Optimization and efficiency increase of syngas fermentation through control of elementary process variables

Lukas Perret, Nikolaos Boukis, Jörg Sauer, Karlsruhe Institute of Technology (KIT), Institute of Catalysis Research and Technology (IKFT), Eggenstein-Leopoldshafen, Germany

The fermentation of synthesis gas mixtures using anaerobic bacteria as biocatalysts represents is a promising process for the production of fuels and basic chemicals. In this process, microorganisms (acting as whole-cell catalysts) convert gas mixtures of H_2, CO_2 and CO to alcohols and organic acids. Microbial conversion of synthesis gas offers the potential for simplification and increased efficiency compared to classical thermocatalytic processes. For example, upstream gas purification can be simplified because microorganisms are much less sensitive to interfering substances such as sulfur components than chemical catalysts (Perret et al., 2022 a). On the path to commercialization of syngas fermentation, two current difficulties remain to be overcome: low cell density and low space-time yield (Perret et al., 2022 b). Therefore, an important goal is to increase the overall efficiency. Important variables are synthesis gas composition, gas flow rate, pH, process pressure and the resulting cell density in the reactor and will therefore be part of the experimental investigation.

At the Institute of Catalysis Research and Technology (IKFT) at the Karlsruhe Institute of Technology (KIT), experimental and conceptual work is being carried out to optimize fermentation in a continuously operated stirred tank reactor (CSTR). The test rig consists of a feeding system for liquids and gases of variable composition, a reactor system with biomass retention, which can be operated at elevated pressures up to 10 bar, and a process analysis unit, which allows the continuous acquisition of compositional data of the process streams of the test rig under transient and stationary conditions. The anaerobic bacterium *Clostridium ljungdahlii* is used as the biocatalyst and produces acetate and ethanol by the fixation of CO_2 via the so-called Wood-Ljungdahl pathway. The volume of the fermentation broth is 2.2 liters, the syngas is consists of H_2, CO, CO_2 and N_2 as inert standard. A hollow fiber filter module is used for cell retention.

Cell retention can significantly increase the biomass concentration compared to the "open" CSTR mode of operation for the microbial biomass. Due to the higher cell density, the space-time yield of C_2 compounds is increased. However, cell retention not only affects cell density, but also leads to an increase in carbon-based ethanol selectivity and a decrease in acetic acid selectivity. In addition, the gas conversion is higher with cell retention (see Fig. 1). Due to the high reaction rate of CO, a complete CO conversion (X_{CO} = 0.98) is achieved in the CSTR. This appears to result in less inhibition of hydrogenase, an enzymatic reaction that is highly sensitive to CO. Less inhibition results in an increased hydrogen uptake and a higher product ratio of ethanol to acetic acid (Perret at al., 2023). An inhibitory effect of CO_2, similar to the residual value of CO, cannot be observed. A slight decrease in pH combined with total cell retention results in an increase in ethanol productivity and an increased ethanol to acetic acid product ratio (Perret at al., 2024).

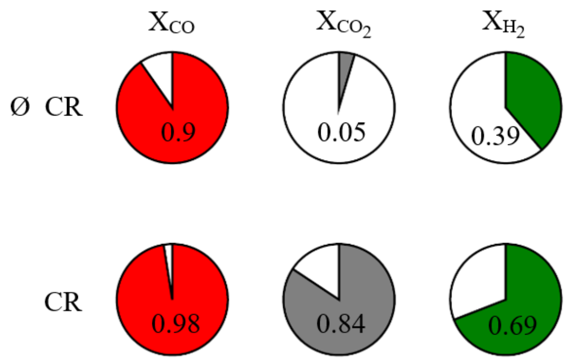

Figure 1. Gas conversion without cell retention (Ø CR) vs. gas conversion with cell retention (CR) for the synthesis gas fermentation with the microorganism Clostridium ljungdahlii

References

Perret, L., Campos, B., Herrera Delgado, K., Zevaco, T. A., Neumann, A., Sauer, J. (2022 a). CO_x Fixation to Elementary Building Blocks: Anaerobic Syngas Fermentation vs. Chemical Catalysis. Chem. Ing. Tech. 94 (11), 1667-1687. DOI: 10.1002/cite.202200153

Perret, L., Boukis, N., Sauer, J. (2022 b). Methods of reaction and reactor engineering to adjust product ratios and increase efficiency of syngas fermentation with Clostridium ljungdahlii. Chem. Ing. Tech. 94 (9), 1252. DOI: 10.1002/cite.202255034

Perret, L.; Boukis, N.; Sauer, J. (2023). Influence of Increased Cell Densities on Product Ratio and Productivity in Syngas Fermentation. Ind. Eng. Chem. Res. 2023, 62 (35), 13799–13810. https://doi.org/10.1021/acs.iecr.3c01911.

Perret, L.; Boukis, N.; Sauer, J. (2024) Synthesis Gas Fermentation at High Cell Density: How pH and Hydrogen Partial Pressure Affect Productivity and Product Ratio in Continuous Fermentation. Bioresource Technology 2024, 391, 129894. https://doi.org/10.1016/j.biortech.2023.129894.