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Hybrid process of BAC and sMBR for treating polluted raw water

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ABSTRACT

The hybrid process of biological activated carbon (BAC) and submerged membrane bioreactor (sMBR) was evaluated for the drinking water treatment from polluted raw water, with the respective hydraulic retention time of 0.5 h. The results confirmed the synergetic effects between the BAC and the subsequent sMBR. A moderate amount of ammonium (54.5%) was decreased in the BAC; while the total removal efficiency was increased to 89.8% after the further treatment by the sMBR. In the hybrid process, adsorption of granular activated carbon (in BAC), two stages of biodegradation (in BAC and sMBR), and separation by the membrane (in sMBR) jointly contributed to the removal of organic matter. As a result, the hybrid process managed to eliminate influent DOC, UV_{254}, COD_{Mn}, TOC, BDOC and AOC by 26.3%, 29.9%, 22.8%, 27.8%, 57.2% and 49.3%, respectively. Due to the pre-treatment effect of BAC, the membrane fouling in the downstream sMBR was substantially mitigated.

1. Introduction

Due to the lack of stringent legislation on environmental protection, domestic sewage and industrial wastewater are often discharged before effective treatment, which leads to the pollution of many surface water supplies in developing countries. The organic contaminants and ammonium presented in raw water have always been the major issues in drinking water treatment. They would increase the chorine demand during disinfection process and increase the disinfection-by-products formation potential (DBPFP) (Duong et al., 2003; Sirivedhin and Gray, 2005). On the other hand, the regulation of drinking water qualities becomes more and more restrict, which promotes the development of advanced water treatment technologies.

Biological activated carbon (BAC) has been extensively employed in drinking water treatment all over the world, for the removal of organic substances and ammonium (Andersson et al., 2001; Li et al., 2006; Xu et al., 2007). In BAC, adsorption of biorefractory compounds and bio-oxidation of biodegradable organic matter (BOM) could be achieved simultaneously (Seredyńska-Sobecha et al., 2006). As a result, the DBPFP could be substantially reduced (Toor and Mohseni, 2007), and the bio-stability of treated water be improved after BAC treatment (Laurent et al., 1999). Xing et al. (2008) conducted adsorption and bio-adsorption experiments on granular activated carbon (GAC) for dissolved organic carbon (DOC) removal from wastewater, demonstrating that with the adsorption and biodegradation mechanisms, BAC has the advantage of prolonging the life of GAC, and thus lowering the regeneration cost.

However, it was noticed that colonized carbon fines could be released from the BAC, and carry bacteria to the drinking water distribution system (Morin and Camper, 1997). Thus, the concern over the microbial risk of BAC increased in despite of the many advantages BAC could offer. On the other hand, microfiltration (MF) and ultrafiltration (UF) are effective processes for the rejection of particles and microbes from drinking water (Fiksdal and Leiknes, 2006; Oh et al., 2007). In fact, the combination of BAC with membrane filtration has been evaluated for drinking water treatment by several researchers (Tsujimoto et al., 1998; Wend et al., 2003). The synergetic effects were observed between the BAC and membrane filtration for the improvement of treated water qualities. Furthermore, the pre-treatment effect of BAC could also reduce the membrane fouling in the subsequent membrane filtration.

The introduction of immersed membrane configuration results in not only the simplicity of installation but also the decrease of energy consumption, as compared with the pressure-driven membrane module (Yang et al., 2006). Therefore, the immersed membrane filtration process becomes more and more popular in both wastewater treatment and drinking water purification (Hillis, 2006; Meng et al., 2009; Ngo et al., 2008). If the operational conditions are optimized, microorganisms could be colonized and activated sludge formed in the membrane filtration tank. Thus, the immersed membrane unit is converted to the submerged membrane bioreactor (sMBR), namely the integration of immersed membrane and conventional activated sludge process. The sMBR have been widely studied and applied in full-scale wastewater treatment by this time (Lyko et al., 2007). A few researchers also

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evaluated the effectiveness of sMBR for the drinking water treatment (Li and Chu, 2003; Sagbo et al., 2008; Seo et al., 2002). However, because the natural organic matter (NOM) in source water is bio-refractory as a whole, the individual sMBR might not be able to achieve satisfactory treatment efficiencies.

Ng et al. (2006) investigated the operation of MBR with the addition of powered activated carbon (PAC) for wastewater treatment; the results indicated that the PAC in the bioreactor was not only able to enhance the removal of organic matter, but also able to improve the membrane filtration performance. The enhanced organic matter removal through PAC addition was also observed by Hai et al. (2008) in a MBR for the treatment of textile wastewater containing azo dyes. While Ngo and Guo (2009) developed a modified green bio-flocculant (GBF) for the conventional aerated MBR, showing that 95% of DOC and 99.5% of total phosphorous could be removed, and nearly zero membrane fouling could be achieved through the GBF addition. Thuy and Visvanathan (2006) studied the treatability of industrial wastewater containing high concentrations of phenolic compounds by the MBR coupled with BAC in the bioreactor, and found that the removal efficiencies could reach to 99% for phenol and 95% for 2,4-dichlorophenol, respectively. On the other hand, Gur-Reznik et al. (2008) evaluated the GAC adsorption as a pre-treatment to the reverse osmosis (RO) of MBR effluents for enhanced wastewater reclamation, with the results demonstrating that 80–90% of the dissolved organic matter (DOM) in the MBR effluents could be removed through GAC adsorption.

In this paper, the hybrid process of BAC and sMBR was brought forward and investigated for the drinking water production from polluted raw water. In the hybrid process, two stages of biological treatment barriers were constructed for the pollutants in the raw water. The BAC could remove a large amount of organic matter and ammonium through adsorption and biodegradation, which could also reduce the membrane fouling in the downstream sMBR; on the other hand, the sMBR was capable of further eliminating organic matter and ammonium through biodegradation, and separating particles in the BAC effluent.

2. Methods

2.1. Experimental set-up

Mini-pilot-scale devices of BAC and sMBR were constructed and employed in this study (Fig. 1). The BAC filter consisted of a 60 mm

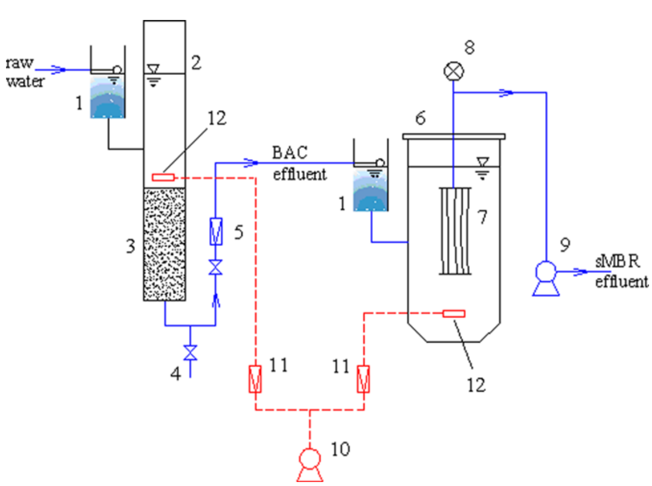

Fig. 1. Schematic diagram of the experimental set-up (1 – constant level water tank; 2 – BAC; 3 – granular activated carbon layer; 4 – backwashing valve; 5 – BAC effluent flowmeter; 6 – sMBR; 7 – UF membrane module; 8 – manometer; 9 – suction pump; 10 – air blower; 11 – air flowmeter; 12 – air diffuser).

inner-diameter Plexiglas pipe, with a height of 2.0 m. Coal-based GAC (ZJ-15, Ningxi, China) was used in the BAC filter, with the carbon bed depth of 1.0 m. The sMBR had a bioreactor with an effective volume of 2 L. A hollow fiber UF membrane module (Litree China) was directly immersed inside the reactor. The membrane was made of polyvinyl chloride (PVC), with a nominal pore size of 0.01 μm. There were 300 membrane fibers in the membrane module, with an effective length of 30 cm. The inner and outer diameters of each membrane fiber were 0.85 mm and 1.45 mm, respectively, corresponding to the total membrane area of 0.4 m^2.

The BAC was fed with raw water through a constant level tank. The effluent flux of BAC was adjusted through a flowmeter; while the sMBR effluent was drawn with a suction pump. Continuous aeration was provided at the bottom of the sMBR to provide dissolved oxygen (DO) for microorganisms in the bioreactor and generate strong turbulence for membrane cleaning (Meng et al., 2008), which was also provided on the top of the GAC layer in the BAC filter to saturate influent water with DO.

2.2. Operation conditions

The flux of the sMBR was set at 10 L/m^2 h, corresponding to the hydraulic retention time (HRT) of 0.5 h. As for BAC, the empty bed contact time (EBCT) was also set at 0.5 h. No sludge discharge was performed for the sMBR except for sampling and membrane cleaning, which resulted in a solids retention time (SRT) of more than 80 days. On the other hand, the BAC was backwashed once a week. The volume ratio of air and influent water was kept at 20:1 in the sMBR, while the ratio was approximate 5:1 for the BAC to saturate the raw water with DO. The suction pump was controlled by a timer based on a time sequence of 8 min on and 2 min off in each cycle.

A predetermined amount of PAC (1.5 g/L) was added into the bioreactor of the sMBR at the beginning of start-up to support bacterial growth (Guo et al., 2008); there was no further PAC addition during the following experiments. The experimental set-up had been in stable operation for several months before this investigation was conducted.

2.3. Polluted raw water

To simulate the polluted raw water, domestic wastewater was mixed into the local (Harbin, Chian) tap water with a ratio of 1:30. Meanwhile, 1 mg/L of humic acid (Jufeng, Shanghai, China) was also added to the simulated raw water. The NH_4^+—N concentration of the raw water was maintained at 3–4 mg/L by dosing NH_4Cl (Analytical grade). The simulated raw water was firstly stabilized for 2 days in the laboratory before feeding to the BAC and sMBR. During the experimental period, the raw water had an average temperature of 25.2 ± 2.5 °C (19.3–29.0 °C) and pH of 7.17 ± 0.16 (6.76–7.59).

2.4. Analytical methods

Water quality analyses were conducted following the standard methods. COD_{Mn} was analyzed by the potassium permanganate oxidation method. Ammonium and nitrite concentrations were determined by the colorimetric methods using a spectrometer (UV754, Cany, China); UV_{254} was also determined by using the spectrometer. TOC and DOC (pre-filtered through 0.45 μm membrane) were measured by a TOC analyzer (TOC-VCPH, Shimadzu, Japan). Turbidity was analyzed by a turbidimeter (TURBO550, WTW, Germany). DO was measured by the DO electrometer (pH/Oxi 340i, WTW, Germany) with a probe (Cellox® 325). Total coliform was enumerated by using the membrane filtration method, with M-Endo Broth (DIFCO) as the nutrient medium.