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Comparative study on the treatment of raw and biologically treated textile effluents through submerged nanofiltration

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HIGHLIGHTS

- Raw textile effluent was efficiently treated through submerged nanofiltration.
- A comparison between raw and biologically treated textile effluents was conducted.
- Increase of TMP resulted in decreased water permeability, COD and color removal.
- Increase of VCF resulted in both increased COD reduction and color removal.
- Higher COD reduction and color removal were obtained with the raw effluent.

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ABSTRACT

Raw and biologically treated textile effluents were submerged filtrated using lab-fabricated hollow fiber nanofiltration membrane with a molecular weight cut-off of about 650 g/mol. Permeate flux, chemical oxygen demand (COD) reduction, color removal, membrane fouling, and cleaning were investigated and compared by varying the trans-membrane pressure (TMP) and volume concentrating factor (VCF). It was found that both raw and biologically treated textile effluents could be efficiently treated through submerged nanofiltration. The increase of TMP resulted in a decline in water permeability, COD reduction, color removal, and flux recovery ratio, while the increase of VCF resulted in both increased COD reduction and color removal. Under the TMP of 0.4 bar and VCF of 5.0, fluxes of 1.96 and 2.59 l/m^2 h, COD reductions of 95.7 and 94.2%, color removals of 99.0, and 97.3% and flux recovery ratios of 91.1 and 92.9% could be obtained in filtration of raw and biologically treated effluents, respectively. After filtration, the COD and color contents of the raw effluent declined sharply from 1780 to 325 mg/l and 1.200 to 0.060 Abs/cm, respectively, while for the biologically treated effluent, they decreased from 780 to 180 mg/l and 0.370 to 0.045 Abs/cm, respectively.

1. Introduction

Effluents from textile industry are generally loaded with spent dyes and chemical additives, and high in both biochemical oxygen demand (BOD) and chemical oxygen demand (COD) [1,2]. The extremely polluted textile effluents must be properly treated before disposal or reuse, since the presence of dyes even at a very low concentration is highly visible and toxic to aquatic life through damaging the esthetic nature of water and reducing the photosynthetic activity of aquatic organisms [3–5].

Biological and physical–chemical processes with previous screening and pH adjusting steps are commonly adopted to treat the textile effluents. Biological process using activated sludge offers high efficiency in the reduction of chemical oxidation demand (COD), but can not completely eliminate the color due to the biodegradable difficulty of the dyes presented in the effluents [6,7]. Physical–chemical process, which reduces dissolved, suspended, colloidal, and non-settleable materials from wastewater through

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chemical coagulation–flocculation followed by gravity settling, can completely eliminate the color, but has the main drawbacks of high chemical cost and low removal efficiency of soluble COD [8]. Advanced oxidation processes including chemical oxidation, photocatalytic degradation, and electrochemical treatment that have been proven to be alternatives for better treatment of textile effluents are still quite costly for practical application [9–14]. Therefore, more advanced treatment processes are required to meet the increasing stringent legislations on wastewater discharge, the necessary of wastewater reclamation, the reduction of the disposal cost, as well as the minimization of the volume of the waste discharged.

Membrane technology, as an advanced separation technology for water desalination and purification, has attracted more attention in treatment and reclamation of textile effluents for its high treatment efficiency and quality of treated water [15,16]. Among the pressure-driven membrane processes of reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF), and microfiltration (MF) that have been adopted for the treatment of textile effluents, nanofiltration has been proven to be the most effective one for its unique separation characteristics and lower energy consumption compared with reverse osmosis [17]. For example, Amar et al. [18] found that, as the tertiary treatment of textile effluent for water reuse, the NF membrane exhibited lower total dissolved solid rejection and higher yield compared with the RO membrane. Bes-Piá et al. [19] tested and compared the behaviors of six nanofiltration membranes TFC-SR2, ESNA, NF270, DS-5 DK, DS-5 DL, and Duraslick in reclamation of a secondary textile effluent. They concluded that all the tested membranes yielded permeate streams of high quality meeting reuse criteria. Ellouze et al. [20] applied nanofiltration as the post treatment of coagulation–flocculation process to enhance the treatment of textile effluent and reported that color retention of 100% was achieved. More recently, Sun et al. [21] developed a novel double-repulsive NF hollow fiber membrane by cross-linking hyperbranched polyethyleneimine on the out surface of a polyamide-imide substrate hollow fiber. Ong et al. [22] adopted the membrane to treat textile wastewater through pilot-scale tests. It was reported that the rejections to various tested dyes were higher than 90%, to NaCl and Na_2SO_4 were lower than 20 and 10%, respectively. When this hollow fiber nanofiltration membrane was combined with chemical/flocculation process, the removal of the tested dyes could reach almost 100% [23].

However, nanofiltration process now used were generally operated under the model of tangential pressurized filtration, which has the main drawbacks of high energy consumption and severe membrane fouling even with the pretreatment of activated sludge treatment or coagulation–flocculation process[24,25]. Therefore, innovative research still needs to be conducted on improvement of the treatment efficiency of nanofiltration process.

In consideration of the fact that submerged filtration technology has the advantages of lower operation pressure, energy consumption and cleaning requirement compared to the pressurized filtration model [26,27], submerged ultrafiltration (UF) or microfiltration (MF) systems have been widely adopted for the advanced treatment of wastewater in membrane bioreactors [28,29] and the pretreatment of seawater in seawater reverse osmosis (SWRO) desalination plants [30,31]. In recent years, membrane scientists have also devoted their attentions to the application of this technology in nanofiltration process [32–35]. Compared with the conventional submerged membrane bioreactor (SMBR) system using UF/MF membrane, the combination of biological treatment and submerged nanofiltration will produce filtrated effluent of better quality, but has relatively lower water permeability. In our previously study, submerged nanofiltration with a negatively charged NF hollow fiber membrane has been successfully applied to the treatment of a specific biologically treated textile wastewater [36]. The color and COD presented in the biologically treated textile wastewater could be effectively removed under low suction pressures ranging from 0.5 to 0.9 bar.

Table 1
Properties of the lab-fabricated thin-film composite hollow fiber nanofiltration membrane used in this study.

Parameter	Unit	Value
Pure water permeability (PWP)[a]	l/m^2 h bar	9.2 ± 0.3
Molecular weight cut-off (MWCO)[b]	g/mol	650 ± 40
Surface zeta potential at pH 7.0[c]	mV	2.5 ± 0.8
Rejection to NaCl[d]	%	10.5 ± 1.0
Rejection to Na_2SO_4[d]	%	8.0 ± 0.8
Inner diameter of hollow fiber (d_{in})	mm	0.40
Outer diameter of hollow fiber (d_{out})	mm	0.51

[a] Tested with de-ionized water under TMP of 0.8 bar and 25.0 °C.
[b] Obtained from the retention cure of PEG with different molecular weights according to the method described in [37].
[c] Obtained from the measured streaming potential according to the Helmholtz–Smoluchowski equation with the Fairbrother and Mastin substitution [38].
[d] Tested with 500 mg/l salt aqueous solution under TMP of 0.8 bar, 25.0 °C, and pH 7.0.

Accordingly, in this work, we tried to apply submerged nanofiltration with a positively charged NF hollow fiber membrane to the treatment of raw textile effluent and make a comparison with the treatment of biologically treated textile effluent. Submerged filtration tests were conducted employing a tailor-fabricated hollow fiber membrane module under different trans-membrane pressures (TMPs) and volume concentrating factors (VCFs). Water permeate flux, COD reduction, color removal, membrane fouling as well as membrane cleaning were investigated and compared.

2. Experimental

2.1. Materials

The raw and biologically treated textile effluents used in this study were taken from a textile industry located in Zhejiang Province, China. The biologically treated effluent was the output of the existing wastewater treatment plant composed of screening, acidification, activated sludge process, and clarifier, while the raw textile was only pretreated with screening, acidification, and clarifier.

The nanofiltration membrane used in this study was thin-film composite hollow fiber nanofiltration membrane with a selective layer of cross-linked polyvinyl alcohol (PVA) and polyquaternium-10 (a reaction product of hydroxyethyl cellulose with a trimethylammonium substituted epoxide) on the outside of the polypropylene microporous support hollow fiber. The membrane was prepared in our lab according to the method described in our previous work [35] and its properties are summarized in Table 1. The reason of choosing this NF membrane is its relatively low rejections to NaCl and Na_2SO_4, which generally presented in the textile effluent.

De-ionized water with a resistivity of 18.0 MΩ was used as pure water. Other chemicals involved were all analytical grade and used without further purification.

2.2. Lab-scale submerged filtration setup and tests

The lab-scale experimental setup for submerged filtration was nearly the same as that described in our previous study [36]. It consists of a suction pump, a 10 l feed tank equipped with a temperature controller, an aerator device and a submerged hollow fiber membrane module. Aeration was adopted to reduce membrane fouling through scouring. Each module contains fifty hollow fibers