Joule-heated structured catalytic reactors for CO_2 valorization

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Abstract

The growing environmental concerns have driven the catalytic CO_2 valorization as a forward-looking solution to mitigate the carbon footprint of valuable chemical products. Processes for CO_2 conversion into synthesis gas, such as CO_2 reforming of methane or reverse water-gas shift, may have a strategic role for the future sustainable production of chemicals and energy carriers. However, fuel combustion to supply the heat of the associated endothermic reactions would result in unwanted CO_2 emissions, which strongly reduce the CO_2 valorization potential. Electrification of the endothermic processes may represent the technological solution to such an issue [1].

Here we report a promising approach for the direct electrification of both the CO_2 reforming of methane (eCRM) and the reverse water-gas shift (eRWGS) processes in washcoated structured reactors. Similar to a concept recently demonstrated for electrified stema reforming of methane [2], we employ catalytically activated open-cell foams that provide optimal heat and mass transfer properties as catalyst substrates and simultaneously serve as Joule heating elements for the catalytic conversion of CO_2 via its reaction with methane or hydrogen.

With the proposed system utilizing Joule-heated Rh/Al_2O_3-coated SiSiC foam, CO_2 conversions approaching equilibrium were measured across a wide range of conditions for both eCRM and eRWGS. We further show that such a new reactor concept ensures remarkably low specific energy demand for CO_2 valorization, reaching approx. 0.7 kWh/Nm^3_{CO2} for eRWGS in an optimized process configuration, assuming an overall adiabacity of 95% and a recovery of 90% sensible heat. If the feed H_2 is sourced from water electrolysis (3.8 kWh/Nm^3_{H2}) [3], it is possible to achieve an overall specific energy consumption of 4.5 kWh/Nm^3_{CO2} for CO_2 valorization, which is lower compared to solid oxide electrolyzers for CO_2 reduction to CO (6-8 kWh/Nm^3_{CO2}, [3]). Furthermore, the system demonstrated excellent catalytic and electrical stability for over 75 hours.

By replacing fuel combustion with Joule heating driven by renewable electricity, the electrified CO_2 valorization processes provide an important approach for dealing with the intermittent nature of renewable sources by storing the energy in chemicals with a low carbon footprint.

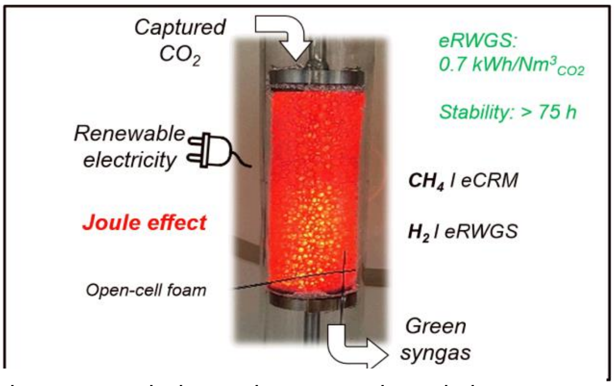

Figure 1. Joule-heated structured catalytic reactor.

References:

[1] S.T. Wismann et al., Science 364 (2019) 756.
[2] L. Zheng et al., AIChE J. 69 (2023) e17620
[3] D.J. Jovan et al., Energies 13(24) (2020) 6599.