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RESEARCH ARTICLE - CHEMICAL ENGINEERING

Optimum Operating Parameters for Hollow Fiber Membranes in Direct Contact Membrane Distillation

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Abstract The aim of this study is the optimization of the operating conditions of PVDF-co-HFP hollow fiber membrane for direct contact membrane distillation applications. The influence of the operation parameters, such as the feed temperature (40–80 °C), the feed flow rate (0.3–0.6 L/min), and the PVP content (0–9 %), as well as the feed concentration increased from 3.5 to 5.0 wt%, and their interactions on the PVDF-co-HFP hollow fiber membrane permeate flux have been investigated. The optimum operating parameters have been specified using second-order FULL FACTORIAL and Taguchi optimization techniques to find optimum values for operation parameters in the DCMD process in order to obtain a good value of permeate flux. The results showed that PVDF-co-HFP membrane has the best performance at 21 (kg/m^2 h) when a hot feed temperature of 80°C with 0.6 L/min flow rate, 3.5 wt% NaCl feed concentration and 9 wt% PVP content in the casting solution were used. The PVP % content and inlet temperature had a significant impact on the permeate flux, while feed flow rate and feed concentration have less influence.

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Keywords Optimization · Permeate flux · Hollow fiber membrane · Operating conditions · Factorial method

Abbreviations

ANOVA	Analysis of variance
Cm	Distillation coefficient
CMDC	Continuous membrane distillation crystallization
DCMD	Direct contact membrane distillation
DMAc	Dimethylacetamide
EE	Thermal efficiency
MD	Membrane distillation
PVDF	Poly (vinylidene fluoride
PVDF-co-HFP	Poly (vinylidene fluoride-co-hexafluoropropylene)
PVP	Polyvinylpyrrolidone
SWGMD	Sweeping gas membrane distillation

1 Introduction

Water desalination is a very significant challenge to obtain fresh, pure water. Seawater desalination means the removal of salt and other undesirable particles from salty water. The feed seawater is heated to raise the slope vapor pressure along the two parts of the membrane, as it is the driving force, then the feed stream molecules which are close to the membrane evaporate, and just vapor transfers through the pores of the hydrophobic membrane to condense in the permeate zone [1–3].

Previous studies suggested that there are several difficulties to be addressed in order to develop a viable DCMD operation for water treatment applications, and one of these difficulties is how to obtain an optimal operating condition for the process. Choosing appropriate range of the operating conditions is critical to determining the operation of the DCMD processes with the formula that gives higher flux with minimal losses. It was concluded that more than 95 % of the energy required in the DCMD system is consumed by the heater for heating of the feed stream, so the feed temperature is one of the important operating parameters.

Broadly, in MD process an optimization dilemma is represented in maximization or minimization of some parameters (such as operating conditions). Chen et al. [4] studied the optimization of operating conditions for a continuous membrane distillation process. The study was based on the effect of three levels for each of the four parameters, with nine experiments. He assessed the feed flow rate, inlet temperature, and permeate-side flow rate and found inlet temperature as the major parameter that affects the permeate flux.

Song et al. [5] studied the optimization of spinning conditions and the effect of these conditions on the polyvinylidene fluoride (PVDF) hollow fiber membranes characterization. They found that the diameters of hollow fibers indicated significant dependence on PVDF concentration and the non-solvent content in the dope solution. They also suggested that the content of non-solvent content (i.e., glycerol) in the dope solution has the most considerable impact on both membrane distillation coefficient Cm and thermal efficiency EE, while the external coagulant composition is less effective.

Khayet et al. [6] applied a new design to optimize the sweeping gas membrane distillation operation (SWGMD), and he studied the membrane distillation flux influenced by the operating conditions, the temperature of liquid, gas temperature, liquid and gas flow rate with their interactions. Using Monte Carlo technique, the optimum operating parameters have been specified, liquid inlet temperature found to be 71.6, 17.3 °C was the gas inlet temperature, water pumping velocity of 0.16 m/s and gas flow rate of 36 L/min. The optimal distillate flux of water under these conditions was 2.789×10^{-3} (kg/m^2 s).

In order to achieve a near-zero salt discharge by changing the flow rates and operating temperatures on the feed and permeate sides together, Chen et al. [7] studied the continuous membrane distillation crystallization operation for saturated brine feed solution and also optimized the operating conditions using an orthogonal fractional factorial technique, he reported that the experiment design specified that the flow rates on the feed and permeate sides are the essential parameters controlling the CMDC performance, while the temperatures on either the feed or permeate sides are not major parameters.

To optimize the design of an operating condition of DCMD process, it is indispensable to identify which parameters have the greatest influence. So, the experiments were carried out using Taguchi experimental design. Taguchi's tactic complements two important fields; first, he obviously determines a group of orthogonal arrays, each of which is possible to utilize for many experimental cases, and second he develops a standard mode for analysis of outcome. The collection of standard experiments design methods and analysis method in the Taguchi approach gives consistency and reproducibility seldom found in another statistical technique. Analysis of experiments using Taguchi method gives allowing for several influences of parameters to be simultaneously specified, effectively and efficiently [8,9]. Using this technique, it can be dramatically minimize the time required for experimental realization. This is substantial in investigating the impacts of multiple parameters on performance as well as the influence of one factor to determine which parameter has more effect and which one has less effect [10]. Consequently, via using Taguchi method, the optimum level for each parameter is specified. With (Taguchi) method, the outcomes of the experiments are resolved, and by investigating the main impacts of each parameter, the overall trends of the affecting factors can be described. The characteristics can be controlled, such that a minimum or a maximum value of a particular parameter achieves the preferred outcome [11].

From the published literatures, it was found that there are no studies available using optimization approach to relate the operating conditions of MD process with the weight percent of the PVP as additive in the casting solution. Therefore, in this work the optimization of operating conditions in addition to the percentage of PVP content in the dope solution on the basis of Taguchi approach was discussed.

This study is aimed at optimizing various operating parameters such as feed temperature (40−80 °C), the feed flow rate (0.3–0.6 L/min), and PVP content (0–9 %) as well as the feed concentration increased from 3.5 to 5.0 wt%. Feed concentration for four hydrophobic membranes made of PVDF-co-HFP with various concentrations of PVP added was utilized for desalination of seawater by DCMD configuration using second-order FULL FACTORIAL and Taguchi optimization techniques. Meanwhile, the interaction effects between operating parameters were also studied. The performance evaluation was carried out considering the effect of different operating parameters including feed temperature, PVP % content, feed flow rate and feed concentration. DCMD runs were conducted to evaluate permeate flux. Permeate flux is known as the mass or volume (kg or L) of the water permeate collection per the membrane efficient area (m^2) per operating time (h) [12,13].

2 Experimental

2.1 Chemicals

Poly(vinylidene fluoride-co-hexafluoropropylene) PVDF-co-HFP (Mw 400,000) from Sigma-Aldrich Chemical Com-