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Short Communication

Techno-economic comparison of anode-supported, cathode-supported, and electrolyte-supported SOFCs

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ABSTRACT

Different types of self-supported SOFCs (i.e., anode-supported, cathode-supported and electrolyte-supported SOFCs) have been compared in literature mostly from technical point of view. In this study, the mentioned types of SOFCs are compared from technical and economic points of view simultaneously. In this regard, "maximum power density" and "material cost of PEN layer" are taken as objective functions. These functions are evaluated through numerical modeling and based on available cost data, respectively. The results illustrate that the cathode-supported SOFC is the optimal choice when power density is regarded alone. On the other hand, the electrolyte-supported SOFC is observed to be the optimal option when the material cost of PEN is considered as the only objective function. However, the anode-supported SOFC makes the best trade-off between the two objective functions when they are simultaneously taken into consideration. The results also indicate that the electrolyte-supported SOFC leads to a symmetrical and most uniform current density distribution as compared to the electrode-supported ones in which peak local current densities tend toward non-supporting side. The paper discusses in detail the reasoning for the mentioned observations.

Introduction

The enormous environmental pollution arising from the consumption of fossil fuels, the depletion of the fossil fuel resources in the coming decades, and the ever-increasing global energy demand necessitate paying special attention to the alternative sources of energy.

Fuel cell technology is one of the most promising types of alternative electricity generation technologies. Solid oxide fuel cells (SOFCs) are highly regarded because of their several beneficial characteristics such as high efficiency, working in silence, low emission of pollutants, fuel flexibility, long-term stability, and the capability of being coupled with power plant applications [1–3].

In recent years, various studies have been conducted to improve the viability of SOFCs. These research works may be classified into the following general categories:

- A group of works investigated the effects of various operating parameters on SOFCs' performance [4–17]. In brief, these works reported the positive influences of the

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Nomenclature

AS	Anode-supported
c_p	Specific heat capacity, J kg^{-1} K^{-1}
CS	Cathode-supported
D	Diffusion coefficient, m^2 s^{-1}
ES	Electrolyte-supported
F	Faraday constant, 96,485 C mol^{-1}
GDL	Gas diffusion layer
GFC	Gas flow channel
I	Current, A
j	Transfer current density, A m^{-3}
k	Thermal conductivity, W m^{-1} K^{-1}
k_p	Permeability, m^2
M	Molecular weight, kg kmol^{-1}
MPD	Maximum power density, W cm^{-2}
P	Pressure, kPa
R	Universal gas constant, 8.314 kJ kmol^{-1} K^{-1}
T	Temperature, K
TPB	Triple phase boundary
$\vec{u}$	Velocity vector, m s^{-1}
V	Voltage, V
X	Molar concentration, kmol m^{-3}
Y	Mass fraction

Greek letters

α	Charge transfer coefficient
γ	Concentration dependence
ε	Porosity
η	Over potential
μ	Viscosity, kg m^{-1} s^{-1}
ξ	Specific active surface area, m^{-1}
ρ	Density, kg m^{-3}
σ	Electrical conductivity, Ω^{-1} m^{-1}
φ	Phase potential, V

Subscripts

An	Anode
Ca	Cathode
elec	Electric
i	Gas species
Mix	Mixture
OC	Open circuit
React	Reaction
Ref	Reference

Superscripts

Eff	Effective

increases of operating temperature and pressure on the cell power density as well as the useful effects of increasing the air flow rate and the re-circulation of outlet gases on the uniformity of temperature and current density within SOFCs.

- A group of research works have dealt with the geometrical aspects of SOFCs. Some proved that the shape (e.g., triangle, rectangular, trapezoid) and dimensions of gas flow channels play a major role on the cell performance [18–30]. Some others indicated that the co-flow pattern leads to the lower levels of power densities. On the other hand, it results in lower temperature gradients and thermal stresses as compared to the counter-flow and cross-flow patterns [31–37].
- A group of research works have discussed the influence of physical and microstructural parameters (such as porosity, permeability and the diameter of particles and pores) on the performance of SOFCs [38–43].
- The present work lies within another category of works comparing the different types of self-supported SOFCs (i.e., anode-supported, AS, cathode-supported, CS, and electrolyte-supported, ES, cells). Presenting a detailed analysis of over-potential within a cell, Chan et al. [44] showed that an ES cell performance is poor compared to an AS one. The experimental investigations of Zhao et al. [45] indicated that the output power of an AS cell deteriorates with increasing thickness of the supporting element. Theoretical analyses made by Pramuanjaroenkij et al. [46] and Patcharavorachot et al. [47] revealed the performance superiority of an AS cell over an ES one. Moreover, it was shown by Patcharavorachot et al. [47] that decreasing the thicknesses of anode and electrolyte layers can be beneficial to the performance of an AS cell. Moon et al. [48] studied the effects of the thicknesses of different elements on the performance of an AS cell. The results showed that the cell performance is more sensitive to the electrolyte thickness than anode or cathode thickness. The numerical study of Shichuan et al. [49] indicated that the performance of a CS stack was superior to that of an AS stack for any practical contact resistance and pitch width. The numerical study of Park et al. [18] showed that although increasing anode thickness in an AS SOFC leads to a greater mechanical strength, it results in a lower performance.
- Finally, some CFD-based studies that have focused on the thermo-electrochemical behavior of solid oxide fuel cells [50–55].

Regarding the provided literature survey, the different types of self-supported SOFCs have been compared mostly technically. To the best of the authors' knowledge this is the first time that they are compared from technical and economic points of view simultaneously. Maximum Power Density (MPD) and the initial cost of PEN layer are considered as the technical and economic objective functions. These functions are evaluated through a verified numerical modeling and based on available cost data, respectively. The paper investigates the influence of supporting layer thickness on the performance of the different types of SOFCs, compares the different types of SOFCs from technical and economic points of view both individually and simultaneously, and interprets the observations by pointing to the detailed computational results.

Modeling and governing equations

A typical SOFC is composed of a gas flow channel (GFC), a current collector (CC) and a reaction zone layer (or TPB) at each anode and cathode side, and a solid electrolyte in the

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