Development of a Structured Reactor System for CO_2 Valorisation under Dynamic Operating Conditions

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Abstract

The share of renewable electricity in energy systems worldwide is increasing due to the decreasing cost of renewable power generation and regulatory incentives. One major challenge of renewable energy sources, such as wind or solar energy, is the intermittent and fluctuating electricity production depending on daytime and local weather conditions. This leads to an imbalance of the actual needs and the current production. Several energy storage technologies exist that can be used to provide energy on demand from fluctuating sources. Next to batteries, capacitors or thermal storage systems, such as Power-to-X (PtX) processes are of special interest in this context.
In the first step of PtX-processes, a surplus of renewable electricity (in fact electricity at very low cost) is used to produce H_2 and O_2 using electrolysis of water. A promising technology is the proton exchange membrane (PEM) electrolysis that can operate under very dynamic conditions. In this way, the fluctuating electricity production from renewables leads to a strongly fluctuating H_2 output of the electrolyzer. It is an important technological challenge in the following conversion step to use this unsteady hydrogen feed for an efficient conversion process. We propose a novel reactor concept for exothermic gas phase reactions under dynamic operation conditions. In detail, we report CO_2 methanation using an additively manufactured structured reactor (catalyst: 2.5 wt.-% $Ru/Al_2O_3/MgO$). The dynamic operation was simulated by changing the reactant flow rates (loads) based on the operation strategy of an electrolyzer connected to a wind farm. Due to the high heat conductivity of the metallic structures, temperature hotspots related to load variations can be avoided efficiently. In our test rig, these structured reaction systems reached equilibrium CO_2-conversions with only minor axial temperature gradients for various loads and thus offer high potential for the dynamic operation of exothermic gas-phase processes. The presented modular catalyst system offers several options for further optimization. Additional catalyst structures with adjusted precious metal loading can be combined in the reactor. Moreover, the application of different temperature zones in the reactor offers additional degrees of freedom, e. g. for further improving CO_2-conversion at high loads.