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Performance Analysis of Syngas Fueled Solid Oxide Electrolysis Cells

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There is an increasing focus on hydrogen and synthesis gases production as alternative energy carriers mostly due to limiting fossil fuel sources and environmental issues. Solid oxide electrolysis cells (SOEC) integrated with renewable energy sources may be an efficient route for producing hydrogen and synthesis gases without emitting green-house gases.

An SOEC is a reversely operated solid oxide fuel cell (SOFC) with similar material sets and geometric configurations. The reverse operation not only changes the reactions directions but also affects the cell electrochemical and thermal behavior which is relatively far from the ones observed in SOFCs. Thus, understanding of the complex SOEC operating mechanisms in terms of heat, mass, and charge transfer phenomena that are closely coupled with heterogeneous and electrochemical reaction chemistry is valuable.

Although steady-state and dynamic behavior of SOFCs at both cell and system levels have been widely investigated in the open literature, both experimental and numerical prediction of SOECs performance has yet to be reliably established given its relative technological infancy. Consequently, the present study focuses on the development of a high fidelity cell model that can be used for identifying favorable electrochemical and thermal performance of SOECs. The model includes mass, energy, and momentum conservation equations as well as the detailed analysis of the cell electrochemical losses. Global reaction rates for reverse water gas shift (rWGS) and methanation (i.e., reverse steam reforming (rSR)) reactions are also included in the model in order to calculate the rate of CO_2, CO, and CH_4 species production or consumption. The present work improves and extends existing models to enable exploration of cell geometry, operating conditions, and feed gas effects.

The model is validated with the available experimental data in the open literature and then employed to investigate the effect of several parameters such as the inlet fuel compositions and temperature. The results show that the SOEC energy consumption significantly increases as the inlet fuel temperature decreases mostly due to the cell higher polarization losses. It is also shown that the rWGS reaction might be considered as the main pathway for CO_2 consumption in the presence of sufficient inlet water vapor. Thanks to the model fidelity, the detailed analysis of the cell polarization losses under various operational conditions is also derived from the model which can be used for the cell performance optimization purposes.