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Optimization of hollow fiber-supported liquid membrane operating parameters for levulinic acid separation: Modeling and experimental investigation

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A B S T R A C T

Hollow fiber-supported liquid membrane (HFSLM) is a highly promising technology for the separation of levulinic acid (LA), which is one of the leading biomass products. This process is particularly advantageous for industrial-scale applications due to its capability for continuous extraction and back extraction within a single operational device. This study employed HFSLM for the extraction of LA from an aqueous solution. To optimize HFSLM performance, response surface methodology with central composite face-centered (CCF) design was used to fine-tune three key factors: the concentration of trioctylamine (TOA) as a carrier, the concentration of sodium hydroxide (NaOH) as a stripping agent, and the concentration of LA in the feed solution. The ideal operating conditions for HFSLM were determined to be 0.32 M TOA, 0.77 M NaOH, and 10.08 g/L LA, resulting in the highest LA extraction efficiency of 74.82 % ± 3.83 %. The study also investigated the mass transfer mechanisms within the HFSLM system. Key parameters such as the extraction equilibrium constant (K_{ex}), stripping equilibrium constant (K_{st}), distribution ratio (D), aqueous mass transfer coefficient (k_f), and membrane mass transfer coefficient (k_m) were determined. The k_m value, measured at 5.1012 × 10^{-3} cm/s, exceeded the k_f value of 0.6613 × 10^{-3} cm/s, indicating that the rate-limiting step in LA transport occurred during its diffusion through the film layer separating the feed and organic phases. A new mathematical diffusion flux model focusing on the extraction side of the liquid membrane system was developed to estimate the concentration of LA at different times. The model offers valuable insights into the transport mechanisms during LA extraction using HFSLM and can serve as a benchmark for integrating HFSLM into actual biomass processing.

1. Introduction

Levulinic acid (LA) stands as one of the bio-organic acids with a growing demand, featured prominently in the US Department of Energy's top-twelve building blocks. Currently, conventional resources, primarily fossil fuels, are facing limitations [1,2]. Consequently, modern society has initiated the adoption of biomass as an alternative energy source and a valuable chemical resource [3]. The production of LA from lignocellulosic biomass has gained significant attention from researchers [4]. In summary, deriving LA from cellulose biomass entails several steps: hydrolyzing cellulose into glucose, isomerizing glucose into fructose, converting fructose into hydroxymethylfurfural (HMF), and ultimately oxidizing HMF into LA [5]. Typically, these stages involve employing diverse catalysts and specific conditions to maximize the yield of LA [6]. Malaysia, in particular, generates nearly 30 million tons of biomass residues annually from the oil palm sector [7]. These residues, including empty fruit bunches, trunks, and fronds, are abundant in cellulose, hemicellulose, and lignin. As a result, the production of LA from oil palm waste has garnered substantial interest in Malaysia [8]. Remarkably, the utilization of just 5 wt% of these oil palm waste feedstocks for LA production yields a 1.5-fold increase in profitability and eliminates costs for waste processors [8].

The separation of LA from biomass products poses a substantial challenge in biorefineries, yet it is critical to meet the demand for LA. Among the various methods, the supported liquid membrane (SLM) process stands out as particularly promising because it enables continuous extraction and back extraction within a single operational device [9]. Furthermore, the use of a small organic phase in SLM offers the

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