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# Highly condensed polyvinyl chloride latex production by forward osmosis: Performance and characteristics



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## ABSTRACT

Forward osmosis (FO) has attracted attention in industry because of its low energy consumption and low fouling tendency. In this paper, the condensation of polyvinyl chloride (PVC) latex with FO as a pre-treatment step prior to the final drying process was investigated. The effect of agitation speed, FO membrane type, and the NaCl concentration of the draw solution (DS) were evaluated. For the membrane performance, the water flux, NaCl flux, and total organic carbon (TOC) flux were evaluated. When the feed solution was sufficiently agitated, a PVC concentration of 75 wt% was achieved using model seawater as the DS. FO performance was experimentally compared with reverse osmosis (RO) performance using similar apparatus and the same water flux conditions. The TOC rejection in FO was higher than that in RO. Latex condensation using FO was characterized by a decrease in outlet water flux by cake-enhanced osmotic pressure, a decrease in inlet water flux by the capillary force resistance in the cake layer, and an increase in TOC rejection by the retarded forward diffusion of solutes. The control of cake-layer formation was important for the condensation of PVC latex by FO.

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## 1. Introduction

In recent years, synthetic resins have attracted the attention of both the scientific and industrial communities worldwide, and have been used in numerous applications [1]. Several commercially important polymers, such as synthetic rubbers or plastics, are produced by emulsion polymerization [2,3]. Emulsion polymerization is a type of radical polymerization that usually proceeds from an emulsion containing water, a monomer, and a surfactant. A dispersion containing polymer particles resulting from emulsion polymerization is called a latex. In order to isolate polymer particles as a product from the latex, it is necessary at some stage to remove the water. A spray drier is normally used to isolate finally the solid product after stripping process for residual monomer [4,5].

**Abbreviations:** AL-DS, active layer facing to draw solution; AL-FS, active layer facing to feed solution; CFR, capillary force resistance; CTA, cellulose triacetate; CEOP, cake-enhanced osmotic pressure; DI water, deionized water; DS, draw solution; ECP, external concentration polarization; FO, forward osmosis; FS, feed solution; HTI, Hydration Technologies Innovations; ICP, internal concentration polarization; NF, nanofiltration; NOM, natural organic matter; PRO, pressure-retarded osmosis; PVC, polyvinyl chloride; RO, reverse osmosis; SDS, sodium dodecyl sulfate; SEM, scanning electron microscopy; TDS, total dissolved solid; TOC, total organic carbon

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When latex is dried by vaporization such as spray drying, most energy is consumed by the conversion of water from liquid phase to vapor phase (i.e., the latent heat of vaporization for water), which requires 2260 kJ/kg. For reduction of energy consumption with the conversion of water at the final drying process, membrane separation is one of the key processes. Membrane separation processes operate without the phase change of water, and thermal energy is not required. Thus, the condensation of latex by membrane separation prior to the final drying process helps to decrease the total energy consumption of the process. Generally, the latex concentration range from approximately 61 to 69 wt% is the target of membrane separation performance considering the final drying process [6]. Too high latex concentration and unstable dispersibility cause the gelation of latex. The low fluidity latex with gelation cannot spray due to the trouble of solution feeding in the final drying process. In addition, the gelation of latex causes the decrease of water flux in membrane process. Thus, latex stability and fluidity are very important in isolation process of polymer particles. Surfactant addition is usually the most effective way to enhance latex stability.

Nanofiltration (NF) and reverse osmosis (RO) membranes have the potential to separate organic compounds of low molecular weight, such as pharmaceuticals, surfactants, and natural organic matter (NOM) [7]. However, pressure-driven membrane processes using these membranes require a high pressure to be applied to the feed solution. Generally, the pressure in NF and RO process is

more than 0.5 MPa and more than 1.0 MPa, respectively. Furthermore, membrane performance reduction due to cake-layer formation on the surface and pore blocking (membrane fouling) are major problems in these processes. Numerous studies have addressed the physical and chemical factors governing colloidal or organic fouling on pressure-driven membrane processes [8,9]. Membrane fouling causes deterioration of the quality of the products and increased operation time, consequently resulting in higher process costs.

Recently, the membrane process forward osmosis (FO), has gained much attention because of its low energy consumption and low fouling tendency [10,11]. FO enables water transfer through a semipermeable membrane from a low-osmotic pressure solution side, i.e., the feed solution (FS), to a high-osmotic pressure solution side, i.e., the draw solution (DS), in accordance with an osmotic pressure difference. Theoretically, hydraulic pressure is not required for the selective water transportation, unlike in pressure-driven membrane processes [10]. Using seawater as the DS, and pure water as the FS, an osmotic pressure of approximately 2.8 MPa can be applied as a driving force for water permeation [12]. In addition, FO membranes have the potential to separate low molecular weight compounds, similarly to NF and RO membranes [13]. Furthermore, Zhao et al. have used FO in the treatment of surfactant wastewater, and reported that it exhibited effective rejection of surfactant, good water flux, and effective physical cleaning [14].

In this study, the condensation of polyvinyl chloride (PVC) latex using an FO process as a pretreatment step prior to the final drying step is investigated as a means of decreasing the total energy consumption of the process. As a feasibility study for practical use, PVC latex samples obtained from a commercial production plant are used. Water flux, salt and surfactant leakage, and fouling tendencies are evaluated as indicators of the potential of FO for the production of highly condensed PVC latex.

## 2. Materials and methods

### 2.1. Materials

The PVC latex samples, the feed solution (FS) in this paper, were kindly provided by Kaneka Co., Japan. The latex was produced using an oil-in-water emulsion that consisted of PVC monomer and 0.35 wt% sodium dodecyl sulfate (SDS) as a stabilizer. The total dissolved solid (TDS) measured by the dry weight method was 47–49 wt%. The PVC latex was dispersed well, and the

particle shape was almost spherical, as shown in Fig. 1(a) and (b). The mean diameter of the particles as measured by a SALD-7500 nano particle size analyzer (Shimadzu Co., Japan) was approximately 1  $\mu\text{m}$ , as shown in Fig. 1(c). The total organic carbon (TOC) in the supernatant separated by centrifugation (himac CF15RX II, Hitachi Koki Co., Ltd., Japan) of the PVC latex was measured with a TOC-VCSH TOC analyzer (Shimadzu Co., Japan). The TOC of the supernatant was 2600–3200 mg/L. It was found that other organic compounds besides SDS were present in the supernatant, as the TOC value should be 1750 mg/L if the supernatant contains only 0.35 wt% SDS. The pH of the supernatant was 3–4, and chloride ion concentration, measured by a 6560–10C chloride ion electrode (Horiba, Ltd., Japan), was 50–80 mg/L.

Analytical grade NaCl (Wako Pure Chemical Industries, Ltd., Osaka, Japan) was used to prepare the draw solution (DS). Milli-Q water (Millipore, Bedford, MA, USA) was used as ultrapure water.

### 2.2. Forward osmosis membranes

Commercial flat-sheet cellulose triacetate (CTA) FO membranes embedded with screen support (denoted as CTA-ES) or with non-woven support (denoted as CTA-NW) were obtained from Hydration Technologies Innovations (HTI, Albany, OR, USA), as shown in Fig. 2. CTA-ES and CTA-NW membranes were employed to investigate the effect of membrane type on performance, particularly water permeability. For the CTA-ES membrane, the water permeability coefficient  $A$  ( $\text{L m}^{-2} \text{h}^{-1} \text{bar}^{-1}$ ), the salt permeability coefficient  $B$  ( $\text{L m}^{-2} \text{h}^{-1}$ ), and the structure parameter  $S$  ( $=l\tau/\epsilon_m$ ) ( $\mu\text{m}$ ) were 0.50, 0.44, and 619, respectively [15]. Here,  $l$  is the membrane thickness ( $\mu\text{m}$ ),  $\tau$  is the tortuosity, and  $\epsilon$  is the porosity.  $A$ ,  $B$ , and  $S$  for the CTA-NW membrane were reported as 0.28, 0.15, and 872, respectively [15]. The membranes were cut into disks of 75 mm diameter and soaked in ultrapure water overnight to remove the glycerin coating.

### 2.3. Condensation of the PVC latex by osmosis-driven and pressure-driven processes

Schematic illustrations of the systems used for osmosis-driven and pressure-driven tests are shown in Fig. 3(a) and (b), respectively. Condensation tests were carried out using a C40-B batch-type flat membrane test cell (Nitto Denko Corporation, Osaka, Japan) with an effective membrane surface area of 0.0032  $\text{m}^2$ , and a working volume of 380 mL. The C40-B cell is commercially designed for pressure-driven RO tests, as shown in Fig. 3(b). The bottom part of the cell was modified to have 2 ports, as shown in

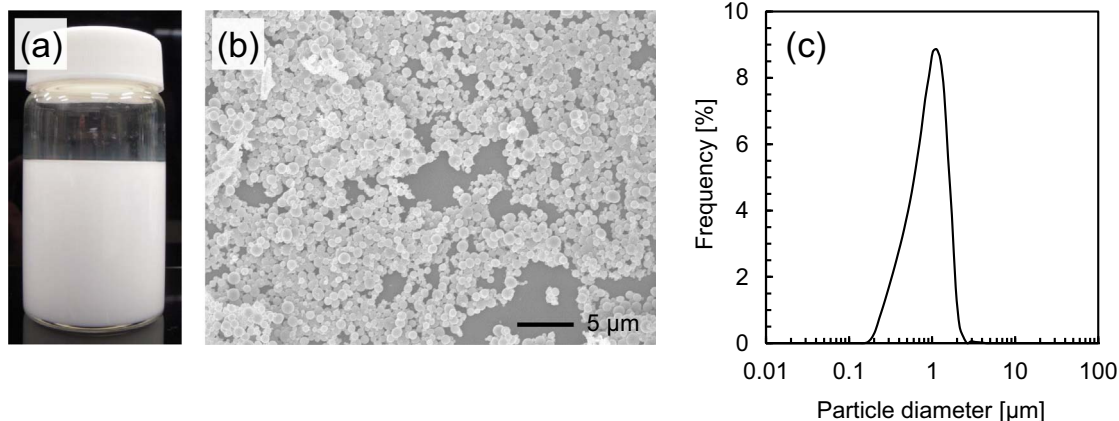


Fig. 1. (a) Optical photograph of a 48 wt% solution of PVC latex, (b) SEM image of the particles of latex, and (c) particle size distribution.

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