Power-to-Gas: Thermally Stable Multi-Tubular CO_2 Methanation Reactor Design

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Highlights

- Novel thermally stable CO_2 methanation reactor design
- Bench-scale experimental validation
- Model-based reactor modeling and design in gPROMS

1. Introduction

The Power-to-Gas process makes use of renewable energy to generate hydrogen, which combined with carbon dioxide, can produce carbon-neutral methane. The latter can then serve as an energy carrier or as a feed to gas grid.

The CO_2 methanation reaction is highly exothermic. A major challenge for reactor designers is, therefore, how to avoid hot spots that can cause catalyst damage, and ensure robust operation under dynamic operation and flexibility [1]. The reaction is conventionally carried out in a series of adiabatic reactors with interstage cooling. However, in such designs, it is very difficult to prevent high temperatures which lower catalyst life. Using cooled reactors usually allows operation at lower temperatures; however, such reactors are prone to formation of hot spots and thermal runaway, which may render them practically inoperable under dynamic conditions [2]. Fluidized bed designs are faced with typical challenges such as catalyst attrition. New reactor concepts are being considered, including microstructured reactors and slurry reactors [3]. Structured reactors have the advantage of high GHSV, their main drawback being the complex procedure needed to immobilize the catalyst on the structures. While slurry reactors can offer a high efficiency of heat removal due to liquid circulation, they typically have to be operated at low GHSV due to additional mass transfer resistance and issues related to liquid phase circulation, all of which limit their wider application.

The CO_2 methanation reactor design proposed in this work involves a series of two multi-tubular, cooled fixed-bed reactors. The proposed design leads to thermally stable operation, thus ensuring good temperature control and long catalyst life while delivering high performance. Moreover, by maintaining a relatively low coolant temperature, the design allows the use of a liquid cooling medium that allows easy recovery of the reaction heat.

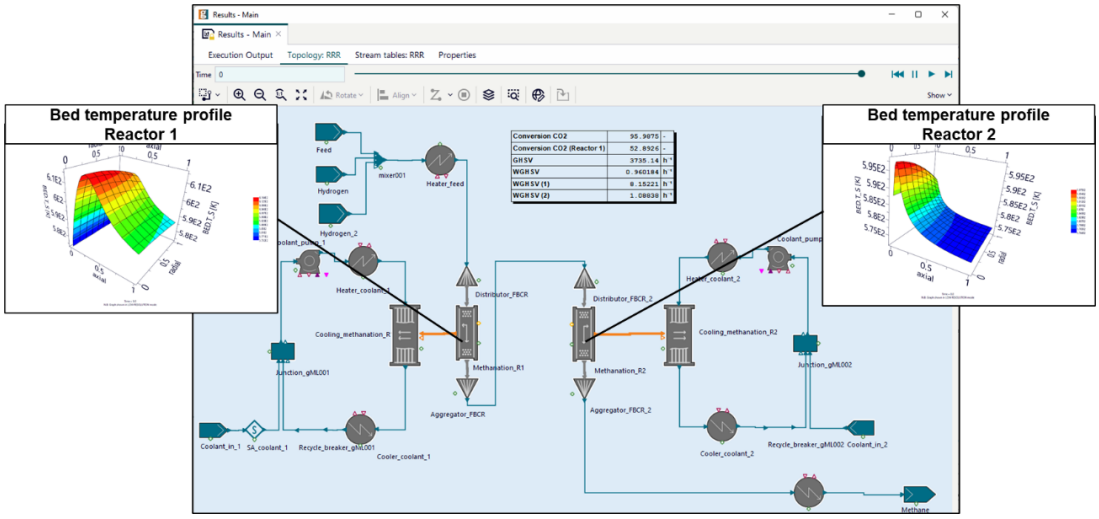

Figure 1. High-fidelity model of two-stage multi-tubular reactor for CO2 methanation in the gPROMS Process modeling platform [4].

2. Methods

The reactor was designed and optimized using a high-fidelity model of a catalytic reactor (see Figure 1). The tube-side model incorporates a state-of-the-art surface microkinetic model for CO and CO_2 methanation over Ni-based catalysts [5] and takes account of all important mass and heat transfer phenomena. The shell side is modelled as a tube bank with baffles and coolant crossflow. Silicone-based heat transfer fluid was chosen as the circulating coolant with inlet temperature kept at 300°C.

The resulting reactor design has recently been validated experimentally in a pilot-scale reactor setup (see Figure 2) operating a fixed-bed reactor with 0.5kg of commercial Ni-based catalyst.

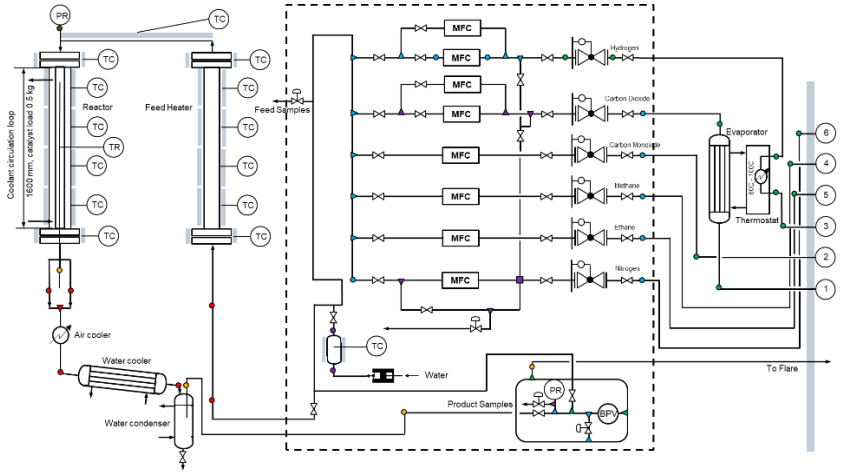

Figure 2. Experimental rig for CO_2 methanation used for validation of reactor design.

3. Results and discussion

A model-based study of different tubular reactor designs for CO2 methanation reactor was performed, resulting in a reactor design that achieves the required performance (95% conversion) while ensuring thermal stability by avoiding hot spots. More details of the design and its experimental validation will be presented at the conference.

4. Conclusions

A thermally stable two-stage CO_2 methanation reactor design was proposed, ensuring easy temperature control and long catalyst life while delivering high performance. The reactors utilize a cooling medium that allows for easy recovery of the large energy generated due to the reaction.

References

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Keywords

Power-to-Gas, CO_2 Methanation, gPROMS, Multi-tubular reactor