# Low-carbon $H_2$ production via electrified steam reforming of biogas in conductive structured reactors

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***Highlights***

- Biogas steam reforming in a structured reactor joule heated with a resistive wire.
- Copper POCS with an internal skin in contact with the wire enable efficient heat transfer.
- Intensification of heat exchange keeps the wire temperature under control with high $H_2$ productivity.

## 1. Introduction

Biogas is a widely available feedstock that can be used to produce low-carbon $H_2$, thus contributing to the reduction of $CO_2$ emissions. The typical size of biogas plants (500 $Nm^3/h$) poses a significant problem for conventional steam reforming, related to the decrease of heat transfer efficiency at low flow rates in small-scale systems (where convective heat transfer is unfavorable). In this work, we propose a new reactor concept based on: (1) the use of conductive open cellular structures (foams or POCS, periodic open cellular structures) made of copper [1] and packed with catalytic pellets, that introduce a conductive mechanism of heat transfer insensitive to flow rates, and (2) the use of joule heating wires in thermal contact with conductive internals, to exploit renewable electric energy. The combined design is expected to ensure efficient radial heat transport and enhanced mass transport, eventually leading to high yields of zero (or even negative)-C hydrogen.

## 2. Methods

To demonstrate the new reactor concept, biogas steam reforming tests were performed with Heraeus $Rh/Al_2O_3$ egg-shell catalytic pellets (1 mm nominal diameter). The catalyst was produced following a formulation previously developed and tested in our laboratory [2]. The lab scale reactor (L=20 cm , Dint=2.95 cm)), loaded with copper foams or POCS packed with catalyst particles, was heated by means of a commercial resistive wire (THERMOCOAX), which was placed at the reactor centerline and connected to an external AC power supply (30 V, 50 A). Axial temperature profiles were measured by axially sliding thermocouples along the reactor, in two radial positions (mid-radius and outer wall), while an online micro-GC was used to quantify the reaction products. A 2D heterogeneous reactor model [2] was developed for the cylindrical geometry with the embedded heating element and validated against experimental data. The model considers two phases: the copper internal and a pseudo-phase (gas and pellet lumped together). The energy balance of the heating element is also included to provide the estimation of the wire temperature under working conditions. The kinetics of the reactions involved (methane steam reforming and water gas shift) were taken from a previous study [3]. The model input parameters are the composition, pressure, flow rate and temperature of the feed, and the measured axial profile of the wall temperature (providing the boundary condition of the energy balance at the wall).

## 3. Results and discussion

Experimental results showed that the presence of the copper conductive internal leads to very small radial temperature gradients for this reactor scale and volumetric heat duties up to 7 $MW/m^3$. By comparing the temperature profiles obtained with packed foams and packed 3D-printed POCS at the same gas hourly space velocity and outlet temperature, it appears that POCS allow for much lower radial gradients than foams (about 1/3 in the example shown in Figure 1) and a higher methane conversion (95% vs 90% in the example reported). This advantage is due to the presence of an internal skin that keeps the POCS in direct contact with the wire, thus enhancing the local heat transfer. The model (solid lines) predicts the pseudo-phase and solid-phase temperatures without adaptive parameters. In addition, it calculates the temperature of the heating element (blue line), which is the highest in the system, and therefore the most critical one when selecting materials for a scaled-up unit. The calculated wire temperature is markedly lower for POCS than for foams because of the improved thermal contact between the wire and the conductive structure. The simulations of the radial profiles at the exit of the catalytic bed for the two systems are shown in Figure 1 in the right hand panels; here it can be observed that the POCS are characterized by a more uniform temperature distribution on the cross-section compared to the foams. Indeed, in the case of foam, a significant increase of temperature is predicted in the area close to the wire. The benefits of POCS on wire temperature and radial gradient also result in a lower risk of catalyst sintering or coke formation and improved reformer stability.

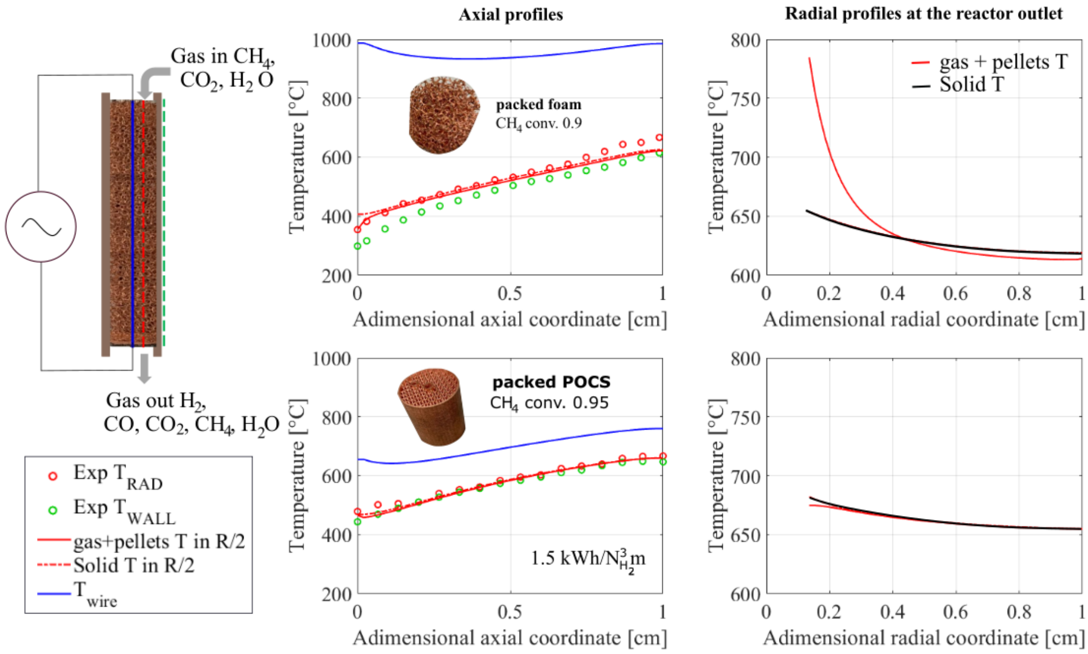


**Figure 1.** Scheme of the lab-scale electrified reactor with the temperature profiles obtained for packed foams and packed POCS in steam biogas reforming experimental (dots) and according to model simulations (lines).

## 4. Conclusions

Experimental tests in a lab-scale reactor allowed to prove the concept of electrified biogas reformer with packed foam and packed POCS, where the reaction heat is provided via an internal heating wire and distributed across the volume by the conductive internals. The enhanced heat transfer of POCS allows to reduce the radial temperature gradients, with increment of methane conversion and reduction of the wire temperature, an essential feature for stable operation of the reactor and for reducing the cost of low-carbon $H_2$ production.


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***Keywords***
Biogas reforming; Process Intensification; Process Electrification.