Hybrid resonant-traveling microwave reactor for high temperature catalytic reactions

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High-temperature endothermic reactions, such as methane steam reforming (MSR), are central to sustainable H_2 production but are typically powered by fossil-based heating systems, which are carbon-intensive. Microwave (MW) heating offers a promising electrified alternative due to its selective, volumetric energy transfer.

A hybrid resonant–traveling wave MW reactor was developed and optimized using a 3D multiphysics model to enable efficient heating and catalytic conversion. The reactor, built from AISI 316L stainless steel and with about 90 mm internal diameter is comparable to industrial MSR reactor units. It is powered by a 500 W solid-state generator and operates at 2.45 GHz. The fixed bed contains 2 mm β-SiC-catalyst particles (up to 30% catalyst vol.), with bed height optimized to enhance MW absorption and thermal uniformity.

The reactor operates under both in inert and MSR conditions (S/C = 3). Under reactive flow, nearly 90% CH_4 conversion is achieved with 414 W input, with temperatures ranging from 600°C at the wall to 880°C at the core. Conversion peaks in zones of high field intensity (and temperature) and reactant concentration, with H_2 selectivity aligned with MSR stoichiometry. The energy demand of 4.2 kWh/Nm^3H_2 is comparable to other H_2 production methods.

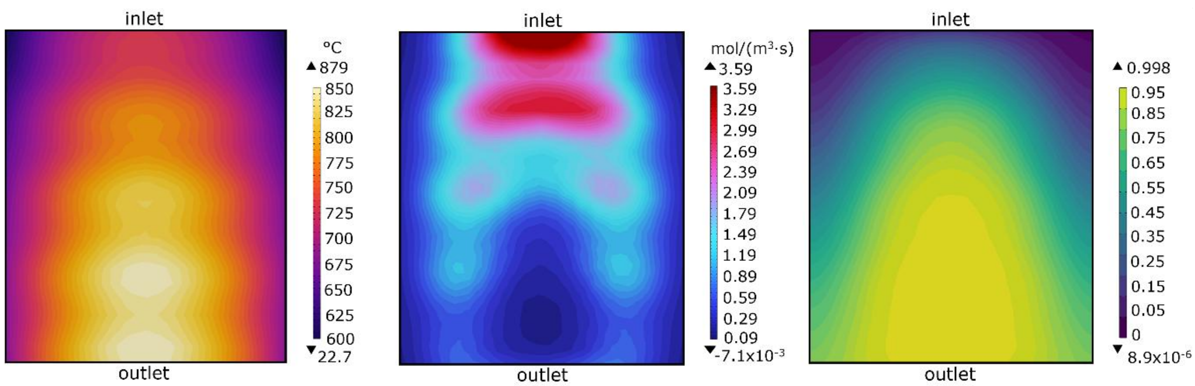

Figure 1: Maps of (a) Temperature, (b) MSR rate, and (c) methane conversion in the bed, on a vertical plane, parallel to the inlet/outlet pipes.

The thermal model was validated experimentally under inert flow, with MW power set to 250 W. Twelve thermocouples mapped axial and radial temperatures, showing excellent agreement with simulations ($\Delta T < 15$°C). Minor discrepancies near the wall were linked to local packing effects not captured in the homogeneous model.

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