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Dynamic fouling behavior and cake layer structure changes in nonwoven membrane bioreactor for bath wastewater treatment

Can Wang [a,*], Wei-Nan Chen [a], Qing-Yuan Hu [a], Min Ji [a], Xin Gao [b]

[a] School of Environmental Science and Engineering, Tianjin University, No. 92, Weijin Road, Tianjin 300072, China
[b] Grundfos Pumps (Shanghai) Co., Ltd., Maxdo Center, No. 8, Xingyi Road, Shanghai 200336, China

HIGHLIGHTS

- The NWMBR exhibits excellent performance on bathing wastewater treatment.
- The membrane fouling mechanisms are different in various operating phases.
- Pore blocking cause the fouling of NWMBR during the early-stage phase.
- Cake layer morphology change with increasing flux, thus affecting membrane fouling.

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ABSTRACT

A nonwoven fabric module was used as a solid–liquid medium in a membrane bioreactor for bath wastewater treatment. The flux-step method was performed to define the maximum allowable flux and then was verified over a long period operation under six different imposed fluxes ranging from 8 L/(m^2 h) to 18 L/(m^2 h). During the long-term tests, the treatment performance and filtration characteristics of the nonwoven membrane bioreactor (NWMBR) were investigated. The membrane fouling mechanisms under the different operating phases of the NWMBR were also discussed. Results show that the NWMBR operated in two stages during the six tests. In the early stage, the filling up of the internal structure of the membrane caused the rapid formation of a dense cake layer. In the late stage, the increasing imposed flux changed the morphology of the cake layer and affected the membrane fouling differently. When the flux exceeded the critical flux of 15 L/(m^2 h), a thin but dense cake layer formed rapidly and decreased the membrane permeability. When the flux was lower than the critical flux, a loose filamentous biomass layer formed on the nonwoven membrane surface, which acted as a secondary membrane that prevented the adsorption of extracellular polymeric substances, soluble microbial products, and particles onto the membrane surfaces.

1. Introduction

Membrane bioreactors (MBRs) are a new generation of biological technology that involves membrane filtration and biological treatment. However, the widespread application of MBR is limited because of its high initial membrane costs and pore blocking, which significantly affects the trans-membrane pressure (TMP) and permeate flux. The pore blocking is mainly caused by the deposits in the internal structure of the membranes or the cake layer formation, which consists of microorganisms, colloids, solutes, and cell debris on the membrane surface [1]. Lee et al. [2] found that the cake layer is a self-forming dynamic membrane that prevents pollutants or sludge flocs from being adsorbed directly into the pores. However, excessive cake layer accumulation will increase the TMP and reduce permeate flux. Therefore, low cost and large pore size membranes, such as nonwoven fabrics and mesh, have been proposed as alternatives for MBR systems.

Nonwoven fabrics are composed of random networks of overlapping fibers that create multiple connected pores. This material is extensively applied as liquid filter media for separating solids. Given the large pore size (1.5–50 μm) and high porosity, nonwoven fabrics achieve higher fluxes than microporous membranes under low pressure conditions [3–5], demonstrating the great potential of nonwoven fabrics for MBR applications [1].

To investigate the use of nonwoven fabrics in MBR, a few studies evaluated the performance of nonwoven membrane bioreactors (NWMBR). Meng et al. [3] reported a slight difference in the

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* Corresponding author. Tel./fax: +86 22 27406057.
E-mail address: wangcan@tju.edu.cn (C. Wang).

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effluent quality between NWMBR and traditional MBR. Chang et al. [4] successfully developed a nonwoven module for a submerged bioreactor. Some studies have investigated the filtration characteristics of NWMBR. Chang et al. [6] compared nonwoven membranes with three different pore sizes and concluded that the difference in flux decline between polysulfone and nonwoven polypropylene is insignificant. All membranes produce an extremely low amount of organic matter (10–10^3 μg/L) under a low effluent turbidity (less than 5 NTU). The permeate flux of NWMBR can be maintained quite stably under low TMP (less than 10 kPa) [7] and NWMBR shows lower filtration resistance than microporous membranes in MBR applications [8]. These studies found that the filtration behavior of NWMBR is different from that of traditional MBR because of the special structure and large pore size of the nonwoven membrane, which causes particle deposition and pore blocking. However, studies on the long-term performance and dynamic fouling behavior of NWMBR are still limited. Therefore, the fouling characteristics and corresponding mechanisms of submerged NWMBR should be further studied to extend the lifespan of the nonwoven membrane.

In this study, a submerged NWMBR was used and operated continuously to investigate its filtration characteristics and pollutant removal performance under various imposed fluxes. The TMP and resistance accumulation were examined to explain the fouling phenomena of the NWMBR. The cake layer characteristics and its effects on membrane fouling were also studied. Moreover, the mechanisms of membrane fouling under different operation phases of NWMBR were discussed.

2. Materials and methods

2.1. Experimental setup

Fig. 1 shows the experimental setup. A flat sheet module was submerged in a 28 L bench scale MBR. The four pieces of flat sheet membrane used in this work were made of nonwoven fabric with a mean pore size of 38.1 μm. The nonwoven membrane surface was hydrophobic, with the contact angle was 120°. Each nonwoven membrane had an effective membrane area of 0.1 m^2 with a total effective membrane area of 0.4 m^2. The influent pump was controlled by a water level sensor to maintain a constant water level in the reactor. Thereafter, the membrane-filtered effluent was obtained by using a peristaltic pump, which was controlled by a time relay to ensure that the nonwoven membrane operated intermittently.

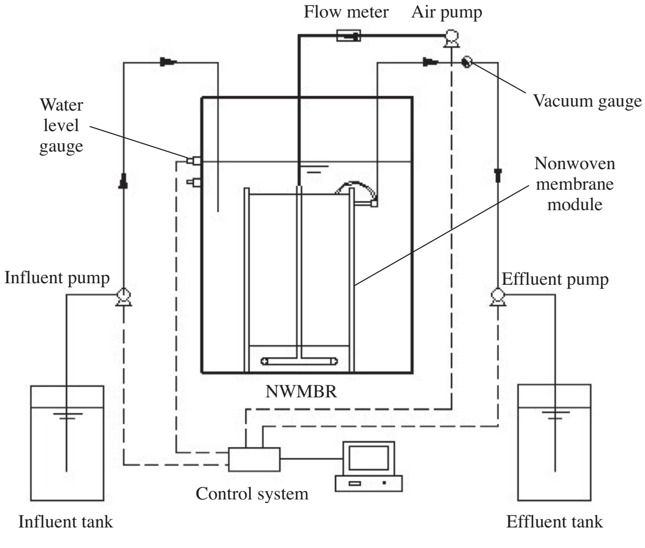

Fig. 1. Schematic diagram of the experimental NWMBR system.

2.2. Operating conditions

The NWMBR was operated continuously for 338 days under the operating conditions described in Table 1. During the entire operation of the NWMBR, six tests were conducted to determine the filtration characteristics of the nonwoven membrane and evaluate the performance of the NWMBR. When the TMP, which was monitored by using a pressure gauge, reached approximately 30 kPa, the nonwoven membrane was removed and cleaned by water flushing to remove the fouling cake on the membrane surface.

The NWMBR was seeded with activated sludge obtained from the Wastewater Reclamation Plant of Tianjin University. Raw bath wastewater was obtained from the swimming center of Tianjin University and its characteristics are shown in Table 2.

2.3. Analytical methods

2.3.1. Critical flux evaluation

Several short-term critical flux determination experiments were performed by using the common flux step method described by Le-Clech et al. [9]. At each step, the flux increased and TMP stability was monitored. Critical flux was determined based on the rapid accumulation of foulants, which occurred when the TMP became unstable and increased rapidly ($dP/dt \geqslant 0$). In the current study, the flux-step duration was 30 min. Flux-step height was maintained at 2–5 L/(m^2 h) throughout the study. The four tests were conducted under four mixed liquor suspended solid (MLSS) concentrations (3, 5, 7 and 9 g/L).

2.3.2. Filtration resistance analysis

The resistance of fouled membranes is usually reflected by the clean water permeate flux measured under constant TMP. Therefore, when membrane fouling occurs, the pore blocking resistance and cake layer resistance can be measured or calculated [10]. Moreover, the resistance of the nonwoven membrane could also be determined by using the aforementioned method. The resistance and flux are described by Eqs. (1) and (2):

$$J = \Delta P / \mu \cdot R_t \tag{1}$$

$$R_t = R_m + R_c + R_p \tag{2}$$

where J is the water permeate flux [$m^3/(m^2\ s)$], ΔP is the TMP (Pa), μ is the permeate viscosity (Pas), R_t is the total filtration resistance (m^{-1}), R_m is the intrinsic resistance of the nonwoven membrane (m^{-1}), R_c is the resistance caused by the cake layer deposit (m^{-1}), and R_p is the fouling resistance (m^{-1}) caused by the internal pore blocking inside the nonwoven fabric.

2.3.3. Measurements of water quality parameters

The chemical oxygen demand (COD), 5-day biological oxygen demand (BOD_5), ammonia nitrogen (NH_3-N), and pH of the influent and membrane effluent were measured. Dissolved oxygen (DO), pH, and turbidity data were obtained by using a HACH HQ30d DO meter, Sartorius PT-10 pH meter, and HACH 2100P turbidity meter, respectively.

2.3.4. Extracellular polymeric substance (EPS) extraction from cake

Extracellular polymeric substance (EPS) is the most significant factor responsible for membrane fouling. The fouled membrane was removed from the NWMBR at the end of each test. A sludge sample was carefully scraped off from the membrane surface by using a plastic sheet. The sludge sample was then diluted in distilled water. The EPS from the sludge mixture was then extracted.