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Effects of cell geometries on performance of tubular solid oxide fuel cell

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HIGHLIGHTS

- A 2D model has been developed for anode-supported tubular solid oxide fuel cells.
- Effects of larger current collectors are more remarkable on cell performances.
- Cells having bigger diameters demand thicker anode support for higher performance.

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ABSTRACT

A two-dimensional model comprising fuel channel, anode, cathode and electrolyte for an anode-supported tubular solid oxide fuel cell (AST-SOFC), has been developed, considering mass and charge transport. By using the model approach, different geometries of the AST-SOFC are proposed and simulated, further analyzing and discussing species transport phenomena and current distribution inside the cell. The results illustrate that effects of current collectors are more remarkable to cell performances for AST-SOFC having a larger current collector than that holding smaller one. The cell with thinner anode is in need of the bigger anode current collecting area to have a high performance. While the cell has the bigger diameter, the current demands the wider path to flow from anode to cathode, thus demanding the thicker anode support for obtaining the higher performance. These calculations can be used to design and optimize the AST-SOFC.

1. Introduction

Solid oxide fuel cell (SOFC) is one of the most promising candidates for the power generation because of their high efficiency, clean generation of electric power and silent work [1–3]. Tubular SOFCs have several advantages compared with planar ones, such as the sealing element holding much smaller area in a tubular cell than that in a planar cell [3], fuel and air distribution manifolds having the simpler structure in tubular stacks than those in the planar SOFC, thermal stresses possessing less trouble in the tubular systems because each membrane-electrode assembly is less rigidly restricted. Recent years, tubular SOFCs have been rapidly developed [4–8], mainly including the cathode-supported tubular SOFC (CST-SOFC) developed by Siemens [8] and the anode-supported micro tubular SOFC. The CST-SOFC has an ability to power a high performance from a single cell, facilitating to assembly a kW or MW class stack. But the cathode used as the supporting electrode in CST-SOFC has a lower conductivity than anode material. So, a new anode-supported tubular SOFC (AST-SOFC) is recently developed by Dalian Institute of Chemical and Physics (DICP), having the similar geometry to the CST-SOFC developed by Siemens for the sake of taking advantage of the anode having the higher conductivity in the substrate electrode.

Whichever tubular SOFCs (CST-SOFC or AST-SOFC) are designed for SOFC stack, there is much longer current path in tubular SOFCs than that in planar cells. The current collecting is still one of the most concerned issues for the sake of achieving the high cell performance with regard to AST-SOFC. The long path of the current flowing limits the geometry of the tubular SOFC to the larger one, hindering the low cost. Improving the geometry design of tubular SOFCs can optimize the current distribution, making the cell performance better. Therefore, this paper will study an optimized

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geometry of AST-SOFC to enhance the AST-SOFC performance.

Numerical calculations are a very useful tool in the SOFC research because detailed measurements on the mass and charge transfer process in SOFCs are very difficult [9–11]. Up to now, most of cell performance simulations have been carried out for the cathode-supported tubular SOFC and anode-supported micro-tubular SOFC [10–14], not having simulation work for the AST-SOFC at open literature. So, for the AST-SOFC, it is necessary to develop a new model to simulate the current and mass distribution at the anode substrate in order to understand the transfer process at anode, optimizing the geometry to obtain a high performance.

In this paper, a two-dimensional model containing fuel channel, anode, cathode and electrolyte inside the AST-SOFC will be built, associating with electro-chemical, transfer phenomena and current flow process inside the cross-section of the tubular cell. This work will investigate the current density at the anode/electrolyte interface, comparing effects of different geometries of the AST-SOFC to the cell performance.

2. Numerical model

2.1. Model assumptions & general description

For the tubular SOFC, the current collection is one of the most concerned difficulties to improve the cell performance, in need of considering many factors for the issue, including electrochemical reaction, charge transport and mass transfer, etc. In this research, the effect of current collecting area on the cell performance is considered to optimize the cell geometry, through choosing a cross-section of the tubular SOFC in which the performance lose occurs when the current flows around the center axis of cell. The two dimensional model will be built to solve the problem of current collection, where the thickness of electrolyte and cathode is 40 and 100 μm, respectively, employing different geometries of tubular SOFC to evaluate effects of different current collecting areas on the cell performance.

In this steady state model, the reactant gas mixtures are approximated as ideal gas and incompressible, including the mixture of H_2 and H_2O with the constant ratio of 1:1 as fuel at anode channel, and assuming that oxygen concentration at the outside surface at cathode is the same as that in air. Electrochemical reactions are considered to only take place at the electrode/electrolyte interface, assuming cells running at 800 °C under the cell operating voltage of 0.7 V in the isothermal model. The model makes use of differential equations which are integrated in the 2D domains through commercial software, COMSOL MULTIPHYSICS®, showing input parameters in Table 1 and comparing the current density values under the operating voltage of 0.7 V for the cross-section of SOFC. The following model assumptions are employed:

- The model is based on steady state.
- Gas flow in the channels is laminar.
- Reactant gas mixtures are approximated as ideal gas and incompressible.
- The fuel cell operates with 100% current efficiency.
- The model is assumed to be isothermal, cell running at 800 °C.

2.2. Model geometry

For the design of the AST-SOFC stack, the cell bundle can be assembled through the series and parallel connected with current collectors of the stainless steel, where each single cell is comprised by cermet anode, electrolyte and air electrode, respectively from inside to outside, maintaining gas separation from anode in one cell to cathode in the other cell through the material of lanthanum chromites. The cross-section of the AST-SOFC is chosen for this study in 2D model, shown in Fig. 1. The shadow part is the current collector, where the break part of the electrolyte and cathode is the position of the anode current collector, employing the below semicircle for the cathode current collector. The half cell in the

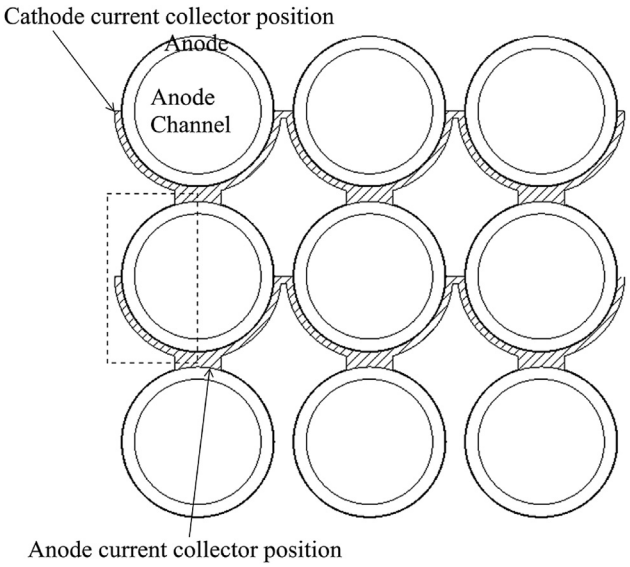

Fig. 1. Schematic of the AST-SOFC.

Table 1
Input parameters to model [15–17].

Descriptions	Symbol	Value
Cathode thickness (μm)		100
Electrolyte thickness (μm)		40
Anode conductivity (S m^{-1})	σ_a	$95 \times 10^6 T^{-1} exp(-1150/T)$
Cathode conductivity (S m^{-1})	σ_c	$42 \times 10^6 T^{-1} exp(-1200/T)$
Electrolyte conductivity (S m^{-1})	σ_{ele}	$3.34 \times 10^4 exp(-10300/T)$
Transfer coefficient	β	0.5
Activation energy of anode (J mol^{-1})	$E_{act,a}$	140,000
Electron transferred per reacting	n_e	1
Permeability (m^2)	K	1e-12
O_2 Diffusion Coefficient (m^2 s^{-1})	$D_{O_2,c}$	7.588e-6
N_2 Diffusion Coefficient (m^2 s^{-1})	$D_{N_2,c}$	7.588e-6
Fuel Diffusion Coefficient at anode channel (m^2 s^{-1})	$D_{channel,m}$	8.506e-4
H_2 Diffusion Coefficient at anode (m^2 s^{-1})	$D_{H_2,a}$	3.14e-5
H_2O Diffusion Coefficient at anode (m^2 s^{-1})	$D_{H_2O,a}$	1.39e-5