Experimental investigation of a directly electrified Si-SiC open cell foam packed with Rh-based catalytic pellets for intensified methane steam reforming.

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Highlights

- A directly electrified open cell foam has been packed with catalytic pellets.
- This concept provided excellent performance in terms of conversion and efficiency.
- This configuration allows for an easier scalability overcoming issues related to washcoating.

1. Introduction

In the forthcoming years, hydrogen is expected to play a pivotal role in the energy transition. Its characteristics make it the perfect candidate for becoming a carbon-free energy vector in several industrial sectors. However, conventional MSR heavily relies on fossil fuels to supply energy to the endothermic reaction implying the emission of about 10 kg of CO_2 per kilogram of hydrogen produced, 40% of them coming from heat supply to sustain the reaction[1]. For this purpose, several concepts of electrified reactors have been proposed to exploit electricity as a source of energy in endothermic processes. Our research group already proposed the use of Si-SiC open cell foams activated by wash-coating Rh-based catalyst on their surface[2]. The Si-SiC foam, characterized by a sufficiently high resistivity, was directly connected to an electric circuit and acted both as catalytic support and resistive element, providing heat to the MSR reaction by Joule effect. This concept proved to be very effective, delivering excellent performance in terms of methane conversion and specific energy consumption but, at the same time, was limited to the use of washcoated systems. This work aims to demonstrate for the first time the possibility of combining a directly electrified Si-SiC open cell foam packed with commercial pellet catalyst to perform methane steam reforming in an electrified and intensified reactor.

2. Methods

The key component of the reactor used to perform these experiments is the heating element, which consists of a cylindrical Si-SiC open cell foam connected to an electrical circuit via two stainless steel electrodes in tight contact. This foam, characterized by a diameter of 33 mm and a length of 80 mm, was packed with 38 grams of 0.3% Rh-Al_2O_3 commercial pellet catalyst with a particle diameter of 1mm provided by Heraeus. Temperature was measured by a thermocouple placed at the bottom of the foam to provide the exact outlet temperature of the reactor. Experiments were run at atmospheric pressure in a temperature range between 600°C and 800°C. Water and methane were fed to the system using Brooks SLA mass flow controllers at steam to carbon ratio of 3 and 4, while flow rates were varied from 190 Nl/h up to 570 Nl/h, corresponding to a GHSV of 5-15 $Nm^3/kg_{cat}/h$. An alternated current power supplier provided the necessary amount of power to run the reaction, while a micro-GC (Agilent 990) was used to analyze the product composition.

3. Results and discussion

Figure 1 shows the methane conversion with respect to measured outlet temperature. Experiments at steam to carbon ratios (SC) equal to 3 and 4 are reported for different temperatures and GHSV. It is possible to observe that an increase of the flow rate leads to a decrease of conversion, an effect that is more marked at lower temperatures where kinetic regime starts to be more evident. At same temperature S/C tests of 3 display lower conversion, given the higher CH_4 content in the feed. Instead, at high temperatures the system is able to reach the thermodynamic equilibrium. In this experimental campaign powers up to 780W were necessary to perform the reaction in such conditions with thermal efficiencies, defined as the ratio of the enthalpy change between inlet and outlet of the reactor to the supplied power, higher than 70%. In such conditions specific energy consumptions of 1.4 kWh/Nm^3_{H2} were recorded, value that, together with efficiency, is expected to improve with the increase of the reactor size.

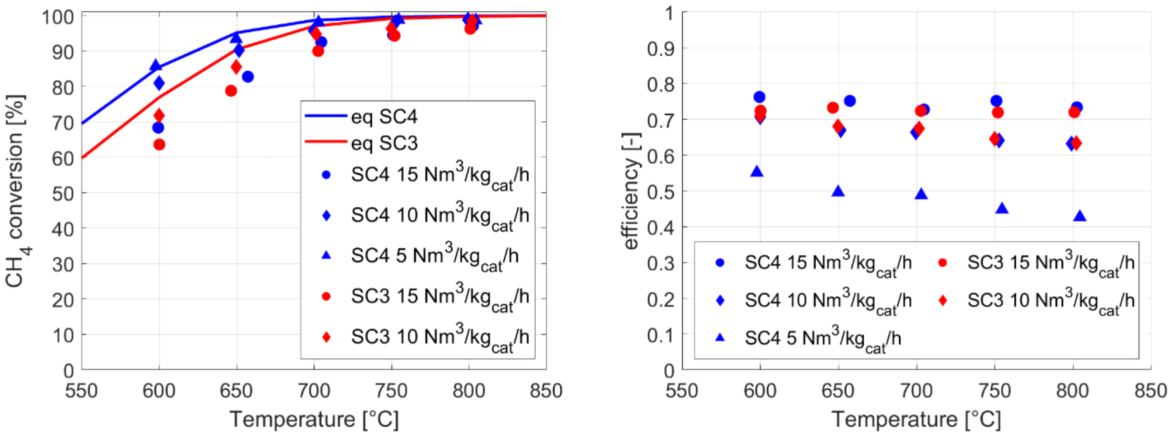

Figure 1 CH_4 conversion and thermal efficiency at different inlet composition (steam to carbon ratio SC) and Gas Hourly Space Velocities [$Nm^3/kg_{cat}/h$]

4. Conclusions

Lab scale tests successfully demonstrated for the first time the possibility of combining a directly electrified Si-SiC open cell foam with catalyst pellets packed into the structure. This concept merges the uniform power generation ensured by the silicon carbide structure with the activity provided by the pellet-shaped catalyst paving the way for scaling-up this concept of electrified reactor. The use of pellet guarantees an easier catalyst replacement in case of deactivation and avoids problems of catalyst detachment from the support, making this configuration more reliable, easier to be scaled up and suitable for slow processes where wash-coated catalyst would not be enough to guarantee the necessary amount of catalyst.

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References

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Keywords

Hydrogen production; electrified reactors; Joule heating; open cell foams.