Peer Review

Review of: "Impedance of a Hydrogen–Fed SOFC Anode: Analytical and Numerical Models Based on the Dusty Gas Transport Model"

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This manuscript presents an analytical low-current and numerical high-current impedance model for a hydrogen-fed anode of an anode-supported button Solid Oxide Fuel Cell (SOFC). The integration of the dusty gas model for H_2–H_2O transport offers an advanced framework for understanding gas diffusion processes within the porous support layer. One of the manuscript's key strengths lies in the precision and physical grounding of the transport phenomena modeling, especially in the context of a binary gas mixture. The authors' emphasis on the pressure gradient's role and its impact on hydrogen diffusivity provides a valuable corrective to oversimplified approaches often adopted in impedance analyses.

The analytical model presented is particularly noteworthy for its applicability to low-current regimes, where linearization is valid and experimental spectra can be interpreted with relatively high confidence. The use of a fitting strategy that relies on the least-squares optimization method to match literature-derived impedance data demonstrates practical relevance and the potential for broader applicability of the model. The clarity with which the authors describe the limitations of Warburg-based equivalent circuits also highlights their attention to methodological rigor, warning readers against common misinterpretations in Electrochemical Impedance Spectroscopy (EIS).

One of the most commendable aspects of this work is its attempt to bridge the gap between purely analytical models and more computationally demanding numerical solutions for higher current densities. The complementary use of both regimes ensures that the model remains relevant across a range of operating conditions. The capacity of the proposed models to retrieve essential physical parameters — including Knudsen diffusivity, permeability, porosity/tortuosity ratio, and electrochemical descriptors — by fitting impedance spectra is a substantial contribution to the field.

However, the manuscript would benefit from an expanded validation effort. While the fitting of the analytical model to one set of literature data is a good proof of concept, incorporating experimental spectra from multiple sources or under varied conditions (e.g., different hydrogen partial pressures, temperatures, or support structures) would significantly strengthen the generalizability of the model. Additionally, a sensitivity analysis to evaluate how robust each extracted parameter is to noise in the impedance data could be included to support claims of parameter identifiability.

In terms of mathematical formulation, the derivations and boundary conditions are clearly outlined, but a more pedagogical exposition for readers who may not be familiar with the dusty gas model would enhance accessibility. The assumptions inherent to the dusty gas model — especially regarding molecular vs. Knudsen diffusion dominance and the treatment of multi-component interactions — should be more explicitly discussed to contextualize the model's limitations.

Another area for improvement lies in the treatment of the electrochemical reaction kinetics, specifically the hydrogen oxidation reaction (HOR). The Tafel slope is included as a fitting parameter, yet more discussion on the mechanistic assumptions — such as charge transfer coefficients and potential influences of adsorption phenomena — would enrich the electrochemical insight. It is unclear whether the model accounts for possible mixed conduction effects or deviation from ideal double-layer behavior in nanostructured or degraded electrodes.

The manuscript mentions traps related to the Warburg finite-length element but does not offer a comparative quantitative analysis to show how the analytical model improves the fit or the extraction of physical parameters. Including a side-by-side comparison of fits using the traditional equivalent circuit versus the proposed model would be a valuable addition. This would help readers visualize the pitfalls of conventional approaches and the diagnostic power of the developed model.

Stylistically, the manuscript is largely well-written and organized, although certain sections could benefit from language polishing for clarity and flow. For instance, the abstract and conclusion could be rewritten to more directly state the novelty and practical implications of the findings. Enhancing visual elements, such as including schematic representations of the anode structure, diffusion profiles, and equivalent circuit diagrams, would help to engage a broader audience and improve comprehension.

Finally, the overall contribution of the work is significant in both the academic and applied realms. By enabling more accurate impedance-based diagnostics, the model supports improved interpretation of degradation mechanisms, optimization of anode microstructures, and potentially more effective quality control in SOFC manufacturing. The authors are encouraged to extend this modeling framework to other gas mixtures or multi-physics couplings (e.g., thermal or mechanical effects) in future studies.

In conclusion, this manuscript provides a thoughtful and technically robust approach to modeling impedance in hydrogen-fed SOFC anodes. The integration of dusty gas transport, coupled with a dual-regime impedance framework, represents a meaningful advance in SOFC modeling. With a few expansions in validation, clearer comparisons to conventional models, and additional discussions on electrochemical kinetics, this study will undoubtedly become a valuable reference in the field of fuel cell diagnostics and modeling.

Declarations

Potential competing interests: No potential competing interests to declare.