

Electrified Sorption Enhanced Reforming: A Novel Approach for Single Step Sustainable Hydrogen Production and Carbon Capture

Abdelrahman Mostafa*, Matteo C. Romano, Alessandra Beretta, Gianpiero Groppi, Enrico Tronconi

Department of Energy, Politecnico di Milano, Via Lambruschini 4, 20156, Milan, Italy

*Corresponding author: abdelrahmanmohamed.mostafa@polimi.it

Highlights

- Introducing the novel technology of electrified sorption enhanced reforming (eSER).
- Dynamic modeling approach demonstrates the feasibility of the technology.
- eSER allows single step production of >95% purity hydrogen with >80% carbon capture rate.

1. Introduction

Recent advancements in electrification of catalytic reactors have paved the way for more sustainable chemical processes, benefiting from renewable energy to mitigate the CO₂ emissions in the production of chemicals and energy vectors. Notably, extensive research has focused on the electrified reforming technology aiming to cut down the carbon footprint associated with hydrogen production. The latest findings reported in literature highlight a significant advantage in heat transfer for the electrified reformers that exploit resistive

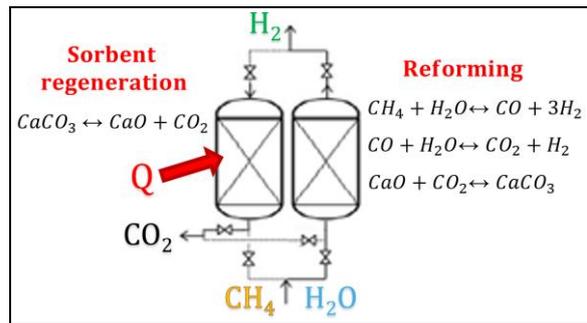


Figure 1. SER process concept

internals, where uniform temperature profiles and rapid dynamic responses have been demonstrated [1]; which opens to the potential of electrified reactors for strongly endothermic and dynamic processes. Among them, sorption enhanced reforming (SER) emerges as a potential solution for rapid large-scale deployment to match the projected increase in the demand of hydrogen [2]. The two-step process, schematized in Figure 1, achieves quasi-steady production of H₂ through the cyclic operation of multiple reactors between SER and sorbent regeneration. While effective in the direct production of low-carbon H₂, scaling up SER faces substantial challenges. In this context, using a reactor modeling approach, this study investigates the behavior of an electrified reactor for the novel large-scale electrified SER process (eSER).

2. Methods

A 1-D dynamic model of a packed foam reactor was developed using gPROMS software. The presence of the thermally and electrically conductive foam inside the reactor results in uniform radial temperature profiles. The model consists of mass and energy balances for the pseudo homogeneous phase (including gas, catalyst, and sorbent), and the energy balance for the solid open cell foam phase. Ni based reforming catalyst and CaO spherical pellets as a regenerable CO₂ sorbent were assumed for this study. The required reactions kinetics for the reforming and CaO carbonation were obtained from the literature [3]. The model captures the reactor's transition between the four steps of a single cycle of the SER process: reforming, depressurization, sorbent regeneration, and reactor pressurization. The duration of the reforming step is determined based on CO₂ breakthrough. Upon reaching the breakthrough criteria, the reactor is depressurized to the selected regeneration pressure, initiating the sorbent regeneration step. Benefiting from the reactor's thermal capacity and the released heat of CaO carbonation, the reforming step is considered to operate adiabatically. On the other hand, the heat necessary for the endothermic sorbent regeneration is to be delivered through resistive heating of the solid foam. Being a dynamic process, the discrete power supply to the foam was assumed to be controlled by the temperature of the effluent exiting the reactor; in that way, the risk of overheating the reforming catalyst is mitigated. Successive eSER cycles were simulated to prevent any impact of the pre-imposed initial conditions on the resulting reactor's dynamic axial profiles of temperature and composition. Results are herein reported after the reforming step of the first cycle. The possible cyclic degradation of the catalyst and the sorbent were not considered.

3. Results and discussion

Figure 2 presents the simulated temperature and composition of the effluent stream across two complete cycles of the electrified Sorption Enhanced Reforming (eSER) reactor. During the reforming step, a CH_4/steam mixture, with a molar ratio steam/C = 4 and $T_{\text{feed}} = 550^\circ\text{C}$, is fed to the reactor to produce H_2 at 10 bar. Sorbent regeneration is simulated without purge gas, employing 5 MW/m^3 electric power on the foam and producing a hot stream of pure CO_2 . Noteworthy, the power control is set to maintain an outlet gas temperature ranging between 930°C and 1000°C .

In the reforming step of the eSER process, steam reforming, water gas shift, and CO_2 sorption reactions occur simultaneously leading to the dynamic advancement of a sorbent carbonation front along the reactor's axial coordinate as explained in [2]. This dynamic fixed-bed configuration results in non-uniform temperatures and sorbent conversion levels along the reactor's axis by the end of the reforming step. Subsequent to the reforming step, passing through a short depressurization step, the reactor transitions to the regeneration phase. Here, the electric power provided to the foam results in uniform heating of the reactor. Governed by the presence of a hot zone with less converted sorbent, the end of the reactor reaches the limiting temperature rapidly and the power supply is stopped. As the endothermic sorbent regeneration proceeds, the reactor's temperature decreases until reaching the lower limiting temperature, reactivating the power supply. This discontinuous supply strategy operates until the regeneration of the sorbent is complete, which represents the end of the eSER cycle. The results highlight the high performance of the eSER process; where 95.8% of the fed CH_4 is converted, a H_2 stream is obtained with 95.2% purity and 82.1% of the carbon fed is captured.

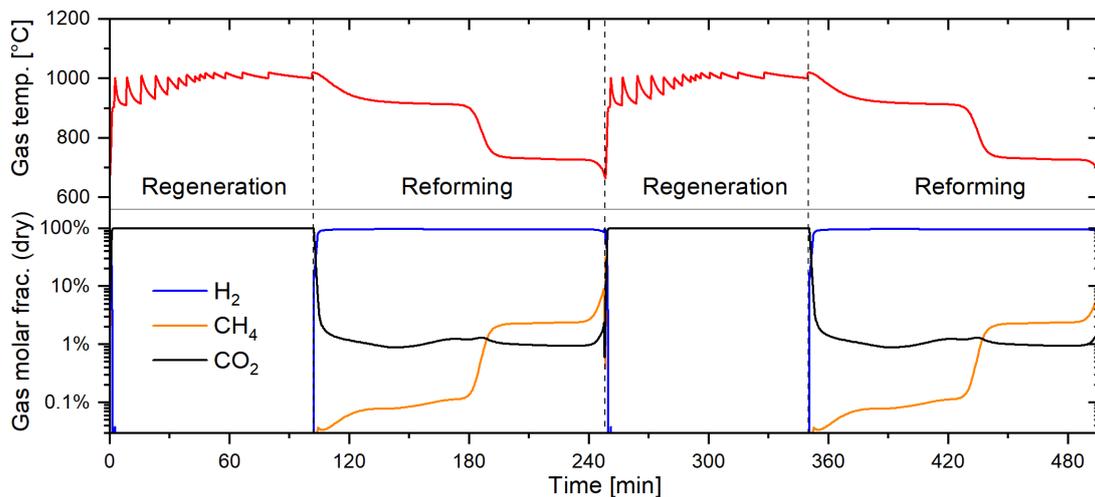


Figure 2. eSER typical dynamic temperature (Top) and composition (bottom) profiles at the exit of the reactor. Operating conditions: Reforming: S/C= 4, $T_{\text{feed}}= 550^\circ\text{C}$, $P_{\text{out}}=10$ bar; Regeneration: $P_{\text{out}}= 1$ bar, $Q_{\text{ele}}= 5 \text{ MW/m}^3$.

4. Conclusions

This modeling study explores the potential of utilizing the electrified reactor technology for the direct production of low-carbon H_2 through sorption enhanced reforming (which turns into the novel e-SER process). Simulations demonstrate the feasibility and remarkable performance of eSER, characterized by full thermal control of the regeneration phase, and production of pure streams of H_2 and CO_2 .

Acknowledgements

The authors would like to thank the MIUR for funding this work as part of the project “PLUG-IN” (PRIN 2020).

References

- [1] L. Zheng, M. Ambrosetti, F. Zaio, A. Beretta, G. Groppi, E. Tronconi, *Int. J. Hydrogen Energy* 48 (2023) 14681–14696.
- [2] A. Mostafa, I. Rapone, A. Bosetti, M.C. Romano, A. Beretta, G. Groppi, *Int. J. Hydrogen Energy* 48 (2023) 26475–26491.
- [3] J. Xu, G.F. Froment, *AIChE J.* 35 (1989) 88–96.

Keywords

Dynamic modeling; Electrification; CO_2 capture; Hydrogen.