Novel developments in reactor technology, new challenges … new possibilities

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Depletion of fossil fuel reserves and increasing costs for energy in combination with growing concerns about the effects of anthropogenic greenhouse gas emissions on climate change and the desire for feedstock diversification have compelled us to – and have given us opportunities to – rethink reactor technology and processes for the production of energy and (intermediate) energy carriers such as hydrogen and synthesis gas. Awaiting the required significant breakthroughs in energy efficiencies for the production of energy carriers from biomass and/or the required major technological advances in energy production via nuclear fusion, for the coming decades we will have to rely on the production of energy carriers from fossil fuels, however, with a strong shift in attention on improving overall energy and carbon efficiencies in combination with carbon capture and sequestration ('clean fossil fuel').

The main developments in reactor engineering are focused on process integration (i.e. carrying out more than one process step in a single unit) and process intensification (i.e. producing more in less volume) with the ultimate objectives to increase overall energy and carbon efficiencies, reduce the number of required process steps and decrease the required reactor volume.

The main advances in process integration were achieved by integrating separation and reaction steps in membrane reactors and by integration of energy exchange, e.g. integration of recuperative heat exchange inside the reactor via forced unsteady operation using the reverse flow concept, or coupling endothermic and exothermic reactions to achieve autothermal operation, or combinations of these.

Via integration of hydrogen perm-selective membranes, novel membrane reactor concepts have been developed for the production of ultra-pure hydrogen (which can be directly used in PEM fuel cells) from natural gas. With fluidized bed membrane reactors the complete conversion of the fossil fuel can be realized in a single apparatus (thus overcoming thermodynamic restrictions), completely circumventing the large number of process units and the complex heat integration required in conventional steam reforming processes, while at the same time much higher energy and carbon efficiencies can be achieved. In addition, autothermal operation and CO_2 capture can be fully integrated via insertion of either perm-selective oxygen or additional hydrogen membranes. These concepts show particular promise for smaller-scale hydrogen production units. Alternatively, ultra-pure hydrogen production with integrated CO_2 capture can be achieved via membrane chemical looping reforming, which opens up further possibilities to use bio-oils as feedstock.

Also novel membrane reactors for the production of synthesis gas have been developed that can largely outperform the current state-of-the-art conventional partial oxidation or autothermal reforming processes. Via integration of recuperative heat exchange via reverse flow operation, overall carbon efficiencies can be enormously increased and large capital investments can be avoided. Moreover, anticipating breakthroughs in membrane material science to develop more stable oxygen perm-selective membranes, the reactor concepts are ready for complete integration of air separation inside the reactor.

In addition, novel process and reactor concepts are being explored that couple endothermic and exothermic reactions. The combination of the exothermic oxidative coupling of methane and endothermic steam reforming for the simultaneous production of ethylene and synthesis gas is particularly interesting.

On the other hand, large research effort is devoted to process intensification via miniaturization (micro-reactors) or, more generally, micro-structuring of large scale reactors and/or dynamic operation of reactors, e.g. via periodically changing inlet concentration or throughput. Spectacular breakthroughs especially in the field of optimization of the contacting in multi-phase flows in micro- or micro-structured reactors are expected, for example for the production of synthetic liquid fuels via the Fischer-Tropsch process. Examples of novel process concepts using dynamic operation that are being developed in our group are chemical looping combustion for energy production with integrated CO_2 capture and cryogenic freeze-out of CO_2 (post combustion capture) both technologies are based on

dynamically operated packed beds, where the dynamic operation avoids difficult (thus costly) solids handling and improves energy efficiencies.
In the presentation the current trends in chemical reaction engineering will be highlighted with examples from our own research group.