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Recovery of succinic acid from whey fermentation broth by reactive extraction coupled with multistage processes

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ABSTRACT

Fermentative production of succinic acid (SA) from renewable resources such as whey is environmentally sustainable compared to petroleum-based synthesis. However, a major drawback of fermentation is the concurrent production of SA with byproducts such as lactic acid (LA), formic acid (FA) and acetic acid (AA). Therefore, appropriate downstream SA recovery and purification steps are significant in ensuring sustainable SA production. In this study, SA was fermented by *Actinobacillus succinogenes* and recovered in an integrated process consisting of ultrafiltration, vacuum distillation and reactive extraction. The extractant used was tri-n-octylamine (TOA) with 1-octanol as a diluent for both liquid-liquid (LLE) extraction and supported liquid membrane (SLM). The produced SA titer and yield was 11.16 g/L and 0.44 g/g, respectively. The steady state ultrafiltration permeate flux ranged from 31.18 to 33.42 L/m^{2}h, and complete decolorization of the fermentation broth was achieved with 10 % (w/v) of powdered activated carbon. The extraction efficiency for LLE was 51.5 %, whereas SLM achieved 57.3 % recovery. SA exhibited transport and permeability coefficient of 0.00697 h^{-1} (R^2 > 0.92) and 0.08605 cm h^{-1}, respectively. Extraction of SA tremendously decreased as the aqueous pH was increased from 2 to 5. In SLM, initial SA flux was calculated as 9.65 g/m^{2}h and doubled that of lactic acid. Selective extraction of only SA was not achieved; however, residue biological material and macromolecular substances were effectively removed. Herein, we clearly demonstrated that process integration applied in reactive extraction is a promising approach for recovery of SA from fermentation broth.

1. Introduction

Succinic acid (butanedioic acid) is a dicarboxylic acid with the chemical formula $(CH_2)_2(CO_2H)_2$, and can be produced from either petroleum-based synthesis or fermentation. Succinic acid and its derivatives are used in pharmaceuticals, food industry, cosmetics and production of biodegradable polymers [1,2]. Owing to its structure, SA can easily be used as a building block chemical for synthesis of γ-butyrolactone, 1,4-butanediol, N-methyl-2-pyrrolidone, 2-pyrrolidone, tetrahydrofuran, maleic acid, polyesters and polyamides [3,4]. Fermentative production of organic acids is renewable and environmentally friendly, yet presently most of commercially available succinic acid (SA) is produced by chemical synthesis of petroleum-based products. The ever-increasing demand for ecofriendly technologies has led to research in fermentative production of organic acids, particularly SA. Moreover, industry analysts project the global SA market to reach 1.1 billion US$ by the year 2022 [5–10]

Various industrial wastes and by-product streams such as sugarcane molasses, cheese whey, crude glycerol, lignocellulosic biomass hydrolysates, wheat milling by-products and agricultural residues have been successfully used as substrates for SA production [10–13]. The presences of cheap and readily available sources of substrate make the fermentative production of SA economically viable and attractive at industrial scale. In another distinct study, SA was successfully fermented using the high sugar-content of by-product streams in beverage production as feedstock [14]. Several microorganisms have been identified for SA fermentations, including *Actinobacillus succinogenes*, *Mannheimia succiniciproducens Anaerobiospirillum succiniciproducens*, *Basfia succiniciproducens* and *Escherichia coli*. Among these, *Actinobacillus succinogenes* is by far the most promising strain for SA fermentation, due to the high SA yield and titer on several substrates [7,15]. In a study by Ferone and co-authors, *A. succinogenes* simultaneously

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