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Pilot study on hydrophilized PVDF membrane treating produced water from polymer flooding for reuse

Jun Xu[a,b], Cong Ma[c,*], Bangqing Cao[a], Jing Bao[a], Yong Sun[d], Wenxin Shi[e], Shuili Yu[e,f]

[a] Department of Civil Engineering and Architecture, Nanyang Normal University, Nanyang 473061, China
[b] State Key Laboratory of Motor Vehicle Biofuel Technology, Nanyang 473000, China
[c] State Key Laboratory of Separation Membranes and Membrane Processes, School of Environmental and Chemical Engineering, Tianjin Polytechnic University, Tianjin 300387, China
[d] Department of Aerospace and Civil Engineering, Harbin Engineering University, Harbin 150001, China
[e] State Key Laboratory of Urban Water Resource and Environment, Harbin Institute of Technology, Harbin 150090, China
[f] State Key Laboratory of Pollution Control and Resource Reuse, Tongji University, Shanghai 200092, China

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ABSTRACT

To meet the oilfield reinjection water quality for low and ultra-low permeability reservoirs in China, a hydrophilized polyvinylidene fluoride (PVDF) membrane (approximate 110 m^2) manufactured by our laboratory was used for treating produced water from polymer flooding for reuse in Daqing Oilfield. The results showed that a temperature of 37 °C, volume reduction factor (VRF) of 4, transmembrane pressure (TMP) of 0.20 MPa and crossflow velocity of 4.5 m/s were the feasible operation conditions for the membrane, and the average flux could reach 75 L/(m^2 h) (LMH). In the permeate, the total suspended solids (TSS) was consistently below detection limits (2.5 mg/L) and the medium grain size was undetectable. The content of hydrolyzed polyacrylamide (HPAM), crude oil and turbidity were respectively lower than 50 mg/L, 1 mg/L and 1 NTU, respectively. The parameters of treated water all met the highest oilfield reinjection water quality in China and the results demonstrated the hydrophilized PVDF membrane had good anti-fouling characteristics in treating produced water from polymer flooding for reuse.

1. Introduction

Daqing Oilfield has the largest polymer flooding project in the world (Jin et al., 2008). At the same time, as much as about 6 × 10^7 m^3 produced water from polymer flooding (PWfPF) is generated per day (Deng et al., 2002). As the contents of crude oil and TSS are beyond the local reinjection criteria, the PWfPF has to be treated before the reinjection into the stratum (Yu et al., 2006). However, for low and ultra-low permeability reservoirs, the local criteria requests the contents of crude oil and TSS in the reinjection water should be lower than 5 mg/L and 1 mg/L, respectively. Such stringent standards are difficulty to reach by conventional treatment systems including gravity separation and skimming, dissolved air flotation, de-emulsification, as well as coagulation and flocculation (Deng et al., 2009; Qiao et al., 2008; Wang et al., 2006). The main reason is that the PWfPF possesses not only high contents of crude oil and TSS, but also high contents of HPAM and salinity. The HPAM could increase the viscosity of the PWfPF and make the TSS and crude oil steadily disperse in the wastewater, so as to reduce their velocity of assembling and rising tendency (Zhao et al., 2008). Therefore, with the progressive exploitation of the low and ultra-low permeability

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* Corresponding author.
E-mail address: macong_0805@126.com (C. Ma).

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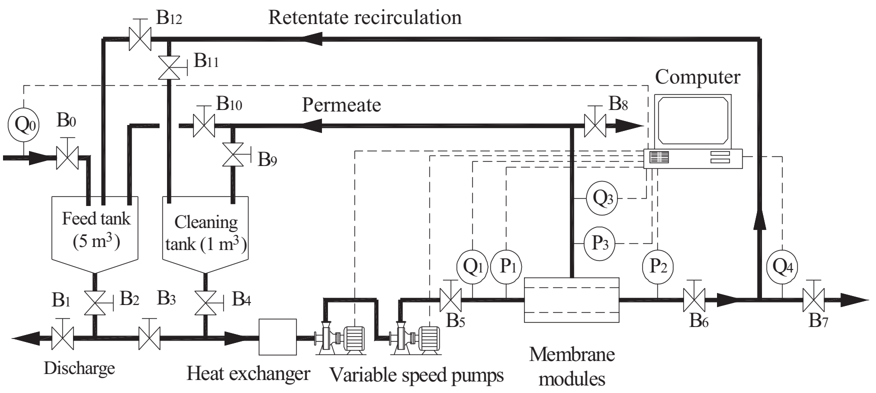

Fig. 1 – Schematic diagram of the pilot-scale membrane filtration system ($Q_{0–4}$, electromagnetic flowmeter; $P_{1–3}$, manometer with pressure transmitter; $B_{0–12}$, ball valve).

reservoirs, it is becoming more and more urgent and crucial to search for an effective process to treat the PWfPF for reinjection.

Membrane technology has gained significant popularity in water and wastewater treatment in recent years (Kimura et al., 2005; Laabs et al., 2006; Yang et al., 2009; Zhang et al., 2009). Distinct advantages of membrane technology for treatment of produced water include reduced sludge and high quality of permeate, etc. (Mueller et al., 1997). In many literatures, it has been reported that the membrane is an effective process alternative to treat oily wastewater (Cheryan and Rajagopalan, 1998; Janknecht et al., 2004; Marchese et al., 2000). However, one of the major challenges or obstacles for the application of membrane technology in treatment on oily wastewater is the decline in permeate flux as a result of membrane fouling (Mueller et al., 1997). Since the PWfPF is high content of crude oil, TSS and HPAM, it might cause serious pollution to the membrane. Basing on our previous studies, it has been found that the poly(vinylidene fluoride) (PVDF) membrane after being hydrophilized by inorganic nano-sized alumina particles presented better antifouling performance on treatment of this produced water (Lu et al., 2006; Yu et al., 2006). However, those studies were just conducted in bench scale for short time and the operation parameters and long-term performance of the membrane were not investigated. Consequently, for more efficient use of this membrane, further studies need to be carried out with special emphasis on the optimum operation conditions, flux evolution and recovery, and the removal effectiveness of foulants during long-term performance.

In this study, a pilot-scale filtration system of the hydrophilized membrane was set up and had been performed for about 12 months. The influences of TMP and crossflow velocity on the membrane flux were investigated when the temperature and VRF of the PWfPF were fixed at 37 °C and 4, respectively. Then, the effectiveness of the membrane during long-term performance was evaluated in terms of crude oil, HPAM, turbidity and TSS retention as well as flux evolution and recovery.

2. Materials and methods

2.1. Pilot-scale membrane filtration system

The pilot-scale experiments were carried out at the Junanba sewage treatment station (Daqing, CN), which processes fractional PWfPF in Daqing Oilfield with the existing traditional technology, i.e., gravity sedimentation, coagulation sedimentation, sand filtration and disinfection. A schematic diagram of the membrane filtration system is given in Fig. 1.

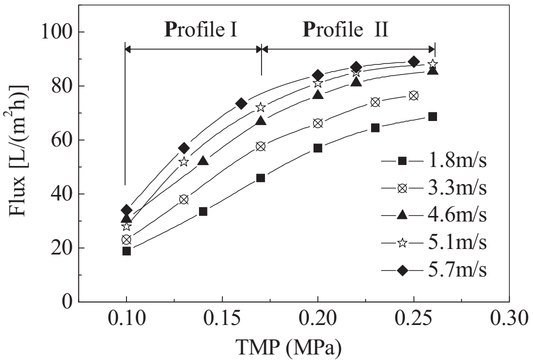

Fig. 2 – Influences of TMP and crossflow velocity on membrane flux (temperature = 37 °C, VRF = 4, 'flux' were the average flux in 24 h).

The filtration system covered a wide range of operation conditions and was automatically controlled through a personal computer with a programmable logical controller (PLC) system. All the operation parameters were specified or modified via the computer. Instantaneous flux, accumulative flux, and pressure of the feed, permeate, and retentate were automatically recorded and sent to the computer. The temperature of the water was adjusted through a heat exchanger. The PWfPF was introduced into the membrane modules by two variable speed pumps and, different volume reduction factor (VRF) could be obtained by recirculating fractional retentate as membrane feed. In this study, TMP (MPa), crossflow velocity (υ, m/s), VRF, permeate average flux (J_{av}, LMH), and rejections (R) of various solutes were obtained by the following equations (Eqs. (1)–(5)), respectively.

$$\mathrm{TMP} = \frac{P_{\mathrm{in}} + P_{\mathrm{out}}}{2} - P_{\mathrm{per}} \tag{1}$$

where P_{in}, P_{out}, P_{per} are inlet pressure (MPa), outlet pressure (MPa), and permeate-side pressure (MPa), respectively, and can be read direct from the manometers P_1, P_2, P_3, respectively, as shown in Fig. 2.

$$\upsilon = \frac{Q}{S} \tag{2}$$

where Q is inlet flux (m^3/s); S is effective sectional area (m^2) of the membrane module.

$$\mathrm{VRF} = \frac{Q_p + Q_d}{Q_d} \tag{3}$$

where Q_p is permeate flux (m^3/s); Q_d is retentate discharge flux (m^3/s); and they can be read direct from the electromagnetic flowmeters Q_3 and Q_4, respectively, as shown in Fig. 2.

$$J_{av} = \frac{Q_T}{At} \tag{4}$$

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