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Enhancing performance of hybrid liquid membrane process supported by porous anionic exchange membranes for removal of cadmium from wastewater

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HIGHLIGHTS

- Fabrication of porous anion exchange membranes and their characterization are explained.
- Those membranes are applied as supporting in HLM process for removal of cadmium.
- The effects of structure of fabricated membrane on process performance are evaluated.
- Mass transfer resistance is mainly due to transport through the supporting membranes.
- Process performance is greatly enhanced using AEMs compared to non-anionic membranes.

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ABSTRACT

In this study, polyethersulfone (PES)-based porous anionic exchange membranes (AEMs) are fabricated. The morphological and transport properties of the membranes such as pore size, roughness, porosity, water uptake, membrane transport number, fixed charge density, and conductivity are determined. These AEMs are used as supporting membranes to enhance the mass transfer flux in a hybrid liquid membrane (HLM) process for removal of cadmium from an acidic feed solution. The liquid membrane phase is prepared by dissolving triisooctylamine (TIOA) in kerosene. The effects of applying porous AEMs with different fixed charge densities, temperature, and initial cadmium concentration are investigated. It is confirmed that the main resistance in the mass transfer in the system is confined in the supporting membranes. Applying PES-based AEMs with a proper fixed charge density of $X' = 0.0197$ meq/cm^3 instead of non-ionic PES supporting membranes can increase the mass transfer coefficient from 0.0068 to 0.017 min^{-1}. Almost all cadmium can be transferred within 3 h. The proposed anionic supporting membranes can yield a much higher fluxes for removal of cadmium in high concentrations comparing to the same hybrid liquid membrane system with non-ionic PVDF supporting membranes while only insignificant loss in removal efficiency is observed.

1. Introduction

Releasing cadmium as a toxic heavy metal initiated from industrial wastewaters into the natural resources causes environmental damages [1,2]. Among the conventional methods [3,4], liquid membrane processes (LMs) are powerful techniques for removal and recovery of cadmium in low contents [5–7]. The advantages of these techniques are their low cost and energy consumption, simple operation, high efficiency, and capability of continuous operation [8–10].

Supported liquid membrane (SLM) combines the extraction and stripping processes optimally in a single unit operation. In spite of many advantages of SLM over other types of LMs [11,12], it suffers from deficiencies such as instability. The problem originates from the loss of embedded liquid in the supporting membrane due to evaporation or dissolution into the aqueous phase [13,14] or precipitation of a carrier complex at the surface of supporting membrane [15,16]. One method to solve this problem is to apply a hybrid liquid membrane (HLM) process, in which the liquid membrane phase is encapsulated between two supporting solid membranes and is isolated from the feed and stripping aqueous phases [17,18]. Although HLM does not need to further purification, and it has significant advantages such as continuous

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operation and higher lifetime, there are still some problems to be resolved for industrial application of this process. The species to be transferred in an HLM system should pass through several barriers in series including aqueous and organic phases as well as supporting membranes. Among the mass transfer resistances, supporting membrane may be considered as a major one. Therefore, any attempt to reduce its resistance may lead to enhancement in the rate and performance of the process.

A proper supporting membrane in the HLM process prevents from phase mixing and loss of the organic phase. It also provides a porous contacting medium for transferring ions and molecules. Therefore, it needs to have suitable wetting properties as well as proper pore size and porosity. In our previous work, in which hydrophilic polyvinylidene fluoride (PVDF) supporting membranes were used, cadmium ions could be removed in the HLM process [18]. However, since in the proposed mechanism cadmium is transferred as the anionic species, an anionic membrane might transfer the species more efficiently.

Polyethersulfone (PES) is a polymer-based engineering material commercially available for preparation of the membranes. It has proper thermal, chemical and mechanical stabilities [19,20] as well as capability to be modified chemically [21,22]. In addition, PES membrane can be fabricated with desirable pore size and porosity [23].

In the present research, PES is selected as the base polymer for fabrication of porous anionic membranes (AEMs). The AEMs with different ion exchange capacities (*IEC*s) are prepared and used as the supporting membranes. The properties of fabricated AEMs such as their structure, pore size, roughness, ion exchange capacity, water uptake, membrane potential, and transport number are studied. The effects of ion exchange capacities of the supporting membranes as well as the effects of temperature, thickness of organic film, and cadmium concentration on removal capacity and mass transfer flux are examined.

2. Mass transfer mechanism

The mechanism of cadmium transport in the proposed HLM process is shown in Fig. 1. As seen in the figure, the transport mechanism is comprised of the following steps where cadmium is transferred as CdI_4^{2-}:

- The CdI_4^{2-} ions are passed across the boundary layer in the feed solution toward the feed-supporting membrane interface.
- The CdI_4^{2-} ions penetrate through the pores in the feed-side supporting membrane to reach the organic phase. (The mechanisms of transferring ions through the pores will be discussed later.)
- The cadmium ions then react to form complexes with the carrier (the complex form of TIOA shown as $R_3NH^+A^-$) somewhere within the boundary layer and bulk of the organic phase depending on the reaction rate. In this reaction, A^- in the structure of carrier is replaced by CdI_4^{2-}:

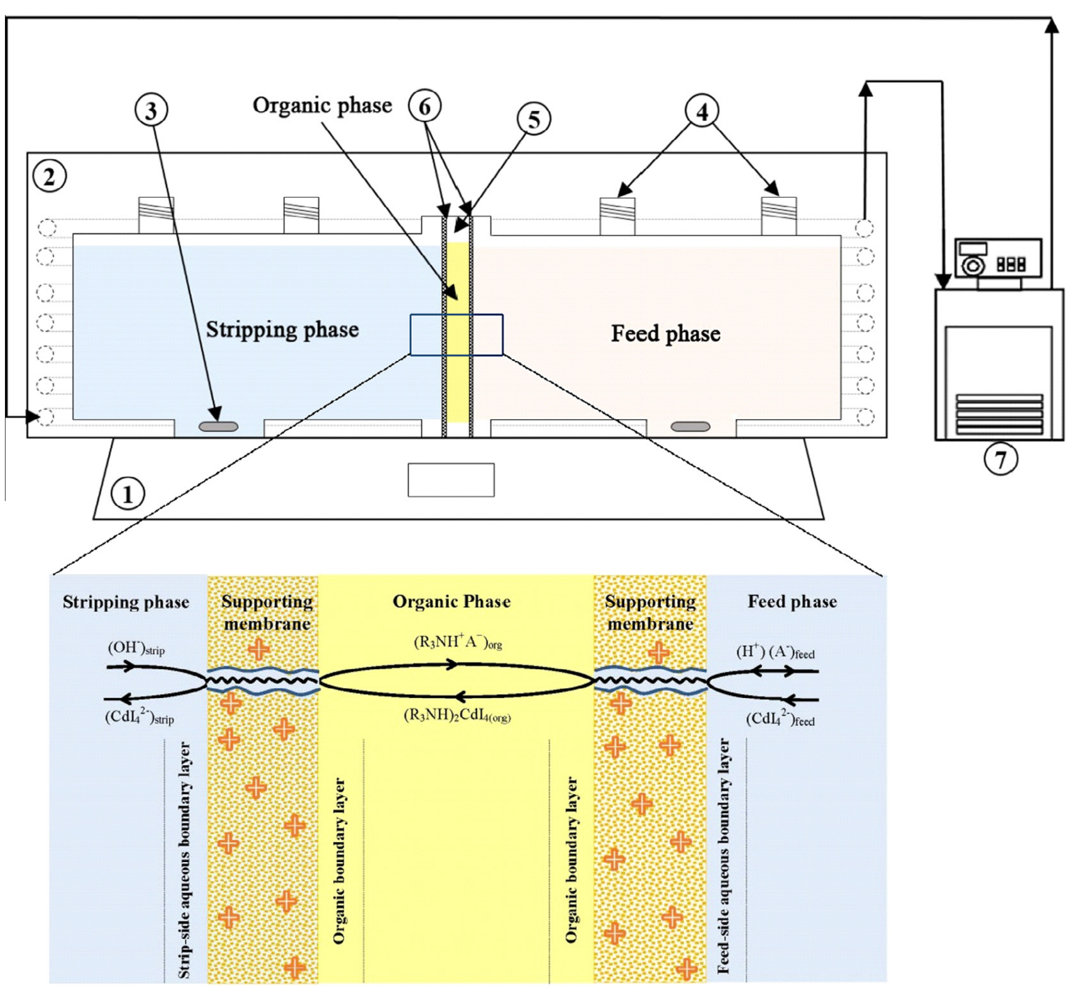

Fig. 1. Schematic of experimental setup and mass transfer path: (1) magnet stirrer; (2) water bath; (3) magnet; (4) sampling and measurement openings; (5) spacer; (6) porous anionic supporting membranes; (7) water circulator.