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Continuous Xylitol Production on Solid Foam Catalyst: Mass Transport and Kinetic Modelling

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The efficient valorization of biomass remains a central challenge in chemical reaction engineering, particularly for three-phase catalytic processes such as hydrogenation. In these systems, a liquid-phase substrate reacts with dissolved gas at the surface of a solid catalyst, coupling hydrodynamics, mass transfer, and intrinsic reaction kinetics. Sugar alcohols such as sorbitol and xylitol, obtained by sugar hydrogenation, are valuable ingredients in alimentary and pharmaceutical products. Conventional slurry reactors using finely dispersed catalysts can reduce internal diffusion limitations, but they complicate catalyst separation and are typically restricted to batch operation. For process intensification, continuous operation is highly desirable. Metallic open-cell foam catalysts represent a promising alternative due to their high void fraction, thin catalytic layers, and excellent heat transfer properties. From a technical viewpoint, continuous operation with solid foams is straightforward, but reactor performance remains strongly governed by liquid distribution, wetting efficiency, dispersion, and gas–liquid and liquid–solid mass transfer, requiring integrated analysis to approach intrinsic kinetic control.

Continuous hydrogenation of xylose to xylitol was investigated using a synthesized Ru/C solid foam catalyst in a parallel screening co-current downflow reactor under varying operating conditions (60–90 °C, 0.25–1.25 mL min^{-1} liquid flow rate, and 0.13–0.39 M xylose concentration). Reactor hydrodynamics were characterized by residence time distribution (RTD) and liquid holdup measurements. The results were interpreted using an axial-dispersion reactor model coupled with a kinetic expression based on non-competitive adsorption of hydrogen and xylose, including external mass transport of the reactants. Temperature and liquid flow rate were identified as key parameters, influencing intrinsic kinetics and residence time, respectively. The analysis quantified gas–liquid and liquid–solid mass transfer contributions. Although solid foams mitigate internal diffusion limitations, external transport resistances remain significant and may limit overall performance. These findings highlight the importance of improving catalyst wetting and interfacial transport to fully exploit foam-based structured catalysts in continuous three-phase hydrogenation.