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Performance of direct contact membrane distillation for simulated dyeing wastewater treatment

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Abstract: It is highly desirable to develop effective technologies to address the serious environmental issues caused by dyeing wastewater. Herein, a promising direct contact membrane distillation (DCMD) process was developed for the treatment of simulated dyeing wastewater. Commercial polytetrafluoroethylene (PTFE) and polyvinylidene fluoride (PVDF) membranes were comparatively studied with phenol, aniline and sulfanilic acid served as the model foulants of simulated dyeing wastewater. The influence of several important operation parameters including feed temperature, feed flow rate, feed concentration on flux and rejection was systematically investigated. The result indicated that increasing working temperature of feed and cross flow velocity contribute positivelyto flux of DCMD process. Limited rejection for phenol and aniline was achieved due to the effumability of these compounds. Sulfanilic acid at lower concentration presented higher rejection performance at all operating conditions. Furthermore, the PTFE membranes presented higher rejection than that of PVDF membranes, which can be due to the strong negatively charged surface of the PTFE membranes. These promising results suggest that DCMD process could be served as an effective process to recover high purity water from dyeing wastewater in practice.

Key words: Dyeing wastewater; direct contact membrane distillation; hydrophobic membrane; model foulant

1. INTRODUCTION

Textile industry in China plays an important role in national economy development because of the increasing demand in both international and domestic markets. With the rapid development of textile industry, huge amounts of dyeing wastewater have been discharged into water bodies and causing serious environmental problems we are currently facing (Gao, 2014). It is, therefore, highly desirable to develop effective technologies to address such issue (Ntuli et al., 2009; Dasgupta et al., 2015; Ozturk et al., 2016). A number of effective water treatment technologies, such as biotechnology and physicochemical methods, have been recently developed (Chen et al., 2007), Chhabra et al., 2015). The biotechnology treatment could achieve efficient BOD removal at lower cost in comparison with physicochemical methods, realizing remarkable improvement in treating textile wastewater (Basava Rao and Ram Mohan Rao, 2006). Nevertheless, the bio-treatment processes are ineffective to deal with dissolved ions from textile effluent. Other effective treatment methods combined with biotechnology and membrane separation are rather limited in industrial applications due to high cost (Liu et al., 2011; Ong et al., 2012). Alternatively, membrane distillation (MD), a thermally driven separation process, allows only water vapor to pass through the pores of a hydrophobic membrane at relatively low temperature and pressure, has been considered as a potential candidate for treating dyeing wastewater (Lawson and Lloyd, 1997; Song et al., 2007; Volkov et al., 2016). Previous studies have proven that MD is a promising process for the treatment of dyeing wastewater using hydrophobic membranes (An et al., 2016; Molehtar et al., 2016).

In this work, direct contact membrane distillation (DCMD) process was developed to treat simulated dyeing wastewater containing several model intermediate products. Commercial PTFE and PVDF membranes with similar pore size were comparatively studied. Meanwhile, the effect of other important operational parameters on foulant rejection and water vapor flux during DCMD process were also systematically investigated.

2. EXPERIMENT

2.1 Materials

Commercial hydrophobic PTFE and PVDF membranes were employed without further modification and their specific structural parameters were presented in Table 1. Phenol, aniline and sulfanilic acid were purchased from Sinopharm Chemical Reagent Co., Ltd and used as model intermediate products of dyeing wastewater.

Table 1. Parameters of the membranes in DCMD system

Membrane	PTFE	PVDF
Mean pore size (mm)	0.22	0.22
Porosity (%)	85.12	70.35
Contact angle (°)	128.5	110.1
LEP of water (kPa)	271	203

2.2 DCMD experiment

The working temperature of feed solution (*e.g.,* 30, 40, 50 and 60 °C) and permeate solution (*e.g.,* 20 °C) were controlled *via* a thermostat water bath. The (hot) feed with initial volume of l.0 L and the (cold) permeate with an initial volume of 0.2 L was circulated continuously in opposite directions across the membrane with effective area of 6.0 cm^2. Different feed flow rate of 0.25, 0.34 and 0.43 L/min were comparatively studied, while the cross flow rate of permeate was maintained at 0.25 L/min during the whole process. The mass change of permeate was recorded using an electronic balance connected with a computer. Each test was repeated three times to guarantee reliable results.

2.3 Permeate flux and rejection efficiency

The permeate flux *J*, in units of LMH can be expressed as follows:

$$\mathrm{J} = \frac{\Delta W}{\Delta t \times A} \quad (1)$$

where ΔW was the change in the mass of permeate collected (kg), Δt was the distillation time (h), A was the effective area of membrane (m^2).

During the DCMD test, the concentration of model foulant in the permeate was determined by an UltiMate 3000 high-performance liquid chromatography (HPLC). The foulant rejection efficiency R (%) was determined by the following equation (Lu et al., 2016):

$$\mathrm{R} = \left(1 - \frac{C_P}{C_f}\right) \quad (2)$$

where C_p was the final foulant concentration (mg/L) on the permeate side and C_f was the initial foulant concentration (mg/L) on the feed side. The dilution factor was taken into consideration.

3. RESULTS AND DISCUSSION

3.1 Influence of the feed temperature

In order to investigate the influence of temperature on the performance of DCMD process, short-term distillation test was conducted. As shown in Figure 1, the permeate flux increased with the increasing of feed temperature, both for PTFE and PVDF membranes. As expected, higher temperature produced higher saturated vapor pressure, leading more vapor across the pores of the membranes (Wiklund and Davis). It was noteworthy that the permeate flux of PTFE membranes was higher than that of PVDF regardless of the temperatures. This phenomenon can be explained by the strong negatively charged surface of PTFE membrane (Abd Jalil et al., 2017).The model foulants block the pores of the MD membranes due to the association and dissociation of the functional groups on the membrane surface. However, the negatively charged PTFE membranes generated stronger repulsion to these negative model foulants in comparison with PVDF counterparts. The rejection result was shown in Figure 1 (b) and (d). DCMD test for sulfanilic acid presented higher rejection than others. Moreover, phenol and aniline could hardly achieve desirable rejection with the increasing temperature, which can be due to different volatility of these compounds. Non-volatile chemicals kept liquid in the feed solution, hardly occurred trans-membrane motion at low temperature.

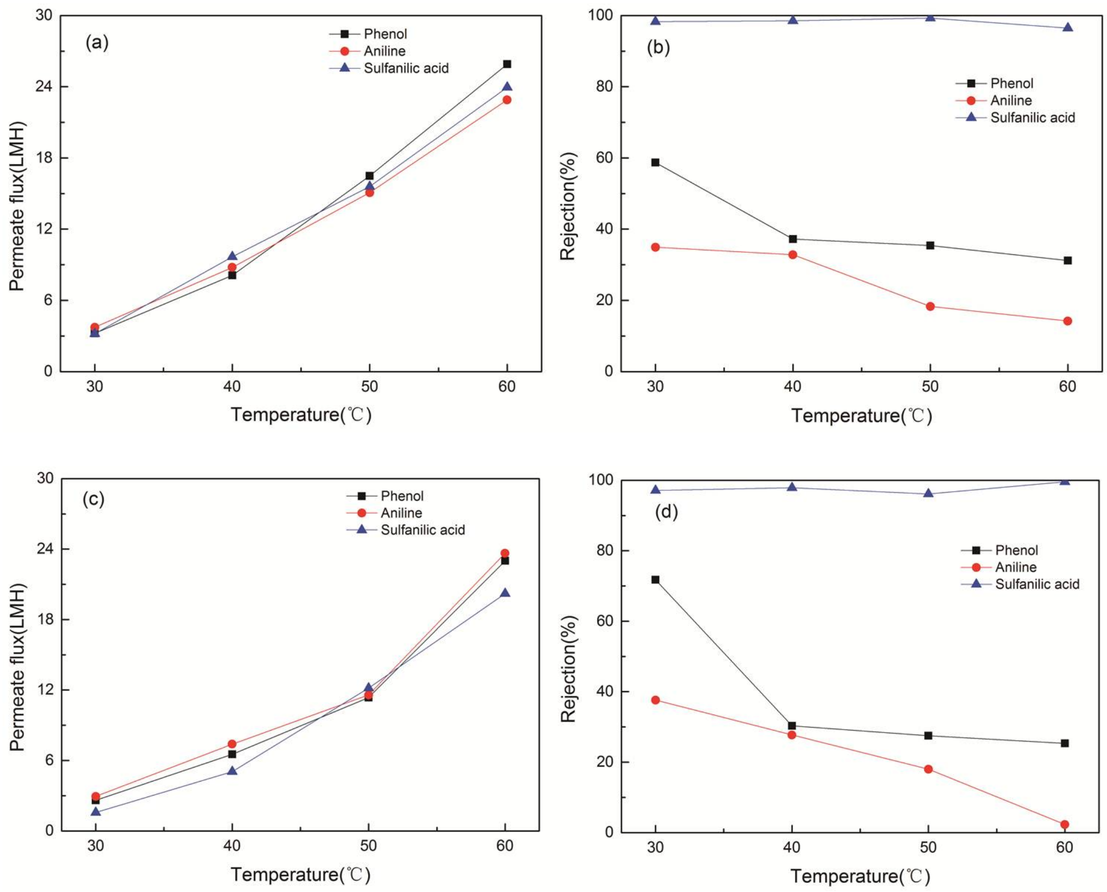

Figure 1. Permeate flux and rejection for three chemicals using PTFE membranes (a), (b) and PVEF membranes (c), (d).

3.2 Influence of cross flow rate

To investigate the effect of cross flow rate and working temperature on the DCMD process, sulfanilic acid was selected as a model intermediate of dyeing wastewater. As displayed in Figure 2, higher flow rate led to higher permeate flux. The formation of a laminar flow on the membrane surface in lower cross flow rate may impede heat transfer between feed stream and membrane surface. Generally, higher velocity leads to higher turbulence which results in reduced boundary layer effects and temperature polarization, hence increasing the driving force across the membrane (Sundar et al., 2017). One key point was that a higher flow rate accelerated the process referred to water vapor and non-condensable gas through the membrane pores. As for the rejection, with increasing the flow rate and temperature, irregular results were obtained as a precondition to experimental deviations. Lower feed concentration may not achieve desirable result for DCMD. Nevertheless, sulfanilic acid at low concentration presented higher rejection at all given operating conditions.

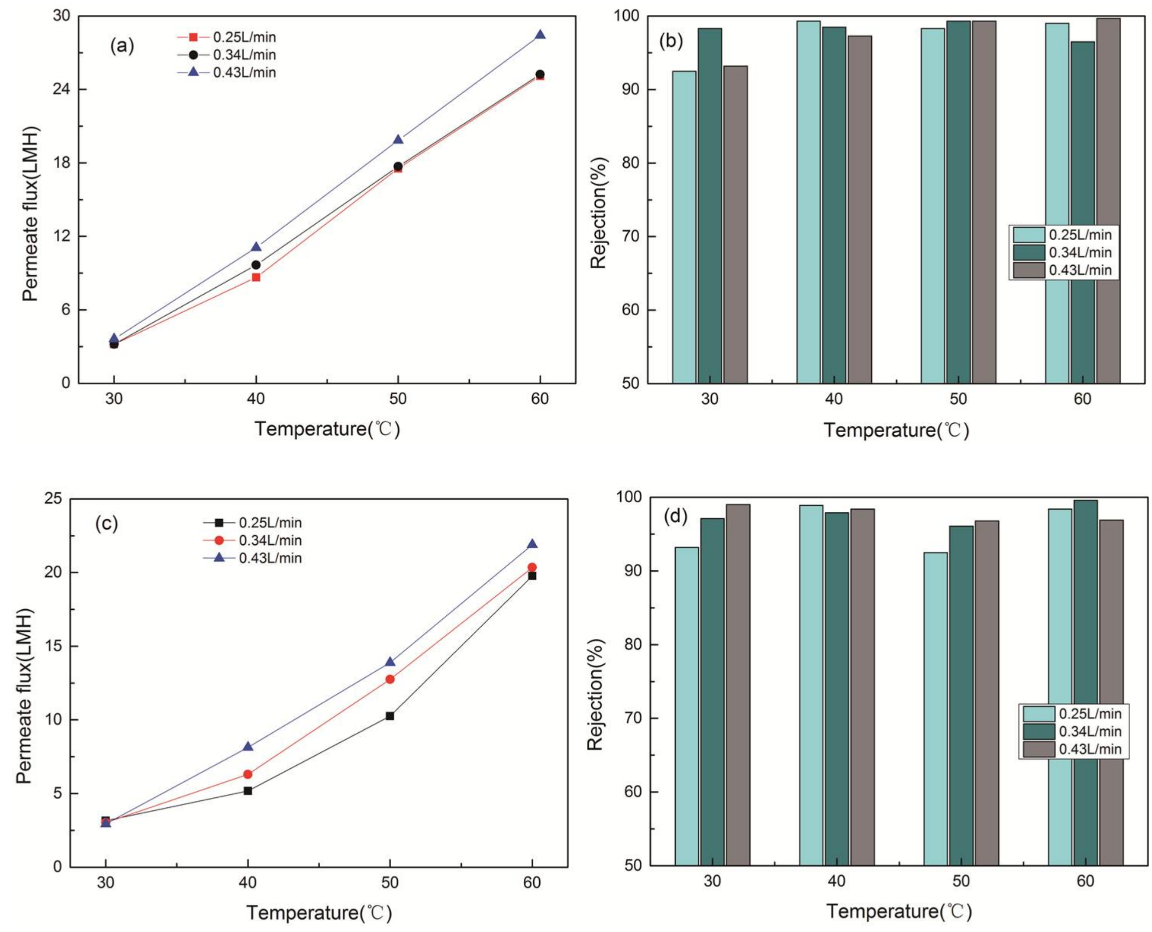

Figure 2. Permeate flux and rejection for chemicals using PTFE membranes (a), (b) and PVDF membranes (c), (d) at various temperatures and cross flow rates.

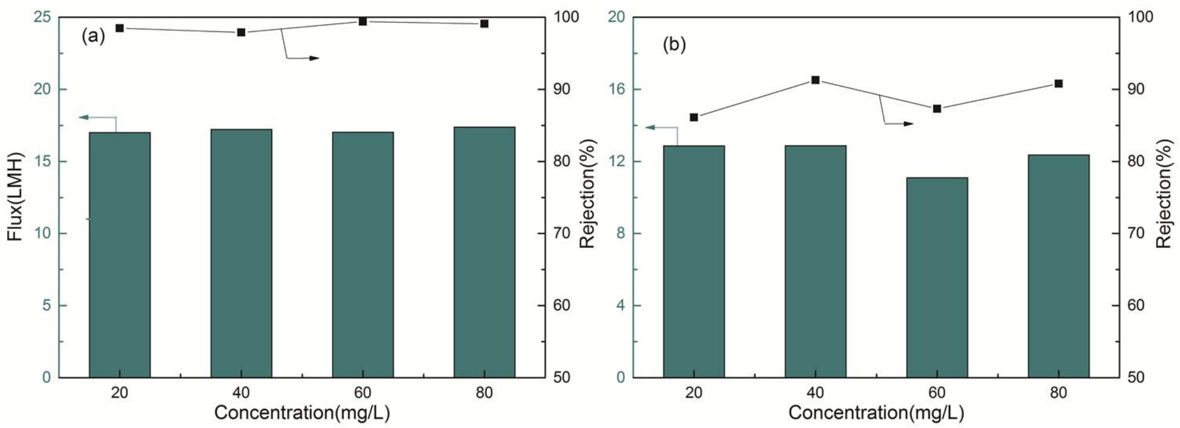

Figure 3. Permeate flux and rejection for chemicals were measured by using (a) PTFE membranes and (b) PVDF membranes at a function of feed concentrations.

3.3 Influence of the feed concentrate

The feed concentration was an important parameter impacting the performance of the DCMD process. As shown in Figure 3, the rejection had no obvious correlation with the feed concentration using sulfanilic acid as a model compound, both for PTFE and PVDF membranes. However, the PTFE membrane presented higher rejection compared with that of PVDF membrane, which may be due to the relatively higher hydrophobicity of PTFE membranes preventing the feed stream into membrane pores (Figoli et al., 2017). In other words, PVDF membranes may suffer from potential wetting during the process of DCMD test.

4. CONCLUSIONS

An effective direct contact membrane distillation (DCMD) system was developed to treat simulated dyeing wastewater. The impact of various important parameters, includes feed temperature, cross flow rate and feed concentration, on the DCMD performance were systematically investigated. Additionally, high feed temperature and fast feed flow facilitated water vapor passing through the membranes and improved the permeate flux. It was noticeable that the PTFE membranes obtained the better performance, *i.e.*, higher permeate flux and longer stability during the experiment, due to its improved porosity and hydrophobicity. In summary, although only limited rejection for phenol and aniline was achieved by the DCMD process, DCMD technique still can be considered as a potential candidate way in reclaiming dyeing wastewater because of its energy-efficient and simplicity.

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