Electrification of Chemical Processes

A-147

Novel Joule-Heated Radial Reactors with Spatially Distributed Heat Generation for the Intensification of Steam Methane Reforming

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Introduction

Electrification of catalytic reactors is a promising route to decarbonize energy-intensive processes. Steam methane reforming (SMR), the main industrial hydrogen production route, requires high heat inputs and suffers from strong thermal gradients due to mismatch between heat supply and reaction heat demand.
To overcome this, two novel Joule-heated radial reactor concepts are proposed: EMERALD [1] and NEPER [2]. Both designs exploit a spatially distributed heat generation tailored to the endothermic reaction demand. EMERALD combines radial electric current (Figure 1A) with centrifugal gas flow through an annular packed foam bed, generating a heat profile decaying as $1/r^2$. NEPER, instead, features tangential current flow (Figure 1B) while maintaining the same power density distribution, offering improved electrical design and scalability.

Methods

The reactor concepts were investigated through combined modeling and experiments. A hierarchical modeling approach [3] linked detailed 3D CFD simulations to reduced 1D/2D porous-media models [4]. Experimental validation was carried out in a lab-scale reactor (0.1 L) using Rh catalyst particles (dp=1mm), packed into SiSiC internals (i.e., foams and POCS) acting as resistive heating elements. Radial temperature profiles were measured via thermocouples, and outlet composition via MicroGC. The reactor wall temperature was externally controlled.

Results and discussion

Preliminary 1D simulations under industrially relevant conditions show that conventional axial Joule-heated reactors develop a pronounced cold spot at the inlet, while radial configurations largely suppress it due to spatially distributed Joule heating matching the reaction heat demand. The radial layout also reduces pressure drop.
Experimental investigation of the EMERALD configuration showed that temperature profiles are governed by the net heat flux, with methane conversion approaching thermodynamic equilibrium. The highest methane conversion achieved was 71%. Both reduced-order models and detailed CFD simulations accurately reproduce the observed behavior.
While EMERALD confirms the effectiveness of the radial concept, it presents limitations related to electrical connections. These are addressed in the NEPER design, which features tangential current flow and enables higher operating temperatures - and consequently almost complete methane conversion - while preserving the same optimal power density profile. Corresponding experimental results for the NEPER configuration are reported in Figure 1C.

Conclusions

Two novel electrified radial structured reactor concepts for SMR have been developed and validated.

EMERALD demonstrates tailored heat generation and cold-spot suppression, while NEPER improves electrical management and enables higher-temperature operation. Together, they highlight the strong potential of spatially distributed Joule heating for process intensification and low-carbon hydrogen production. Scale-up studies are ongoing.

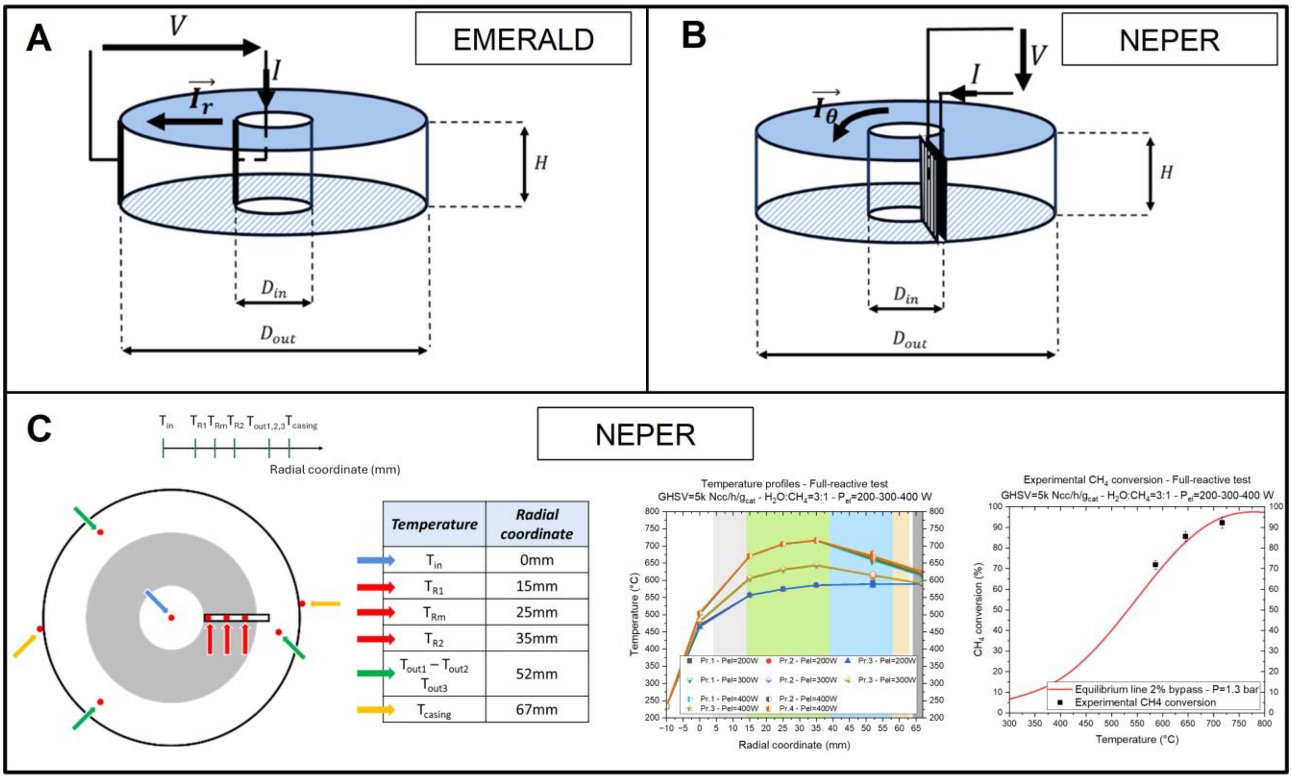

Figure 1. A) EMERALD electrical scheme B) NEPER electrical scheme C) NEPER experimental results

References:

[1] Patent EMERALD - IT202100026456A1; EP4415857A1

[2] Patent Application NEPER - EP26156436.3

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