

Tailored reactor concept for electrified induction heating: Enhancing reactor performance through heat-integration and additively manufactured metallic structures

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Highlights

- Induction Heating of Additively Manufactured Metallic Structures
- Axially Resolved Fiber-Bragg-Grating Temperature Measurements
- Novel Heat Integrated Tube-in-Tube Reactor for Efficient Dry Reforming of Methane
- Washcoated Metallic Catalytic Structures with High Dispersion and Surface Area

1. Introduction

Electrification within the chemical sector represents a fundamental strategy for achieving the EU's decarbonization targets [1]. The development of viable alternatives to high energy intensive systems is crucial to ensure a sustainable and effective transition. Induction heating (IH) exhibits several advantageous features, including a reduced environmental footprint through renewable electricity, direct magnetic field-based heating and operational flexibility, positioning it as a compelling option for future chemical reactor technologies [2]. To fully exploit the potential of IH, it is advantageous to apply it to highly endothermic reactions such as the dry reforming of methane (DRM) ($\Delta_R H = +247$ kJ/mol), in which carbon dioxide (CO₂) and methane (CH₄) are converted into syngas (CO, H₂) at elevated temperatures of 600-800 °C [3].

Traditional reactor concepts are unable to meet emerging IH challenges, such as high localized heat generation, adequate temperature measurements and restricted material options. This creates a strong demand for efficient, concepts capable of effectively coupling the IH susceptor with an appropriate catalyst in a tailored reactor configuration.

2. Methods

A novel reactor is used with a tube-in-tube concept which features heat integration as well as proper insulation to achieve a nearly isothermal reaction zone with high thermal and catalytic efficiencies. The reactor can be seen in Figure 1 and consists of two interlocking quartz glass pieces which feature flexible positioning of the susceptor structures and heat integration to preheat the inlet educt gasses.

The metallic susceptor for the IH consists of additively manufactured metallic structures (AMS) washcoated with a state of the art DRM catalyst. Fiber-Bragg-Grating (FBG) is used to analyze the temperature enabling resolved temperature monitoring throughout the experiments at elevated temperatures up to 900 °C.

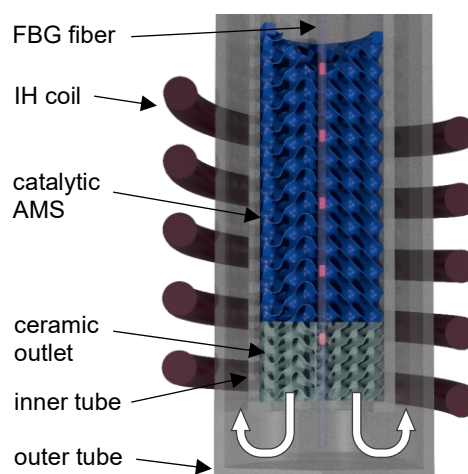


Figure 1. Novel IH reactor with interlocking quartz tubes (22 mm inner diameter), catalytic AMS (blue) with ceramic outlet and FBG fiber with six measuring points surrounded by IH copper coil.

3. Results and discussion

As seen in our previous studies, the metallic structures feature a thin washcoat layer with the Ni-catalyst evenly distributed enabling a large specific surface area with a stable pore radius at elevated temperatures of 600-800 °C during the DRM.

The study revealed the highly effective eddy-current based heating which is suitable powering the DRM at high flow rates with conversions larger 80% and high transfer efficiencies as seen in Figure 2. AMS proved to be superior in comparison with iron chrome alumina open cell foam structures: High heating rates could be noted for the iron chrome alumina foams in the ferromagnetic regime below 600 °C. In contrast, AMS proved ideal for eddy-current development at high temperatures (~800 °C), which is essential for achieving substantial conversions in equilibrium-limited DRM.

The transfer efficiency is largely governed by environmental heat losses, and the new heat-integrated tube-in-tube concept significantly reduce these losses. Heat losses through the inner reactor tube are used to preheat the inlet gases delivering a zone of high temperature throughout the whole metallic structure. As demonstrated already by Almind & Co-workers [4], adequate insulation can easily double the transfer efficiency. Therefore, we expect transfer efficiencies in the >50% range, positioning our reactor concept as a compelling alternative solution for scalable electrification in the chemical sector.

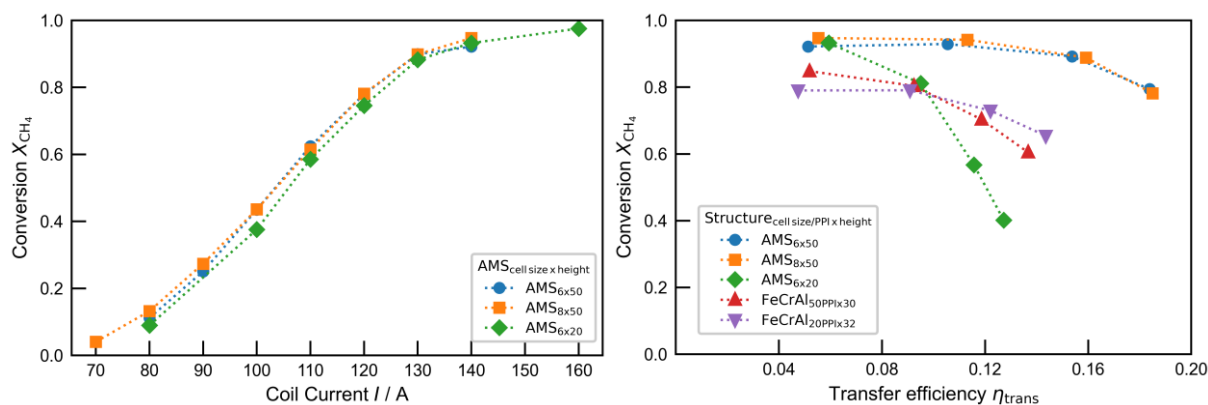


Figure 2. left: Methane conversion over coil current for various AMS with a length of 20 and 50 mm and a cell size of 6 and 8 mm. right: Methane conversion and transfer efficiency for selected structures (open cell metallic foams at different pores per inch (PPI) and AMS) each at an optimized operating point. Transfer efficiency: $\eta_{trans} = \frac{\dot{m}(h_{in}-h_{out})}{P_{in}}$.

4. Conclusions

Dynamic and fast IH offers pronounced synergy with the endothermic DRM process. Achieving an effective synergy relies on the selection of suitable reactor concepts, such as our proposed system, structured elements fabricated by additive manufacturing and compatible DRM catalysts. Through optimization of these interactions, IH can be advanced to higher technology readiness levels and enhanced scalability, supporting its future integration into energy-intensive, high-temperature processes and enabling simplified electrification across the chemical industry.

References

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Keywords

Induction Heating, Additively Manufactured Metallic Structures, Heat Integration, Dry Reforming of Methane