Design and implementation of a highly integrated Power-to-Liquid process

Matthias Jahn, Erik Reichelt, Mihails Kusnezoff, Stefan Megel
Fraunhofer Institute for Ceramic Technologies and Systems IKTS, 01722 Dresden, Germany

Ten Fraunhofer Institutes led by the Fraunhofer Institute for Environmental, Safety, and Energy Technology UMSICHT have joined forces to work on the Fraunhofer lighthouse project "Electricity as a Resource". Their aim is to develop and optimize processes that enable low-carbon power to be used to synthesize important base chemicals. In this lecture results from a new Power-to-Liquid process are presented.

In today's society liquid hydrocarbons are an indispensable raw material. These compounds are vital for the transportation sector as well as the chemical industry, which has a substantial need for various hydrocarbons as feedstock for numerous different processes. As society is trying to limit the dependence on fossil resources alternative pathways to meet the demand for hydrocarbons have to be found.

A promising sustainable alternative route to hydrocarbons is the conversion of carbon dioxide and water using renewable excess electricity. Related processes have been discussed in the literature [1] and were demonstrated by the company Sunfire [2]. Although the technical feasibility was proven, cost covering operation was not possible, due to the high capital expenditures and the considerable feed stock cost for electricity from renewable sources.

In order to accelerate market entry each of the process steps as well as the overall process were analyzed by Fraunhofer IKTS, possibilities to improve overall efficiency and reduce expenditures were identified and a process concept was set up. The system was subsequently validated in a laboratory scale test rig.

A major process step is the syngas production via electrolysis. In contrast to the Sunfire process, which comprises a water electrolysis and a reverse water gas shift reactor, the proposed process utilizes novel SOC's developed by Fraunhofer IKTS for the application in Power-To-Liquid process concepts. Research was conducted at cell and stack level which resulted in stacks that allow highly efficient co-electrolysis of water and carbon dioxide as well as internal reforming of gaseous by-products. The SOC's were tested over 5000 hours with only a minor power degradation of

0.5 %/1000 h [3]. The stacks are housed in a novel hotbox design, which was drafted to enable a high degree of heat integration while minimizing thermal losses.

In contrast to most commercial applications, which use cobalt catalysts, an iron catalyst was developed for the Fischer-Tropsch reaction. While cobalt catalysts show high conversion rates generally alkanes are being produced which are mainly used as fuels. Since these products have to compete with the high supply from fossil sources the profit margin is low. A wider spectrum of products including olefins, alcohols and other oxygenates can be obtained by incorporating an iron catalyst. Furthermore, iron catalysts are more versatile to educt gas composition due to WGS[1] activity. In this case an iron catalyst was optimized to produce long chained alcohols. C3+ alcohols are important base and fine chemicals which are used as fuel additives, pharmaceuticals, detergents and cosmetics. While the state of the art synthesis process of higher alcohols contains many process steps and is fossil oil dependent, knowledge-based catalyst development enabled the production of higher oxygenates in a one step process. Selectivities towards higher oxygenates > 0.25 were achieved.

Models were derived from experimental data of both syngas production and Fischer-Tropsch synthesis. The coupled Power-to-Liquid process was implemented in the simulation environment Aspen Plus. A highly integrated process concept was derived from the data that allows for the production of high value products with an efficiency of $\eta_{en}>0.55$.

Such a process using co-electrolysis and internal reforming of short chained by-products has not been realized, which means there is no experimental data to allow for the reliable design of apparatuses such as heat exchangers. Therefore a simplified version of the process was implemented in a laboratory scale test rig in order to obtain data which allows for the realization of a reliable measurement, control and regulation concept as well as the design of a demonstration scale plant incorporating all identified means of heat integration and by-product utilization.

Literature

[1] W. L. Becker, R. J. Braun, M. Penev, M. Melaina, Energy 47 (2012), 99-115

[2] W. M. Verdegaal, S. Becker, C. v. Olshausen, Chem. Ing. Technik 87 (2015), 340-346

[3] S. Megel, C. Dosch, S. Rothe, C. Folgner, N. Trofimenko, M. Kusnezoff, 15th Int. Symp. on SOFC (2017)

[1] WGS: water gas shift