Systematic development of fermentation and downstream processing concepts for an efficient production of itaconic acid

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Limited fossil sources and an increasing awareness of sustainability problems pave the way for integrated process concepts for the conversion of renewable raw materials. The efficient production of platform molecules represents the key for a sustainable and economic competitive process concept of future biorefineries.
Itaconic acid was identified as a promising platform molecule from lignocellulosic biomass [1] for the production of fuels [2], polymers and a variety of additional products [3], but it has not yet reached industrial scale production. While the global production in 2009 was only 80 kt/a [4], the potential non-fuel market volume for 2020 is envisioned to be 200 to 6000 kt/a [5]. For the envisioned market volume and a successful replacement of petrochemicals in the named applications, the process efficiency in terms of economy, energy efficiency and productivity needs to be improved. These open tasks can only be successfully addressed by a systematic analysis of existing and development of alternative processing strategies. This work shows the improvement potential for the production of itaconic acid by analyzing and developing alternative fermentation and downstream processing concepts.

The fermentation is conducted using the industrial strain *Aspergillus terreus*, which offers the highest yield and titer to date [6]. However, the productivity of the batch fermentation is low compared to state-of-the-art fermentations. A few downstream processing strategies for the recovery of itaconic acid from the fermentation broth were proposed in the literature. At small scale, precipitation using calcium hydroxide and sulfuric acid is often used. Due to impurities from the fermentation broth, the resulting calcium sulfate cannot be sold and the scale-up to industrial-scale production is not favorable [7]. The industrial process, on the other hand, uses a combination of evaporation, centrifugation and crystallization to recover solid itaconic acid [8]. A promising alternative might be liquid-liquid extraction, if the extracting agent can be utilized as solvent in subsequent reaction steps. The potential of this concept is shown with the in-situ conversion of itaconic acid to methyltetrahydrofuran

(MTHF) [2], using MTHF as extracting agent and reaction solvent. In addition a cooling crystallization concept is analyzed taking advantage of the strongly temperature-dependent solubility of itaconic acid. The solubility limit is increased in a preheating step preventing crystallization in the subsequent reverse osmosis, where the acid concentration is increased by removing water. In the final step, cooling crystallization is applied and solid itaconic acid is recovered, while the dissolved acid is recycled. The fermentation conditions of Kuenz et al. [6] form the basis of the calculations, which were executed in Matlab and Aspen Plus.

For downstream processing, evaporation represents the benchmark because of its straightforward implementation. Due to the low concentration of itaconic acid in water, the total energy demand for product recovery is very high. The total energy demand for agitation and aeration in the fermenter and evaporation account for about 39.2 MJ/kg itaconic acid, assuming conversion efficiency from steam to electricity of 40% and a residual moisture content of 10% in the final product.

The energy demand for the production of itaconic acid using cooling crystallization as downstream processing concept is reduced by 58% compared to the benchmark, with the electricity for agitation and aeration being the highest contribution. A fair comparison of the two alternative downstream processing concepts, extraction and cooling crystallization, is only possible for the conversion of sugar to the final product MTHF, as itaconic acid is not recovered in its solid form in the extraction process. Due to a large reduction of the energy demand compared to the evaporation, both downstream processing concepts are promising alternatives, if the extracting agent can be directly utilized in the subsequent reactor as solvent. For the production of solid itaconic acid cooling crystallization is preferred.

The energy demand for the fermentation and downstream processing can be further reduced by shortening the fermentation time and hence increasing the productivity. The lower titer will on the other hand increase the purification effort. The integrated consideration of fermentation and downstream processing results in an increase of the overall productivity and a reduction of the energy requirement. Hence, the energy requirement for the cooling crystallization concept is successfully reduced by 64% and the productivity increased by 24%, compared to the benchmark, showing the high potential of a systematic improvement of downstream processing concepts as well as fermentation strategies. Although all figures are subject to model uncertainty

they provide an evidence of the potential of process integration in biocatalytic processes.

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