Pure methane from CO2 utilizing a structured radial flow reactor system employing a novel bi-functional material.

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Highlights

- Develop a quasi-isothermal structured packing radial flow reactor to achieve 100% CO2 conversion.
- Improvement of heat and mass transfer in a radial flow configuration by using cellular structures.
- Deep study of the kinetics of the reaction.

1. Introduction

Methanation is a highly exothermic chemical reaction where carbon dioxide gets hydrogenated, producing methane and water. This is a complex reaction due to kinetic limitations at low temperatures and thermodynamic limitations at high temperatures leading to the formation of carbon monoxide. Temperature and the control of water as a byproduct are crucial for achieving high methane conversions and good catalyst selectivity (Vogt, 2019). To achieve low temperatures in exothermic reactions there are interconnected metallic structures such as periodic open-cell foam structures, which can be produced using 3D printing technologies. These structures have different geometries and sizes that can be tailored to improve the mass and heat transfer conditions (Fratalocchi et al., 2020) (Ferroni et al., 2023). Three main areas can be addressed for this topic, catalyst improvement, reactor design, and CO_2/H_2 feed ratios.

2. Methods

The first development is towards the production of a highly active catalyst- with zeolite support that can adsorb the water produced as a by-product of methanation. Once the catalysts are ready, then we can use them to fill the microreactor.

To solve the heat and mass transfer problem, VTT has started investigating non-conventional flow configurations like radial flow reactors with periodic open-cell foam structures as an insert. These reactors can be built by using 3D printing technology, which allows us to tailor and design different internal structures. Their main benefit can be attributed to their short-packed bed flow path, leading to a 50-90% reduction of the pressure drop compared to axial flow reactors and better control of temperatures since it improves the conduction and convection properties of the system. The outlet gas flows are directed to a GC unit where they are analyzed to determine the amount of methane that is being produced.

3. Results and discussion

The inserts that have been prepared at VTT have a POCs structure with different geometries and unit cell sizes, all configured in a radial flow design. The tests for the methanation reactions haven't been performed yet but the reactor system is ready to be used.

Figure 1. Insert and reactor shell.

The radial insert with the POCs structure in its interior and the shell of the metal reactor containing the insert are presented in Figure 1. The flow of the gas enters by the hole in the middle of the insert and leaves in a radial direction while converting the CO_2 and H_2 into methane and water.

Figure 2. Reactor system.

The insert is placed in the reactor shell and then pressure-tight using rods around it to prevent pressure leaks. A thermocouple and the inlet gas pipe are placed at the top of the reactor and the outlet gas pipe is at the bottom.

4. Conclusions

Microchannel reactors improve the mass and heat transfer due to their porous structure. A configuration that has been taking interest is the periodic open foam, which unlike monoliths or honeycombs has a more organized structure, where the same channel geometry repeats through the hole shape. This order of the structure allows better thermal convection due to improvements in flow path conditions and better thermal conduction due to the interconnected metallic structure. This configuration is very important, especially for exothermic reactions like methanation where the temperature needs to be kept between 200°C and 400°C.

At VTT we are currently working with different insert geometries in axial and radial configurations. Some have a radial configuration with an outer metallic layer that surrounds the radial structure, aiming to improve the thermal conductive behavior. The tests will start in a couple of months, aiming to have enough experimental data to compare the different inserts and select the best based on structural improvements.

References

Ferroni, C., Bracconi, M., Ambrosetti, M., Groppi, G., Maestri, M., & Tronconi, E. (2023). Coupling cellular substrates and radial flow reactors for enhanced exhaust abatement in automotive DeNOx-SCR. *Chemical Engineering Journal*, *467*. https://doi.org/10.1016/j.cej.2023.143349

Fratalocchi, L., Groppi, G., Visconti, C. G., Lietti, L., & Tronconi, E. (2020). Adoption of 3D printed highly conductive periodic open cellular structures as an effective solution to enhance the heat transfer performances of compact Fischer-Tropsch fixed-bed reactors. *Chemical Engineering Journal, 386*. https://doi.org/10.1016/j.cej.2019.123988

Vogt, C. , M. M. , K. G. J. et al. (2019). The renaissance of the Sabatier reaction and its applications on Earth and in space. *Nat Catal*, *2*, 188–197.

Keywords

Methanation, Radial insert, POCs, Axial insert