Operational Performance of Small Scale Ammonia Converters for Power-to-Ammonia

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In comparison to the traditional ammonia production process, the power-to-ammonia process is a simple and environmentally friendly process with no carbon emission. The rear end consists of hydrogen production from electrolysis of water and nitrogen production from pressure swing adsorption (PSA), whereas, the traditional ammonia production process includes seven gas-solid catalytic steps and hydrogen is produced from fossil fuel reforming. The Haber-Bosch ammonia synthesis loop in principle is similar for both processes though with other constraints: In a traditional ammonia plant, safety and optimization of the ammonia converter for larger capacity is a major concern. However, power-to-ammonia requires a smaller ammonia converter for decentralised production units, along with more flexibility in operation.

This work focuses on the comparative analysis of operational performance and flexibility of four autothermal configurations of ammonia converters containing three catalyst beds, each. The variants differ in terms of inter-stage cooling methods contain quenching, cooling and a combination of them (see figure). The reactor volume, heat exchangers area and/or quench flow rates are customized, so that reaction occurs at maximum reaction rate and gas leaves the reactor at the maximum allowable temperature to maximize conversion. For the catalyst beds, a one-dimensional pseudo-homogeneous model has been applied. Material and energy balances are solved simultaneously for obtaining conversion and temperature profiles. The concepts with inter-stage hybrid cooling (d) and with cooling only (b) yield higher ammonia production, and the higher operational & production flexibilities with respect to hydrogen feed rate. Adjusting internal variables, such as hydrogen concentration, allows stabilizing the converters at different operating points. The impact of different disturbances, such as, feed temperature, reactor pressure, inert and ammonia concentration in feed/recycle loop are quantified.

It is concluded that the concept of inter-stage cooling only (b) and hybrid cooling (d) are most suitable for renewable, i.e. intermittent energy driven operation, as they allow operation even when decreasing hydrogen feed rate by 30% of its nominal value.