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Supported liquid membranes with feed dispersion for recovery of Cephalexin

Zisu Hao [a,b], Michael E. Vilt [b], Zihao Wang [a], Weidong Zhang [a], W.S. Winston Ho [b,c,*]

[a] Beijing Key Laboratory of Membrane Science and Technology, State Key Laboratory of Chemical Resource Engineering, Beijing University of Chemical Technology, Beijing 100029, People's Republic of China

[b] William G. Lowrie Department of Chemical and Biomolecular Engineering, The Ohio State University, 140 West 19th Avenue, Columbus, OH 43210-1180, USA

[c] Department of Materials Science and Engineering, The Ohio State University, 2041 College Road, Columbus, OH 43210-1178, USA

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ABSTRACT

Pertraction through supported liquid membranes with feed dispersion (SLM-FD) has been proposed and studied for simultaneous removal and recovery of Cephalexin from aqueous solutions using a commercially available hollow-fiber module and the carrier Aliquat 336. The feed dispersion, formed by dispersing the feed solution in the organic membrane solution with a mixer, flowed through the shell side of the module, forming the SLM in the nanoporous hollow fibers. Various parameters were investigated including the feed-to-organic volume ratio, initial Cephalexin concentration, Aliquat 336 concentration in the organic membrane solution, KCl concentration in the strip phase, shell side feed-dispersion flow rate, and lumen side strip-solution flow rate. The results showed that an excess of counter ion, KCl, was needed for facilitated transport and that the shell side and lumen side flow rates had little effects on mass transfer performance. The mass transfer process of SLM-FD was elucidated, and a mathematical model was developed to describe the process. Based on this model, both the theoretical and experimental overall mass transfer coefficients were obtained as a function of Aliquat 336 concentration. These mass transfer coefficients were in reasonably good agreement. The average overall mass transfer coefficient obtained was significantly larger than (about 1.7 times) that attained by using the supported liquid membrane with strip dispersion (SLM-SD). In addition, the SLM-FD was shown to be superior to the solvent extraction process in terms of Cephalexin removal from the feed solution.

1. Introduction

Liquid membrane (LM) techniques have been extensively studied for many applications including biochemical separations and wastewater treatment [1–3]. Three main types of liquid membranes, bulk liquid membrane (BLM) [4], emulsion liquid membrane (ELM) [1,5] and supported liquid membrane (SLM) [1,6], have many attractive features [7], such as simultaneous extraction and stripping, a large interfacial mass transfer area, and no flooding. Bulk liquid membrane (BLM) is one of the simplest configurations for performing liquid membrane processes, which are often used to evaluate performance of extractants and kinetics of liquid membrane systems [8–10]. In a BLM, the feed and strip phases are separated by a continuous "bulk" organic phase [11], resulting in a large mass transfer resistance [12]. On the other hand, there are disadvantages including the complexity of the emulsifaction–demulsification process for ELM and the instability of the liquid membrane for SLM [13]. In case of SLM, extraction and stripping occur at the respective liquid/liquid interfaces immobilized at their respective mouths of pores in the microporous polymeric support, and the liquid membrane phase is only in the pores. The relatively small volume of the liquid membrane phase (vs. the two bulk feed and strip liquid phases), interfacial shear force/emulsification and osmotic pressure difference are the main reasons for the instability of the SLM [14,15].

Ho et al. developed the technique of SLM with strip dispersion (SLM-SD) to address the instability issue of the traditional SLM [16–20]. In SLM-SD, the liquid membrane layer is stabilized by constant supply of the organic solution to the membrane pores. This technique can also efficiently remove the target species from the aqueous feed solution while simultaneously recovering it in the aqueous strip solution. It can be used to remove heavy metal ions (e.g., chromium, copper, zinc, cobalt, strontium, cadmium,

* Corresponding author at: Department of Materials Science and Engineering, The Ohio State University, 2041 College Road, Columbus, OH 43210-1178, USA. Tel.: +1 614 292 9970; fax: +1 614 292 3769.
E-mail address: ho.192@osu.edu (W.S. Winston Ho).

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gold, and uranium) [18–23] or to recover organic compounds (e.g., alkaloids and Cephalexin) [24–27].

In our previous work [27], the most widely used Cephalosphorin antibiotic, Cephalexin [28], can be removed in situ by using the SLM-SD technique coupled with an enzymatic synthesis. The maximum yield of Cephalexin was 42% when two hollow-fiber modules were used, demonstrating that SLM-SD is a promising technique for the recovery of Cephalexin. For the integrated technique, the mass transfer performance of using the SLM-SD for the recovery of Cephalexin is very important, which has been reported by Vilt and Ho [25]. The results showed $>99\%$ extraction from the feed solution and 96–98% recovery in the aqueous strip solution with Aliquat 336 as extractant. Moreover, according to the resistance-in-series model, the extraction reaction resistance was shown to be dominant, suggesting that the mass transfer performance can be improved by reducing this resistance.

For the SLM-SD technique, the extraction reaction resistance can be reduced with an increase of the temperature or interfacial area for the extraction reaction. However, the former approach requires an independent heat source, which consumes additional energy and leads to process complexity. The interface for the extraction reaction in SLM-SD locates on the inner surface of hollow fibers, suggesting that the interfacial area can be augmented by increasing the number of hollow fibers. But this would enlarge the size or number of hollow-fiber membrane modules and hence increase the cost. However, according to the solvent extraction operation, by dispersing the aqueous feed solution in the organic phase, the mass transfer area would be increased significantly. Moreover, the mass transfer performance in the feed dispersion may also be improved due to convection caused by its flow and the frequent breakage and coalescence of feed droplets in the dispersion, which has been realized in a hollow-fiber renewal liquid membrane system [12].

In this work, a new pertraction process using the SLM with feed dispersion (SLM-FD), was proposed and applied to the Cephalexin–Aliquat 336 system. Various experimental parameters, including the feed-to-organic phase volume ratio, Cephalexin concentration in the feed phase, carrier concentration in the organic phase, KCl concentration in the strip phase, and flow rates of lumen and shell sides, were investigated. Furthermore, a mathematical model based on the resistance-in-series model under the pseudo-steady state was developed to describe the mass transfer process of SLM-FD. From this model, the theoretical overall mass transfer coefficients were calculated as a function of Aliquat 336 concentration. The calculated mass transfer coefficients compared reasonably well with those obtained experimentally. Finally, the mass transfer performance of SLM-FD was compared with the SLM-SD and solvent extraction techniques.

2. The SLM-FD technique

The SLM-FD technique is shown schematically in Fig. 1, which has a similar two-phase flow pattern with the SLM-SD process [25–27]. In this multiphase flow system, the aqueous feed solution is dispersed as droplets in the continuous organic phase, which has the same composition as the membrane phase. The SLM-FD can be formed by dispersing the aqueous feed solution in the continuous organic phase using a mixer and then pumping the dispersion through one side of a membrane contactor. Typically, in order to obtain a larger mass transfer area, a hollow-fiber module containing microporous hydrophobic polymer fibers should be used. The dispersion phase can flow on the shell side of the hollow-fiber module while the aqueous strip phase can be on the lumen side. In order to prevent the sipping of the organic membrane solution to the aqueous strip phase, a sufficient pressure differential (about 14 kPa or 2 psi) between the aqueous

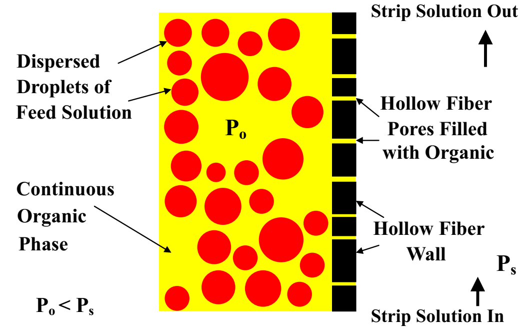

Fig. 1. A schematic diagram of an enlarged view of the SLM-feed dispersion (SLM-FD) process.

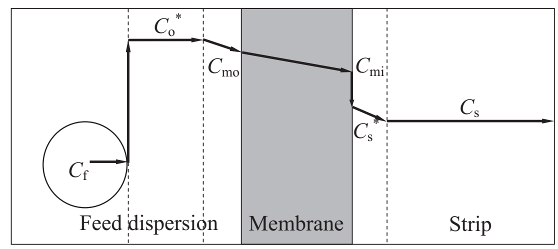

Fig. 2. Schematic representation of the mass transfer mechanism of the SLM-FD process.

strip phase (higher pressure) and the dispersion phase (lower pressure) is maintained. In this work, the dispersion phase was pumped through the shell side of the hollow-fiber module.

3. Theory

3.1. General transport mechanism

The difference between SLM-FD (also for SLM-SD) and traditional SLMs is the presence of a liquid–liquid two-phase dispersion which is typically pumped on the shell side of the hollow-fiber module. In SLM-FD, the aqueous feed solution is dispersed in the continuous organic membrane solution. The concentration profile in pertraction through SLM-FD is shown schematically in Fig. 2, and its transport process is described as follows:

- Solvent extraction phenomenon in the feed dispersion vessel
  Due to the direct mixing of feed and organic phases, some target species in the feed phase can be extracted into the organic phase [12].
- Mass transfer on the shell side of the module
  (a) Due to the small size of each feed droplet in the dispersion being pumped through the shell side of the hollow-fiber module, the concentration profile of the target species in the feed droplets (C_f) is assumed to be uniform. The pumping flow action should enhance the fulfillment of this assumption.
  (b) At the feed/organic interface, the target species reacts with the carrier to form the solute–carrier complex and is partitioned into the organic phase (C_o^*). The complex is then convectively transported across the bulk of the continuous organic phase to the organic boundary layer next to the organic/membrane interface.
  (c) The concentration of the complex reduces as it diffuses across the organic boundary layer to the outside diameter of each hollow fiber.