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Trickle-Bed Reactor For Biological Methanation

ORBIT
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T. Weidlich[1], T. Trabold[1], M. Thema[2], M. Sterner[2], J. Karl[1]

[1]Chair of Energy Process Engineering (EVT), Friedrich-Alexander-Universität Erlangen-Nürnberg, Further Str. 244f, D-90429 Nürnberg

[2]Research Center on Energy Transmission and Energy Storage (FENES), Technical University of Applied Sciences OTH Regensburg, Seybothstrasse 2, D-93053 Regensburg

Energy storage

Energy storage systems become increasingly important due to far-reaching 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 for process heat generation. 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 presently CO_2 is mostly generated by biogas plants or combustion processes, H_2 is gained from electrolysis using excess electricity from renewable energy sources.

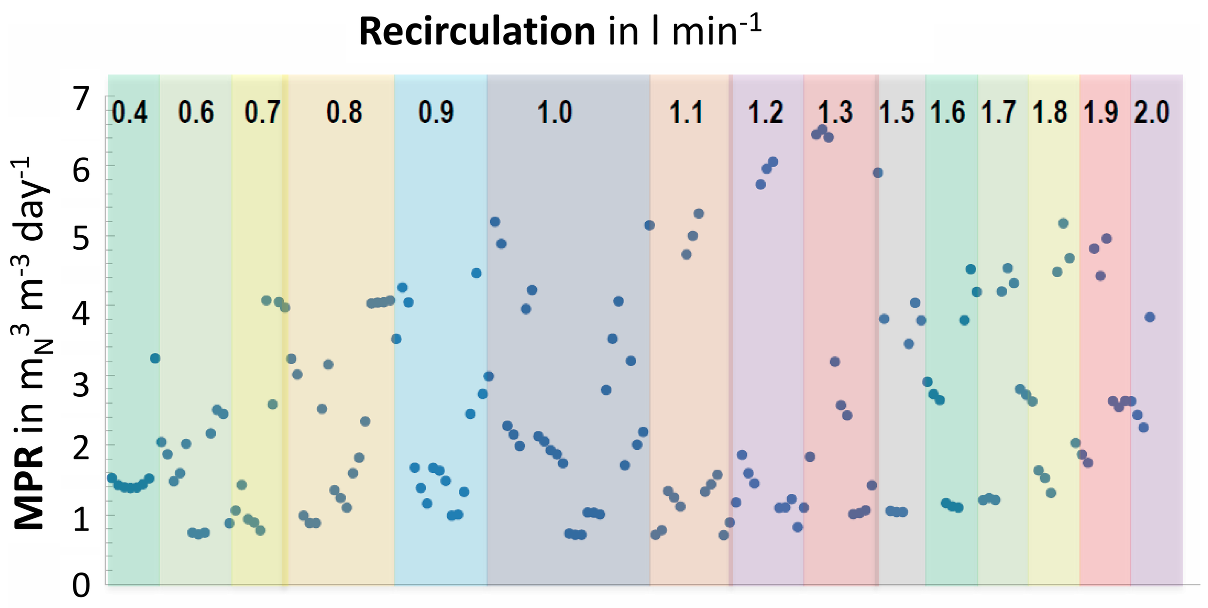

Figure 1: Methane production rate (MPR) per trickle zone over recirculation rate in the 5 liter trickle-bed reactor in batch mode

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 biological methanation holds certain advantages:

- low temperature and pressure possible
- short start-up time and easy operating at partial load
- biological catalyst, tolerates contaminations

One disadvantage is the lower methane production rate of the reactor (MPR_R). It describes the production rate of methane per time and reactor volume. Further research on this topic will be necessary to rise the MPR.

$$MPR_R = \frac{\dot{V}_{CH_4,out} - \dot{V}_{CH_4,in}}{V_R}$$

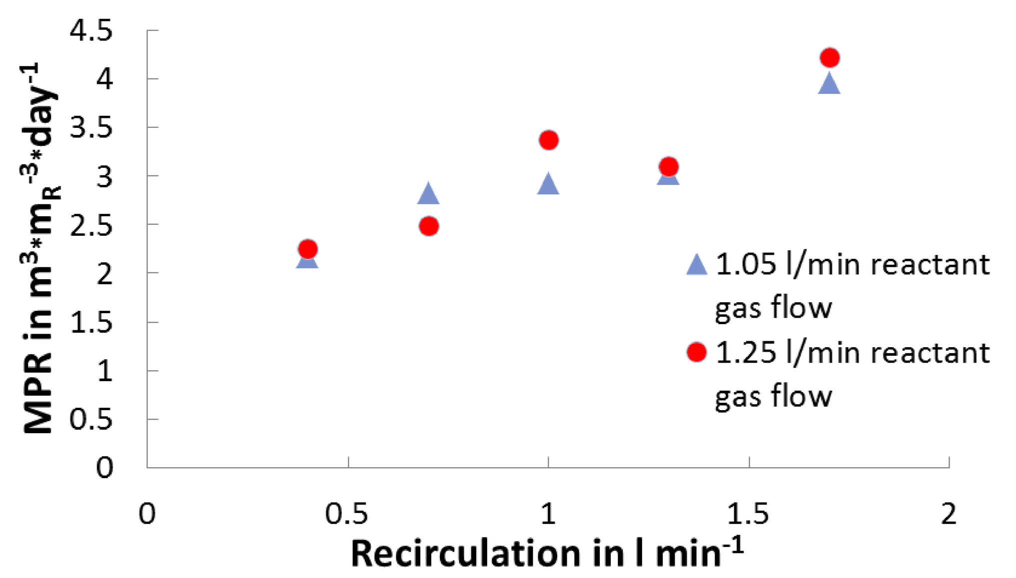

Figure 2: Continuous results of the 5 liter trickle-bed reactor

Trickle-bed reactor

The challenge of the 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 reactor. The EVT is running experiments with both reactor types on a small 5 liter-scale since 2016 with a pure culture. The results are the obvious pressure dependents and a instable system. A pure culture is always sensitive to self inhibition. That is why results are spreaded widely and constant results were rare. This shows figure 1, were the recirculation rate over the MPR is shown. Nevertheless a maximum concentration of methane over 90 % was reached. Changing the system to a mixed culture the system is more stable. Continuous results were stable as seen in figure 2.

Figure 3: 50 liter ORBIT-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 with the 50 liter ORBIT-reactor for grid injection (fig. 3). Therefore, a 1D-model was constructed using mass transfer and absorption rate. As the background parameter, the countercurrent water flow, the gas flow of H_2 and CO_2 , the geometry of the reactor and the trickles were chosen. After the absorption of the gas the reaction rate of the microorganisms, converting the gas to CH_4, was considered.

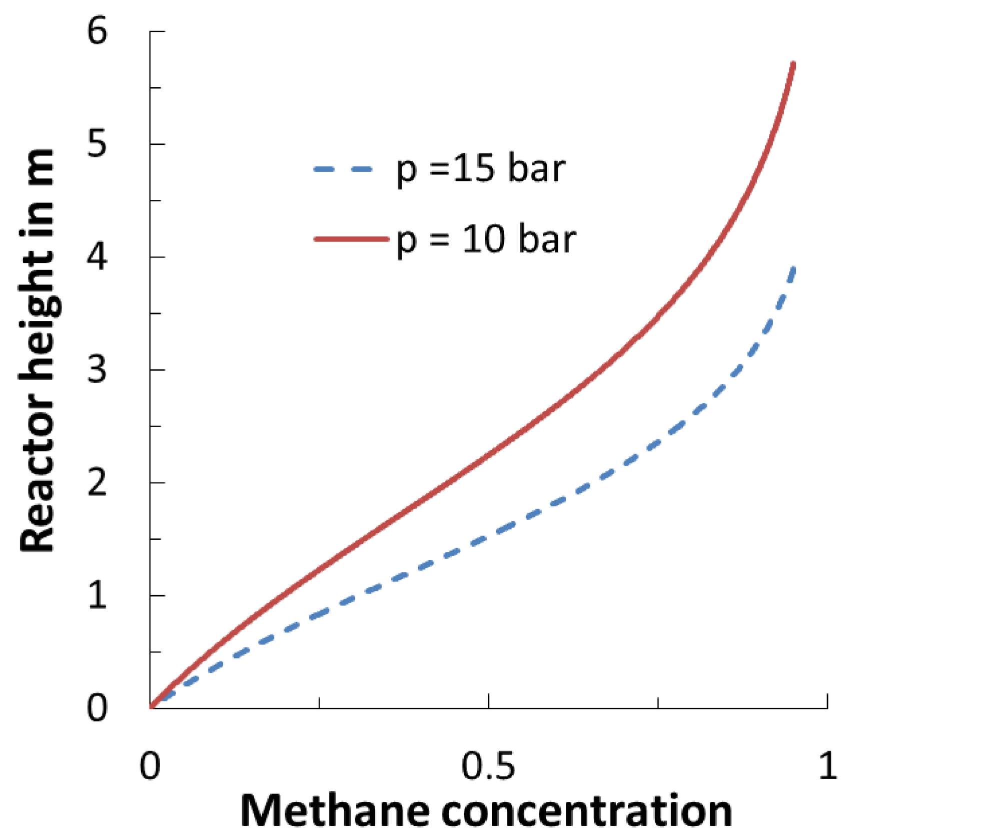

Figure 4: Methane concentration over reactor height at 10 and 15 bar

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 as 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. Therefore the 16 bar ORBIT-reactor was built.

Lehrstuhl für Energieverfahrenstechnik
Prof. Dr.-Ing. Jürgen Karl

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Tobias Weidlich
+49 911 5302 9058
tobias.weidlich@fau.de