathode side of the stack. Namely, the cathode electrode including the silver mesh and the regarding separator plate were splitted into three segments (the left/right channels and the rib) as shown in Fig. 1. The segmented components were electronically isolated from each other by proper sealants (Thermiculite 866, Flexitallic) to measure the local current of each segment independently. Width of the single rib in the anode separator was systematically altered to determine the optimum dimension for mitigating related losses (concentration and ohmic). However, only the experimental data acquired by the widest rib of 9.5 *mm* are used in this study for investigating the mass transport limitation under severe conditions.

Performance characterization

Gas flow rates were metered with mass flow controllers (SEC-E40MK3, Horiba STEC Co. Ltd., Japan) governed by LabVIEW 8.5. To reduce NiO to Ni within the anode, a dry mixture of $H_2/N_2 = 40/40$ *ccm* (273 K and 1 *atm*) was fed to the anode for one hour prior to the experiments. Because the focus of the study was on the mass transport limitation in the anode side, 100,

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