Electrically Heated Oxide Ceramic Tubes for Dry Reforming at High Temperatures

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Highlights

- Layered oxide ceramic matrix composite (OCMC) tube with integrated electrical heating.
- Layered OCMC tubes reach 1150 °C, optimizing conversion for dry reforming.
- Countercurrent flow ensures efficient heat recovery.
- Controlled heat release, high temperatures, and conventional mounting of OCMC tubes.

1. Introduction

Endothermic high-temperature syntheses are the most widely used industrial processes and are the first step in the value chain for almost all products in the chemical industry, including the industrial production of hydrogen. In conventional processes, the required heat is supplied by combustion of fossil fuels. Due to material limitations of the metallic tubes the maximum reaction temperatures are limited to 900°C [1].

In this study we investigate a novel reactor concept to carry out endothermic reactions at temperatures above 1000°C, where the energy demand is supplied by electrical heating. This can be achieved by using a novel ceramic tube which allows to embed a metallic resistive heating. Direct electric heating of the tube walls allows to design reactors with high heat recovery and thus high energy efficiency. The new layered ceramic tubes overcome the fragility and unfavorable failure characteristics associated with conventional ceramics [2].

2. Methods

The reactor tubes consist of a three-layer structure with an inner monolithic ceramic tube to provide gas-tightness. A metallic foil made of Aluchrom Y Hf (1.4767) is used for resistive heating and wrapped around the inner tube. Finally, the metallic foil is cladded by a layer of oxide ceramic matrix composite (OCMC) material. The composite structure of the novel tube is sketched in Figure 1 [3]. The local heat release can be designed by the geometry of the heater. During sintering the OCMC layer shrinks and applies a static pressure on the metallic layer and the monolithic inner tube. The ductile character of the OCMC material compensates thermal stress due to expansion of the metal at high temperatures. The static pressure on the inner monolithic ceramic tube compensates tensile stress due to radial temperature gradients.

To achieve high heat recovery, we apply a tube-in-tube design and reversed the flow at the end of the OCMC tube. Educts enter the reactor on the shell side and are preheated by the products flowing in the opposite direction inside the tube (Figure 1). We use dry reforming as a test reaction since it requires very high temperatures to achieve high conversion [4].

The reaction products, carbon monoxide and hydrogen are industrially relevant intermediates for producing synthetic fuels such as ethanol. The reaction equation is as followed:

$$CH_4 + CO_2 \rightarrow 2H_2 + 2CO \qquad \Delta H = 247\ kJ/mol$$

3. Results and discussion

By using OCMC tubes with embedded electrical resistive heating [3], we can increase temperatures in the reaction zone up to 1150 °C. This allows high conversion and minimizes undesired side reactions. The countercurrent flow of educts and products allows for effective heat integration. With increasing heat transfer between the outer shell and inner tube substantial heat recovery is possible, thus enhancing energy efficiency, as only the heat of the reaction must be provided by the resistive heating. Counter-current flow of feed and products is also advantageous for reactor design, as the products exit the reactor at relatively low temperatures, which allows the use of conventional materials for mounting the tubes. The cold-in-cold-out concept has been investigated experimentally.

First reaction experiments showed a sensitive behavior towards soot formation in regions with reduced temperature where the Boudouard reaction takes place [5]. Due to the porosity of the OCMC layers, soot can build up at the metallic heating element, causing to a local change in electrical resistance and unstable heat dissipation. This could be solved by controlled start-up and temperature control, enabling the first successful experiments under reaction conditions.

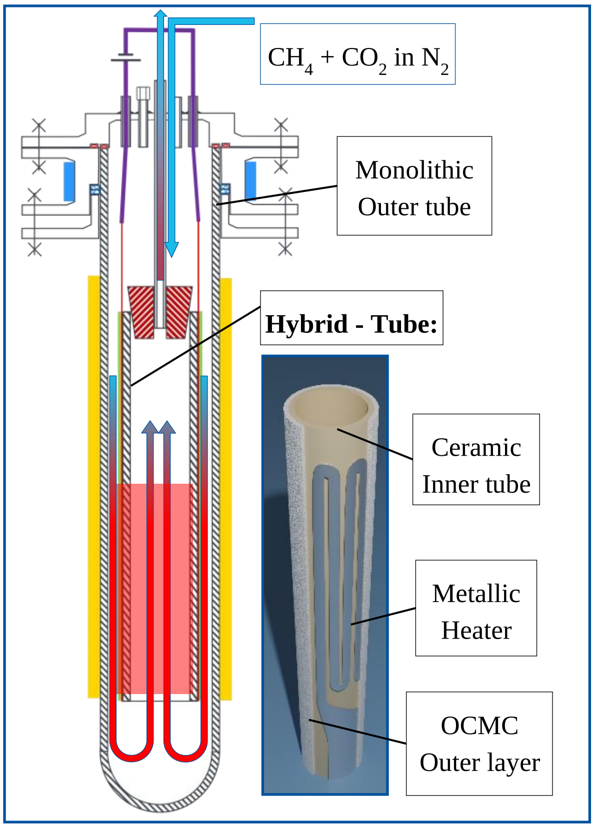

Figure 1. Experimental setup for direct electrical heating and heat recovery.

4. Conclusions

The novel layered ceramic tube allows for controlled heat release and high operating temperatures by direct electrical heating of the tube walls. The novel tube has proven to be stable up to 1100 °C for several hours under inert and reaction conditions. In conjunction with heat integration this allows for high energy efficiency and a considerable reduction of CO2 emission.

References

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Keywords
Electrical heating, High temperature reactions, Oxide ceramic matrix composites, dry reforming