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Biomass to useful molecules – From batch to continuous operation with the aid of structured catalysts and reactors

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The shift from fossil resources to renewable raw materials and sustainable products has been a massive vitamin injection for chemistry and chemical engineering. New catalysts have been discovered, characterized and tested. The trinity for a good heterogeneous catalyst is activity, selectivity and durability. Besides the conventional structures of heterogeneous catalysts, new structures have been developed, such as monoliths, microreactors, solid foams and 3D printed elements. The goal is to combine the benefits of traditional powder catalysts and catalyst pellets, i.e. to minimize the diffusion resistance in the catalyst pores by applying thin catalyst layers but preserving the open structure to minimize the pressure drop. Application of new structures is particularly attractive for chemical applications appearing in the valorization of biomass components to valuable chemicals, food ingredients, pharmaceuticals and fuel components. The shift from batch to continuous production is desirable because continuous operation leads to higher productivity, well-controlled product quality and improved safety. Introduction of structured catalysts and reactors in continuous operation are central elements in process intensification.

Qualitative approach is not sufficient, since the ultimate goal is to gain deep knowledge of the reaction mechanisms and to progress from laboratory to industrial scale. Understanding and modelling thermodynamics, kinetics, transport phenomena and fluid dynamics is the way to breakthrough. The systematic approach is illustrated with several real-life examples, such as hot-water extraction of polysaccharides from forest biomass, hydrolysis of hemicelluloses (arabinogalactan, galactoglucomannan, inulin), as well as hydrogenation and oxidation of monosaccharides (arabinose, galactose, xylose) to sugar alcohols and sugar acids. The power of the new catalyst and reactor technology is discussed, i.e. replacement of slurry and pellet technologies with structured catalysts, such as solid foams and 3D printed structures. Mathematical models for reaction kinetics are obtained from isothermal and non-isothermal batch experiments, after which the feasibility of continuous operation is demonstrated and the parameters for mass transfer and flow pattern are estimated from experiments conducted in continuous mode. Finally, the model elements from batch and continuous operation are merged to working multiphase reactor models, which can be used for predictions in laboratory scale and for process scale-up.