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Biological Methanation in a trickle-bed reactor

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Energy storage

Energy storage systems become increasingly important due to strong changes in the energy sector. The advantage of methane (substitute natural gas) as the product of the CO_2-methanation process is its capability to be directly fed into the existing gas grid. This gas can be used for power generation as well as for heating systems, mobility or as process heat. The reaction proceeds according to the following chemical equation and shows, that CO_2 and H_2 are necessary reactants:

$$4\ H_2 + CO_2 \rightarrow 2\ H_2O + CH_4$$

While CO_2 is mostly generated by biogas plants or combustion processes, H_2 is gained from electrolysis using excess electricity from renewable energy sources.

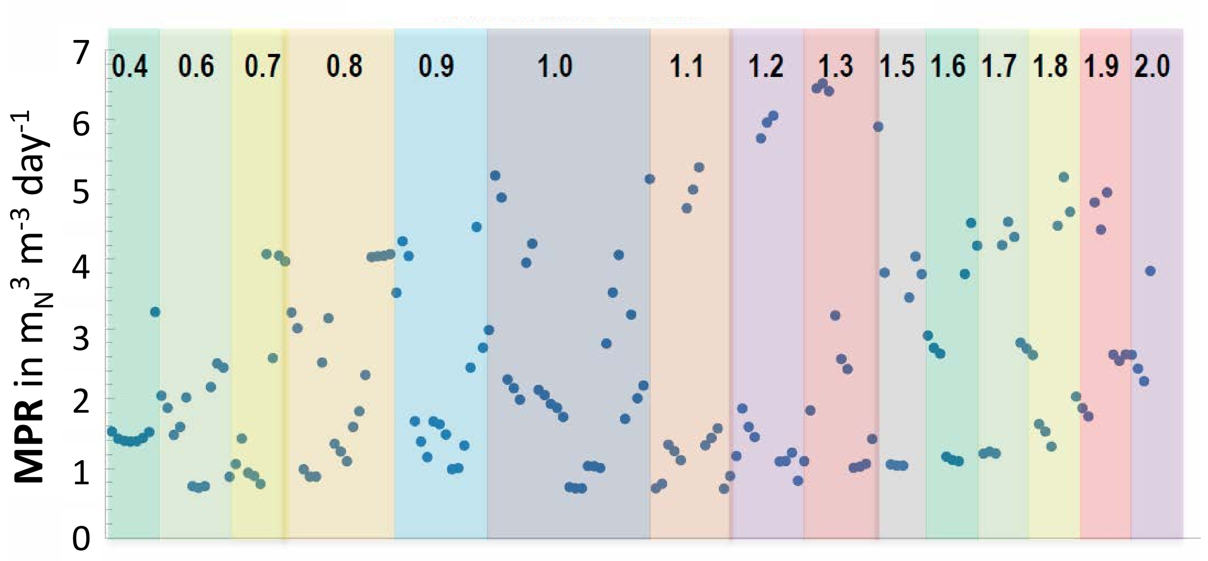

Figure 1: Methane production rate over recirculation in the 5 liter trickel-bed reactor

Biological Methanation

The term "biological" describes the usage of Archaea instead of chemical catalysts to enhance the reaction. These Archaea live in a anaerobic liquid-phase metabolizing H_2 and CO_2 to CH_4. Archaea are undemanding concerning their external environment and are therefore capable of adapting to different environments. The common process of methanation is operated chemical-catalytically. This technology is fully developed and currently superior to the biological methanation. However, the catalytical methanation holds certain disadvantages:

- High temperature and pressure required
- Long start-up time and difficulties operating at partial load
- Expensive catalyst, sensitive to contaminations

The biological CO_2-methanation on the other hand does work at low temperatures and pressures, tolerates contaminations and is also capable of operating at partial load. One disadvantage is the low methane production rate (MPR). MPR describes the production volume rate of methane per time and reactor volume. Further research on this topic will be necessary to rise the MPR.

Trickle-bed reactor

The challenge in biological CO_2-methanation lies in the low solubility of hydrogen in the liquid phase. H_2 is needed by the Archaea to maintain their metabolism. Reactors providing the required gas transfer rate are for example stirred tank reactors or the trickle-bed reactors. The EVT is running experiments with both reactor types on a small 5 liter-scale since 2016. The results are the obvious pressure dependents. But also the recirculation rate of water in the trickle-bed reactor, as seen in figure 1. One challenge is the high spreading of results because of the daily changing performance of the Archaea as seen in figure 1. In the project ORBIT, a 50 liter trickle bed reactor is constructed and optimized with eight partners from research, development and industry. At the end of the project lies the proof of concept in a real power-to-gas site at Ibbenbüren with feeding the obtained gas in the gas grid.

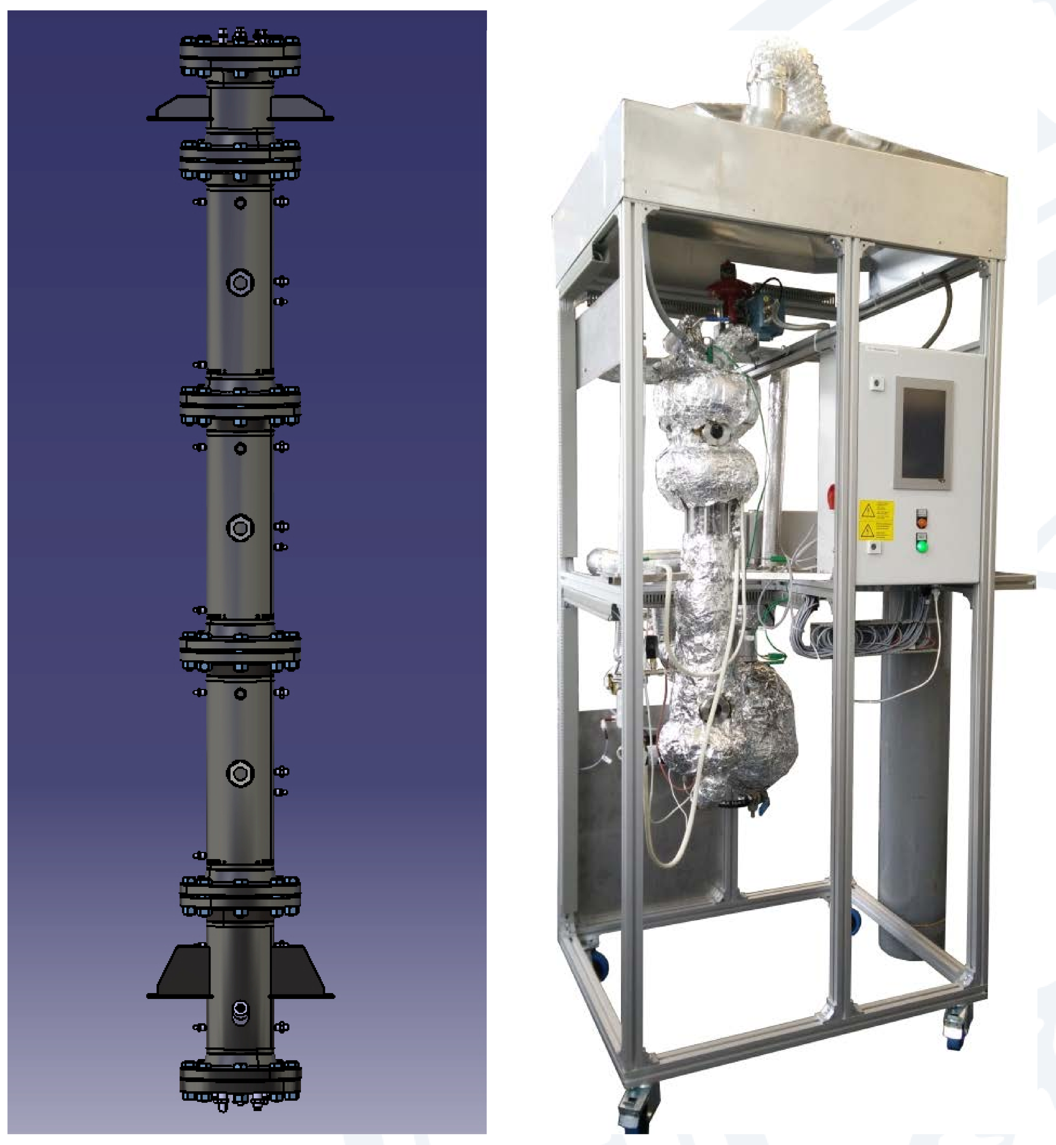

Figure 2 left: CAD-construction 50 liter reactor, right: 5-liter trickle-bed reactor

Simulation of the 50 liter trickle-bed reactor

Several simulations were performed with ASPEN and MATLAB to better predict the concept of the trickle-bed reactor The main goal hereby is to produce ≥ 98 % of CH_4. Therefore, a 1D-model was constructed using mass transfer, absorption rate, and time as variables. As the background parameter, the countercurrent water flow, the gas flow of H_2 and CO_2 and the geometry of the reactor and the trickles were chosen. After the absorption of the gas in the fluid the reaction rate of the microorganisms, converting the gas to CH_4 which then flows upwards, was considered.

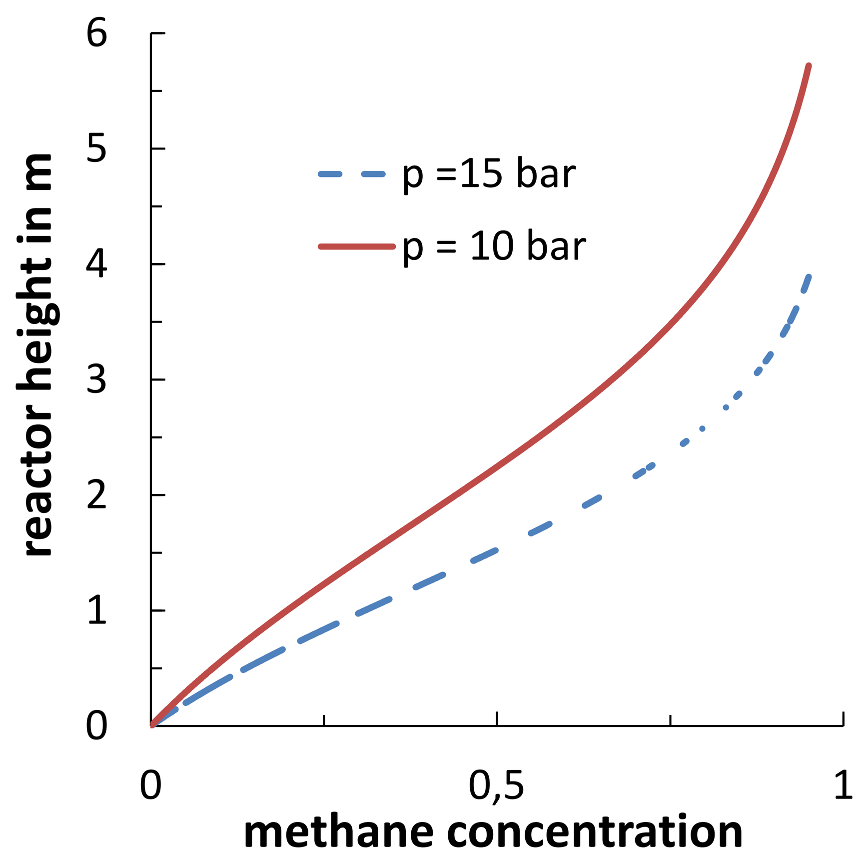

Figure 3: Methane concentration over reactor height at 10 and 15 bar

Simulations of the reactor concept demonstrate the importance of high pressure in the reactor. Towards the top of the reactor, the concentration of methane in the gas rises and the concentrations of feed gases decrease, leading to slow down the species transfer and thus to a reduction of the reaction kinetics. In consequence, targeting a high purity of methane requests high specific reactor heights, reducing the MPR. In Figure 3 the simulated course of the methane concentration over the height is shown.

Conclusion

The biological CO_2-methanation in a trickle-bed reactor is a possibility to store energy in form of CH_4. However, especially the MPR and the purity of CH_4 are challenges which need to be improved to make the system more economically.

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