From Microfluidics to Future Factories in Chemistry: Intensification at all Scales

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Micro Process Technology and Flow Chemistry have given a strong push to continuous chemical manufacture via facilitating heat and mass transfer (transport intensification). With that being available now from commercial suppliers and increasingly used by industry in production, the next big step is to develop a tailored process chemistry in flow under highly intensified conditions. This is based on two research pillars, termed Novel Process Windows [1,2] – the first is based on the exploration of unusual and typically harsh process conditions to boost micro processing (chemical intensification). In a more holistic picture, a completely new and often simpler process design via a new chemical transformation is developed (process-design intensification). Smart organic reactions such as the 1,3-Huisgen cyclo-addition Click Chemistry and Claisen rearrangement are processed harshly; some other instructive chemistries will make tangible the benefit of exploring unusual chemical parameter space. New process designs are developed for large-scale industrial processes such as the direct adipic acid route in the frame of Nylon process and hydroformylation, done under supercritical conditions with ultrathin water film at the microchannel wall. In the latter case, this even starts from an entirely new, much simplified reaction design (novel direct pathway), leading to much reduced forecasted plant complexity.

This all extends at the upper end to implementing the highly intensified processing into new modular production concepts for the chemical industry (Factory of the Future). Plant integration will be shown at the compact container plant Evotrainer of Evonik Industries which is a modular least-cost investment unit of modular nature and amenable both to laboratory and production development. At the lower end, novel polymer based nano-particle catalysts and enzymes are coated in microchannels, for the synthesis of (multi-)chiral or precious pharma intermediates, such as α-amino-alcohols.

Such step- and paradigm changing routes need at a very early stage guidance and evaluation through cost- and life-cycle (environmental) analysis, as the theoretical performance potential is often not even vaguely accessible and developments bear high technological risk. Such ex-ante evaluation was applied to current processes for glucose oxidation and possible improvements using microreactor technology – comparing noble metal catalyst versus enzymatic oxidation and conventional process conditions versus Novel Process Windows [3]. The large impact of proper catalyst choice (wall coating, fixed bed, nano slurry) for the competitiveness of Flow Chemistry is then exemplified further at the copper-catalysed Ullmann ether synthesis, revealed through a full-process cost analysis, including catalyst preparation and product separation [4]. Finally, a cost- and life cycle analysis will be given for a full-process design of the soybean oil epoxidation in flow under industrial constraints [5].

[1] V. Hessel, Chem. Eng. Technol. 32 (2009) 1655-1681.
[2] V. Hessel, B. Cortese, M.H.J.M. de Croon, Chem. Eng. Sci. 66 (2011) 1426-1448.
[3] I. Dencic, J. Meuldijk, M.H.J.M. de Croon, V. Hessel, J. Flow Chem. 1, 1 (2011) 13-23.
[4] F. Benaskar, A. Ben-Abdelmoumen, N.G. Patil, E. Rebrov, E., J. Meuldijk, V. Hessel, L.A. Hulshof, J.C. Schouten et. al, J. Flow Chem. 1, 2 (2011) 74-89.
[5] D. Kralisch, D., E. Santacesaria, B. Cortese, V. Hessel et al., ChemSusChem (2012) in print.