Separation and Purification Technology 70 (2009) 71–78

Contents lists available at ScienceDirect

Separation and Purification Technology

journal homepage: www.elsevier.com/locate/seppur

Evaluation of an innovative polyvinyl chloride (PVC) ultrafiltration membrane for wastewater treatment

Xuezhi Zhang, Yongsheng Chen*, A.H. Konsowa, Xiaoshan Zhu, John C. Crittenden

Department of Civil, Environmental and Sustainable Engineering, Arizona State University, Tempe, AZ 85287, USA

ARTICLE INFO

Article history:
Received 28 October 2008
Received in revised form 20 August 2009
Accepted 25 August 2009

Keywords:
Fouling
Water reclamation
PVC
Hollow fiber membrane
RO pretreatment

ABSTRACT

The use of ultrafiltration (UF) employing a polyvinyl chloride (PVC) membrane (LH3-1060-V) as pretreatment for a reverse osmosis (RO) system treating secondary water effluent at the Scottsdale Water Campus was investigated. Membrane fouling tendency was evaluated, foulants were characterized, and chemical cleaning was optimized. Feed and permeate water qualities were indexed to address the effect of UF as a pretreatment on the RO process, in view of RO design and scale calculations. The results showed that the pilot plant operated stably for 102 days with a chemical cleaning interval of 69 days. The transmembrane pressure (TMP) ranged from 35.44 to 71.15 kPa, and the normalized flux was 72 L/(m^2 h) at 20 °C. The majority of the foulants were organic compounds (tannins, fulvic acids, humic acids, amino sugars, etc.) along with a few inorganic ones (iron, calcium, etc.). SEM–EDX mapping showed that most of the foulants deposited on the inner surface of the fiber. The best cleaning sequence for the fouled membrane was found to be 2% sodium hydroxide–0.5% citric acid, as 97% of the initial membrane flux was restored. The PVC-UF membrane efficiently removed turbidity, suspended solids and color, with removal efficiencies of 96.41%, 88.33%, and 50.00%, respectively. The UF pretreatment was found to enhance the RO average permeate flux and recovery by 34% and 21%, respectively, compared to the simulated conventional pretreatment system.

1. Introduction

Membrane processes can be used successfully to obtain reusable quality water. A dual membrane UF-reverse osmosis (RO) process has become increasingly attractive for the reclamation of municipal wastewater [1–6]. UF is an excellent pretreatment for RO because it can consistently deliver filtrate with a very low turbidity and silt density index (SDI) regardless of feed water quality. However, the high levels of particulates, dissolved organic matter (DOM) and microorganisms in wastewater can easily foul UF membranes. Many efforts have been made to understand and alleviate fouling, including characterization of fouling [7–12], water pretreatment [13,14], development of backwashing and cleaning strategies [15,16], and membrane surface modification and new membrane material development [17,18]. UF processes predominantly use organic membranes, with cellulose acetate (CA), polysulfone (PS), polyethylene (PE), polyethersulfone (PES), and polyvinylidene difluoride (PVDF) in use in water treatment [3]. Polyvinyl chloride (PVC) is an outstanding material because of its robust mechanical strength, low cost, and excellent chemical properties (e.g., acid, alkali, and solvent resistance). In a lab scale study, a membrane made of PVC exhibited higher permeate fluxes and lower rejections [19]. To the best of our knowledge, no data has previously been available regarding the fouling of this PVC membrane during wastewater treatment. In this paper, the fouling tendency and performance of the PVC membrane in wastewater treatment is evaluated.

2. Experimental

2.1. Pilot UF system

A UF pilot plant with a single hollow fiber PVC membrane module was evaluated at the Scottsdale Water Campus (Scottsdale, AZ). The PVC module was provided by Litree Co. (Hainan, China). Table 1 lists the properties of the PVC membrane.

Secondary effluent from media filtration at the Scottsdale Water Campus served as feed water. This feed water was pumped through a 100 μm pre-filter before it entered the UF unit. Dead end filtration was used. A programmable logic controller (PLC) drove all the operational processes of the UF system. The pilot plant was equipped with instruments for on-line monitoring of flow rate, operating pressure, turbidity, and number of particles. The instruments were connected to a data logging system for data keeping,

* Corresponding author. Tel.: +1 404 894 3089.
E-mail address: yongsheng.chen@ce.gatech.edu (Y. Chen).

1383-5866/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.seppur.2009.08.019

Table 1
Characteristics of PVC membrane[a].

Parameter	Value
Membrane material	PVC
Configuration	Inside-out hollow fiber
Cartridge dimension (mm)	⌀277
Molecular weight cut-off (kDa)	50
Membrane area (m^2)	33
Fiber inner/outer diameter (mm)	1.0/1.66
Operating pH range	2–13
Maximum operating temperature (°C)	5–40

[a] Data provided by membrane manufacturer.

analysis and normalization. Operation parameters were optimized with a flux of 72 L/(m^2 h) and a 25 min backwash interval. An air assisted backwash process coupled with a pulsated flushing process was used every 25 min to backwash and flush the fouled membrane. In the air assisted backwash, compressed air (0.1 m^3/min) was used instead of the backwash pump to push water in the housing out of the module through the membrane. At the same time, compressed air scoured foulants from the membrane surface inside the hollow fiber. After that, a pulsated flushing process that employed a mixture of compressed air and water began. At 5th, 15th and 25th second the water flow rate was doubled rapidly for 5 s to improve the flushing efficiency. The membrane was soaked with 100 mg/L NaClO every 3.5 days. The overall water recovery was 94%.

Transmembrane pressure (TMP) and membrane resistance were used to evaluate the different backwash processes. TMP, resistance and flux were recorded and calculated according to the EPA membrane guideline normalized equations with reference to temperature 20 °C, since water temperature can have a significant impact on TMP and flux [5].

2.2. Characterization of foulants

During one of the optimization tests, TMP increased to 80 kPa after 30 days' operation. After an air assisted backwash, stronger air (0.15 m^3/min) was used to scour the membrane for 10 min. Then the membrane was backwashed, and the discharge was collected and dried at 80 °C. Between 2 and 5 mg of foulants was mixed into KBr pellets, and a PerkinElmer System 2000 FTIR spectrometer was used to collect the spectrum. The instrument scanned from 4000 to 400 cm^{-1}, averaging 10 scans at 1.0 cm^{-1} interval with a resolution of 4.0 cm^{-1}. After acquisition the spectrum was normalized to a maximum absorbance of 1.0 for comparative purposes.

To obtain information about the foulants remaining on the membrane, the module was autopsied, and the fibers were removed from the module and dried. To acquire images of both the inner side and the cross section, at the end of the fiber some of the top was further removed. After coating the samples with gold, a scanning electron microscope (SEM) (Philips XL30, FEI Company, USA) equipped with an energy dispersive X-ray analysis (EDX) system was used to determine the morphology and chemical composition of the foulants on the membrane.

2.3. Chemical cleaning

Fouled membranes were cleaned in place after the TMP reached the cleaning limit value. Chemicals including 2% NaOH and 0.5% citric acid were used to soak the membrane. The measured average pH values of the 0.5% NaOH and 2% citric acid were 12.6 and 2.8, respectively. Two cleaning sequences (citric acid–NaOH and NaOH–citric acid) were evaluated by measuring the recovered flux after each cleaning. Three different flow rates that covered the range of anticipated flux rates were tested. Then the normalized specific flux was calculated and plotted against TMP.

After the membrane soaked in NaOH, FTIR was used to characterize changes in functional groups on the membrane surface, and a contact angle meter (EasyDrop, Kruss, Germany) was used to characterize the hydrophobicity of the membrane surface. The average of five measurements was reported.

2.4. Permeate quality

Permeate turbidity was detected online. Other parameters, such as color, total organic carbon (TOC), iron, aluminum, calcium, and SDI were analyzed using standard procedures described in ASTM [10] or Standard Methods [6].

Because no RO system is connected to the UF pilot system, three sets of full design calculations for RO were completed. These considered different types of feed: UF permeate water, secondary effluent with no treatment, and simulated conventionally treated secondary effluent. The effects of these different feeds were evaluated by comparing the average permeate flux and recovery for the RO system. The software used for the calculation was Reverse Osmosis System Analysis, July 2000 Version 4.30 for Windows (FilmTec Co.). A commercially available RO membrane, TWLE-4040, which has a filtration area of 7.6 m^2 and a rejection of 99.5%, was selected in the calculation. RO feed SDI ranges from <3, 3–5 and >5 for UF membrane pretreatment, conventional pretreatment and no pretreatment was used in the calculation. The design calculations were carried on element to element basis and single stage one stream was used.

3. Results and discussion

3.1. Changes in TMP, flux and resistance

The UF pilot plant was operated using the air assisted backwash in pulsated flushing mode for 3.5 days run time intervals between each NaClO soaking. Fig. 1 shows TMP and flux changes. The initial TMP was 35.44 kPa, but as irreversible foulants accumulated, the TMP increased to 71.15 kPa after 69 days of operation (filtration and backwash). The chemical cleaning interval for the pilot test was 69 days, which is in the range of the typical membrane cleaning interval (1–6 months) [20]. After chemical cleaning with NaOH and citric acid, the TMP dropped to 34.56 kPa, and then increased slowly with operation until it reached 55.71 kPa at day 102. The normalized flux ranged from 68.1 to 79.2 L/(m^2 h), and the normalized average flux was 72 L/(m^2 h).

Yamamura et al. studied the fouling tendency of PE (0.1 μm), PVDF (0.1 μm), and PAN (100 kDa) membranes in drinking water treatment, and the results showed that the extent of fouling differed significantly depending on the membrane type. During 30 days of operation, the TMP increased from 24 to 125 kPa for the PAN membrane, from 5 to 160 for PVDF, and the smallest increase

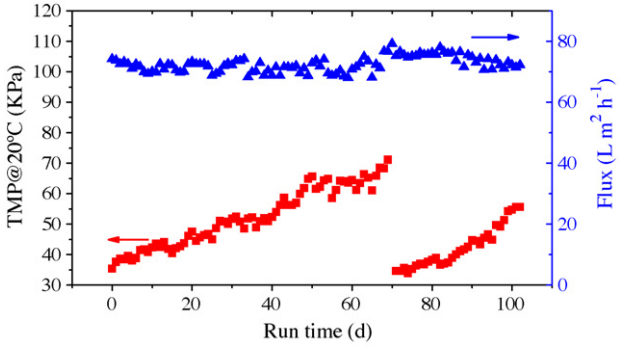

Fig. 1. TMP change profile.