



Ultra-High Pressure Reverse Osmosis by Using Microporous Organosilica Membranes for Concentrating Organic Aqueous Solutions

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Abstract

We consume a substantial amount of organic solvents due to our industrial activities. Meanwhile, the solvents used in manufacturing processes are eventually released into the atmosphere or discharged as industrial effluents that are potentially hazardous to the environment. Industrial effluents containing organic solvents are often treated by incineration. However, incineration requires supplemental fuel for proper combustion, resulting in significant CO₂ emissions. From the sustainable point of view, therefore, recovery of organic solvents from industrial wastewater has been an important task in recent years. Distillation is one of the common techniques that can be used for the recovery of water-soluble organic solvent from wastewater. However, it is not ideal for energy-efficient recovery because it requires an extremely high energy input due to high latent heat of vaporization.

Reverse osmosis (RO) represents an energy-saving alternative to distillation. Unlike heat-driven separation processes, RO does not involve a phase change to achieve separation, and thus, it is more energy efficient in principle. However, conventional polymeric RO membranes suffer from physical compaction and chemical degradation under harsh operating conditions required for solvent recovery, notably ultra-high pressure and high organic solvent concentration, resulting in a severe decline in their RO performances. Herein, aiming to overcome the limitations of existing RO membranes, we present the development of microporous organosilica RO membranes for solvent recovery from aqueous solutions.

Bridged organosilica membranes with controlled pore sizes were prepared via sol-gel processing by employing polymeric [1] and colloidal routes [2]. The former provides membranes with sub-nanometer-sized pores, while the latter provides membranes with nanometer-sized pores. As shown in Fig. 1, the membrane prepared via the polymeric route exhibited higher solvent rejection compared to those prepared via the colloidal route, demonstrating the successful synthesis of organosilica RO membranes with tunable permselective properties. It was also confirmed that organosilica membranes could withstand under ultra-high pressure as high as 15 MPa and at high organic solvent concentration up to 40 wt%. The results indicate that organosilica membranes can be a promising candidate for solvent recovery by RO.

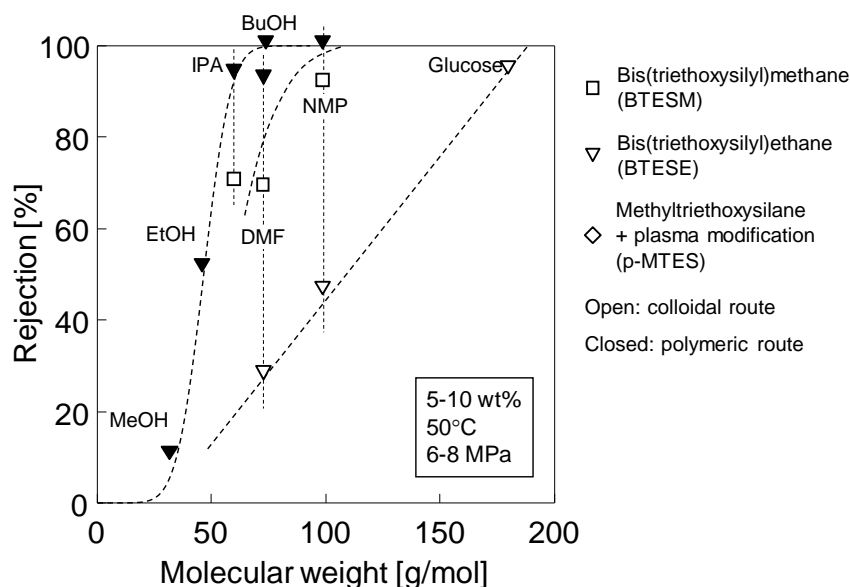


Fig. 1. Rejection in various organic aqueous solutions as a function of molecular weight of solutes. Concentration of solute, 5-10 wt%; applied pressure, 6-8 MPa; temperature, 50°C.



In order to elucidate the technical feasibility of high-pressure RO as a novel strategy for solvent recovery, we also conducted a comprehensive process simulation. By employing the generalized solution-diffusion model [3] as the basic transport equation, solvent recovery from their dilute aqueous solution via high-pressure RO systems was simulated. Our simulation results showed that a single-stage one-pass process requires less energy but significantly large membrane area to accomplish high enrichment. We also found that, in the single-stage process, high enrichment cannot be achieved with an acceptable recovery rate even elevating the transmembrane pressure. By contrast, with a combination use of high-rejection and low-rejection RO membranes, the multistage process (Fig. 2) could achieve both high enrichment and high recovery rate simultaneously without significantly increasing energy consumption. The results demonstrate that the multistage high-pressure RO could be potentially feasible for solvent recovery and enrichment from their aqueous solutions. This research was funded by New Energy and Industrial Technology Development Organization, Japan (NEDO) under a Feasibility Study Program on Energy and New Environment Technology.

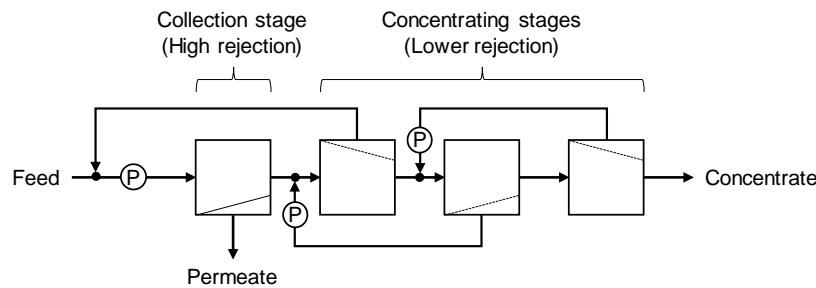


Fig. 2. Schematic image of multistage RO process with a combination use of high-rejection and low-rejection membranes.

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[2] N. Moriyama, H. Nagasawa, M. Kanezashi, T. Tsuru, *J. Membr. Sci.*, 620 (2021) 118895.

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