Eccentricity effects in a Joule heated monolithic reactor for Steam Methane Reforming

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Highlights

- A monolith catalyst with a heating wire in each channel is an effective way to electrify chemical reactions
- The concentric reactor configuration provides high CH_4 conversion with close equilibrium approach.
- Wire eccentricity may negatively affect the performance due to lower mass and heat transport coefficients.
- In presence of eccentricity the conversion decreases due to external mass transfer limitations.

1. Introduction

Electrification is proposed as a viable option for decarbonizing high temperature endothermic catalytic processes. Among the different options for power-to-heat, Joule heating can deliver high temperature heat power with high theoretical efficiency and is the most mature technology towards scale-up and retrofitting[1]. In particular, Electrified Steam Methane Reforming (e-SMR) is a promising concept for low-carbon H_2 production. Among the alternatives proposed in the literature, an interesting solution (SYPOX technology) consists in a reactor with an electrically heated ceramic monolith, coated with Ni-based catalyst, where heating wires are inserted in each channel[2]. This solution provides very high volumetric mass transfer coefficients, low pressure drops and unprecedented heat transfer performances thanks to the combination of radiative and convective heat transfer mechanisms. Understanding the impact of transport properties on the reactor performances is of paramount importance to enable the rational scale-up of the concept.

2. Methods

A 1D steady-state heterogeneous mathematical model was developed in Matlab, which consists of energy, momentum and species mass balances. The reactor, consisting of parallel square channels with identical geometry, is simplified to a single channel under the assumption of uniform flow rate, concentration and temperature at the inlet section and negligible heat dispersion. Ideal gas behavior, fully developed laminar flow, T-dependent properties and radiation from the heating wire to the catalyst were assumed. For the kinetics, Xu and Froment's SMR model[3] was implemented. In this work the effect of the wire eccentricity is accounted by considering transport coefficients available in the literature[4].

3. Results and discussion

Fig. 1 shows the axial temperature profiles computed with: T^{IN} = 573.15K, P^{IN} = 8 barg, Q = 154 W, S/C = 2, GHSV = 710000 $Ncm^3/h/g_{cat}$ at different wire eccentricities. For the concentric reactor configuration (Fig. 1a,b), very small gas-solid temperature and concentration differences are present, leading to 86% methane conversion and an equilibrium ΔT approach of 69K. Conversely, introducing 30% wire eccentricity (Fig. 2a,b), significant deviations between gas and solid temperatures and concentrations are present due to the negative impact of eccentricity on mass and heat transport coefficients. In particular, the methane conversion decreases to 82%, mostly due to the onset of external mass transfer resistances, and the equilibrium ΔT approach increases up to 138K. In fact, while radiation can compensate the reduction of convective heat transfer, lower mass transfer rates significantly limit the reactor performances.

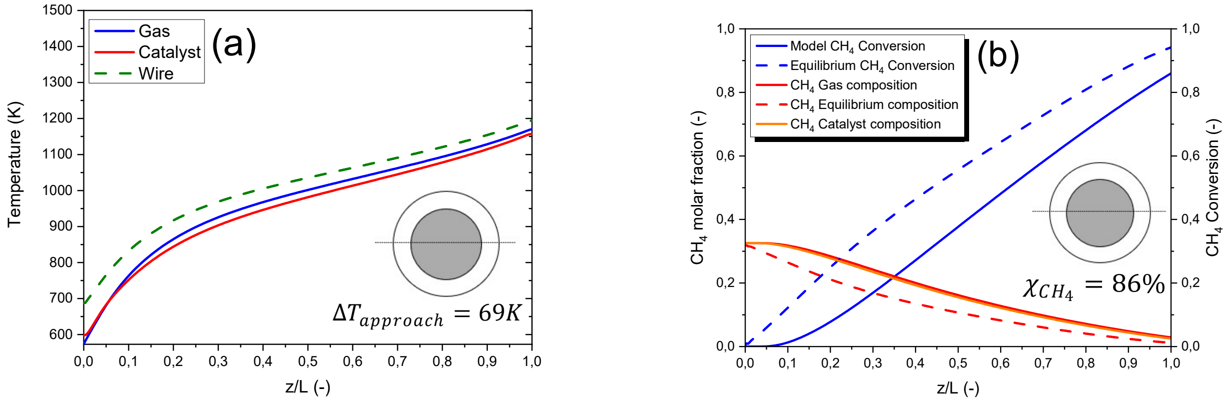

Figure 1. Axial temperature profiles vs. dimensionless reactor length (a) and CH_4 conversion/CH_4 molar fraction vs. dimensionless reactor length (b) of the concentric reactor configuration.

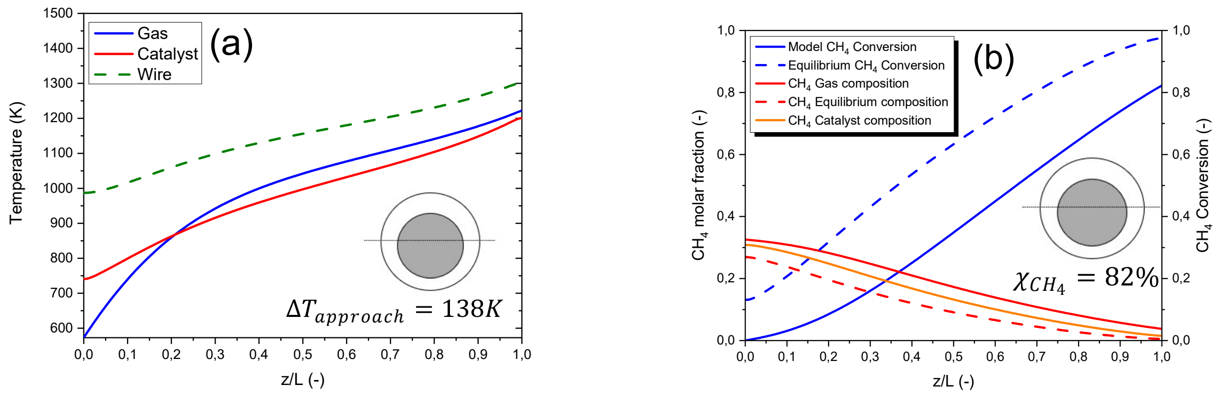

Figure 2. Axial temperature profiles vs. dimensionless reactor length (a) and CH_4 conversion/CH_4 molar fraction vs. dimensionless reactor length (b) of the 30% eccentric reactor configuration.

4. Conclusions

The 1D heterogeneous model offers a quantitative representation of the electrified steam reforming SYPOX reactor. Based on the simulation results, different performances are expected for the concentric and the eccentric reactor configuration: eccentricity results in lower conversion and higher equilibrium ΔT approach mainly due to the onset of external mass transfer limitations. In view of such sensitivity, dedicated experimental tests under mass transfer limited conditions are ongoing to estimate the mass transfer coefficients in the actual reactor configurations.

References

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Keywords

"Electrified Methane Steam Reforming", "Hydrogen production", "Process intensification", "Eccentricity"

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