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Membrane coagulation bioreactor (MCBR) for drinking water treatment

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ABSTRACT

In this paper, a novel submerged ultrafiltration (UF) membrane coagulation bioreactor (MCBR) process was evaluated for drinking water treatment at a hydraulic retention time (HRT) as short as 0.5 h. The MCBR performed well not only in the elimination of particulates and microorganisms, but also in almost complete nitrification and phosphate removal. As compared to membrane bioreactor (MBR), MCBR achieved much higher removal efficiencies of organic matter in terms of total organic carbon (TOC), permanganate index (COD_{Mn}), dissolved organic carbon (DOC) and UV absorbance at 254 nm (UV_{254}), as well as corresponding trihalomethanes formation potential (THMFP) and haloacetic acids formation potential (HAAFP), due to polyaluminium chloride (PACl) coagulation in the bioreactor. However, the reduction of biodegradable dissolved organic carbon (BDOC) and assimilable organic carbon (AOC) by MCBR was only 8.2% and 10.1% higher than that by MBR, indicating that biodegradable organic matter (BOM) was mainly removed through biodegradation. On the other hand, the trans-membrane pressure (TMP) of MCBR developed much lower than that of MBR, which implies that coagulation in the bioreactor could mitigate membrane fouling. It was also identified that the removal of organic matter was accomplished through the combination of three unit effects: rejection by UF, biodegradation by microorganism and coagulation by PACl. During filtration operation, a fouling layer was formed on the membranes surface of both MCBR and MBR, which functioned as a second membrane for further separating organic matter.

1. Introduction

Natural organic matter (NOM), when measured as dissolved organic carbon (DOC), has levels in the range of 0.1–115 mg l^{-1}, with 5.75 mg l^{-1} reported as a global average for streams (Kabsch-Korbutowicz, 2006). The presence of NOM in source water adversely affects drinking water treatments and water quality of finished water (Humbert et al., 2007). Apart from aesthetic problems of color, taste and odor, NOM is well known to cause the potential hazard of disinfection by-products (DBP) such as trihalomethanes (THMs) and haloacetic acids (HAAs), the deterioration of water quality due to bacterial regrowth in distribution systems (Bolto et al., 2002; Karnik et al., 2005).

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Recently, the use of low-pressure membrane filtration technology in terms of microfiltration (MF) and ultrafiltration (UF) has drawn an increasing attention due to several reasons such as stricter regulations for finished water quality, smaller footprint, improved membrane materials and modules, relative simplicity of installation and improved reliability. Both MF and UF processes are considered as an alternative to the conventional clarification and filtration processes (Choi and Dempsey, 2004). MF and UF membranes are able to remove majority of suspended substances such as particles, colloids and microorganisms. Both of them, however, may be ineffective for eliminating color and DOC (Zhang et al., 2003), particularly for those low-molecular, biodegradable organic matter (BOM) in natural waters. Schäfer et al. (2001) addressed that the rejection of DOC was the function of membrane pore size. Karnik et al. (2005) achieved only 12.3–17.3% DOC removal using a UF membrane with a molecular weight cut-off of 15,000 Da. Likewise, Lee et al. (2005) carried out dead-end filtration tests using two different UF membranes with four different source waters, but they merely obtained the DOC removal efficiencies of essentially lower than 10%.

Taking into account of a substantial reduction of energy depletion, immersed low-pressure hollow fiber membrane processes have gained an unprecedented popularity not only in wastewater treatment but also in drinking water production (Huang et al., 2007; Wang et al., 2007). The combination of immersed membrane and activated sludge, namely submerged membrane bioreactor (MBR), which enables excellent solid/liquid separation and biodegradation of organic matter achieved in a single tank, has been studied not only for wastewater but also for drinking water treatment (Fan and Zhou, 2007; Li and Chu, 2003), and applied to municipal wastewater treatment at full scale by this time (Lyko et al., 2007). However, there are still unclear problems regarding the effectiveness of MBR for organic substances removal in drinking water treatment. Li and Chu (2003) found that nearly 60% of influent total organic carbon (TOC) was removed by MBR, accompanied by more than 75% reduction in trihalomethanes formation potential (THMFP). However, Sagbo et al. (2008) only achieved 25% of TOC removal in their experiment, with reduction of UV absorbance at 254 nm (UV_{254}) essentially at the same level. The reason for this phenomenon may be that the source waters used in their studies are quite different. Considering that NOM is biologically resistant in nature as a whole, and the hydraulic retention time (HRT) of MBR for drinking water treatment was substantially lower than that for wastewater, MBR process could not achieve satisfactory treatment efficiency.

Enhanced coagulation has been identified as the best available technology for the reduction of TOC and DBP precursors. The integration of immersed membranes and enhanced coagulation has been successfully applied to drinking water purification for NOM, color and DBP removal (Best et al., 2001). In this process, a single coagulation-separation tank replaces the coagulation, flocculation, sedimentation and filtration units of a conventional treatment plant, and a high solid concentration is maintained in this tank to promote the adsorption onto the settling flocs. However, the membrane coagulation process may not be good for the removal of ammonia and BOM, which directly related to the biostability of finished water and biofilm formation potential (BRP) in the distribution system. Whereas the biological process is believed to be effective for removing biodegradable dissolved organic carbon (BDOC) and reducing BRP (Okabe et al., 2002; Xu et al., 2007).

A few of investigations (Hwang et al., 2007; Wu et al., 2006) have been carried out with regard to the application of inorganic coagulants in MBR systems for wastewater treatment. According to them, adding metal coagulants to MBRs gave rise to the flocculation of activated sludge, the creation of a large floc size, and the increase in sludge cake porosity on membrane surface; meanwhile, dissolved organic pollutants were entrapped in the microbial flocs during the course of flocculation. However, these papers emphasized the effect of inorganic coagulants on membrane fouling reduction and the influence of which on treatment efficiency of MBRs was not dealt with.

Complete rejection of bacteria is one of the most prominent advantages of UF as compared to MF. To utilize the advantages of separation by UF membrane, biodegradation by microorganism and coagulation simultaneously, a novel submerged UF membrane coagulation bioreactor (MCBR) process is brought forward for treating a surface water supply slightly contaminated by domestic wastewater. The effectiveness of the MCBR is assessed for drinking water treatment, the mechanism of which for inorganic and organic pollutants removal is also discussed.

2. Materials and methods

2.1. Experimental set-up

Two identical mini-pilot-scale submerged MBRs were constructed and employed in this study. A schematic illustration of the experimental set-up is shown in Fig. 1. The UF membrane modules (Litree China) were made of polyvinyl chloride (PVC), with a nominal pore size of 0.01 μm and a total membrane area of 0.4 m^2. The bioreactor (effective volume of 2 l) was fed with raw water through a constant level tank and the effluent was drawn directly from the membrane module by using a suction pump. A manometer was set between the membrane module and the suction pump to monitor the trans-membrane pressure (TMP). Continuous aeration was provided at the bottom of the reactor to provide oxygen for activated sludge and generate strong turbulence for membrane cleaning.

2.2. Operation conditions

In order to reduce membrane fouling, the UF membrane flux was set at a relatively low value of 10 $l\,m^{-2}\,h^{-1}$, corresponding to a HRT of 0.5 h. The effluent suction pump was controlled by a timer based on a time sequence of 8 min on and 2 min off in each cycle. The ratio of air and influent in the reactor was kept at 20:1.

Before the study was conducted, the two parallel submerged MBRs had been in stable operation for more than 6 months with the operation parameters stated above. For