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Solid foam catalysts - a clean and green pathway to the production sweet sugar alcohols

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PURPOSE OF THE ABSTRACT

The second-generation biorefinery is oriented to the utilization of lignocellulosic biomass created from agriculture, forestry, and alimentary industry. Lignocellulosic biomass is composed of 40-50 wt.% of cellulose, 16-30 wt.% of hemicelluloses (heteropolymers containing sugar monomers, such as arabinose, galactose, glucose, mannose, and xylose), and 15-30 wt. % of lignin. Currently, most part of hemicelluloses are lost in the dominating Kraft pulping process, which is a pity because hemicelluloses are a rich source of valuable sugar monomers and oligomers. Hemicelluloses can however be efficiently separated from lignocellulosic biomass with hot water extraction at elevated temperatures. In the next process step, hemicelluloses are hydrolysed to sugar monomers and oligomers, which can be chemically converted to very valuable molecules.

A very important valorization process is catalytic hydrogenation of monomeric sugars to sugar alcohols with the aid of metal catalysts, such as nickel or ruthenium. Sugar alcohols find several applications in the alimentary, pharmaceutical, and cosmetics industries. The global market size of the sugar alcohols was 3 billion euro in 2019 and is projected to reach 6 billion euro by 2027, exhibiting an increasing rate of 7.75% within 2020-2027. The main applications of sugar alcohols rely on the alimentary industry, where they are used as healthier alternatives for sucrose due to their sweet taste and low caloric content, especially in case of xylitol. Sugar alcohols are also widely used in the production of hand sanitizers, which have had a remarkable demand increase since 2020. Sugar alcohols exhibit significant health-promoting effects, such as anti-carries and antioxidant activity.

Because nickel is a poisonous and pyrophoric metal, this work is focused on a safer and environmentally friendly approach, namely the utilization of ruthenium as a heterogeneous catalyst in sugar hydrogenation. Finely dispersed supported ruthenium particles can be used in discontinuous slurry reactors, but the need of process intensification is urgent. Thererefore, structured catalysts which can be used both in discontinuous and continuous operation for sugar hydrogenation is proposed . This research effort was focused on the development of efficient structured catalysts, i.e. solid foams for the hydrogenation of individual sugars and sugar mixtures. The catalyst materials are deposited on solid foams as thin porous layers, which minimizes the mass transfer resistance and simultaneously an open structure is provided, which minimizes the pressure drop in continuous operation. The result is a selective, effective and clean production process for sugar alcohols based on the use of renewables. This approach provides the way from green chemistry to green process technology.

Commercial aluminium foams were coated with an active carbon layer after which ruthenium nanoparticles were deposited by the incipient wetness impregnation method (IWI) on the carbon layer. Investigations with transmission electron microscopy (TEM) confirmed that ruthenium existed in the form of nanoparticles in the pores of the active carbon layer. This catalyst was used in kinetic experiments on the hydrogenation of two sugar monomers, L-arabinose and D-galactose originating from the hemicellulose arabinogalactan, at three temperatures (90?C, 100?C and 120?C) and two hydrogen pressures (20 and 40 bar). Kinetic experiments were carried out for individual sugars and binary sugar mixtures at different D-galactose to L-arabinose molar ratios to reveal the interactions of these sugars in the presence of the solid foam catalyst. The temperature effect on the reaction kinetics was strong. Complete conversion of the sugars to the desired sugar alcohols, galactitol and arabitol was achieved on the open form catalyst, which witnessed that the use of solid foams is a very promising and clean production technology for sugar alcohols.

FIGURES

FIGURE 1

FIGURE 2

KEYWORDS
hemicellulose | sugar alcohol | sweetener | solid foam

BIBLIOGRAPHY