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Measuring the activity of heterotrophic microorganism in membrane bioreactor for drinking water treatment

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HIGHLIGHTS

- BRP & TTC–DHA tests were modified to measure biomass activity in drinking water MBR.
- The optimal parameters for TTC–DHA test were obtained.
- Both BRP and TTC–DHA tests were feasible for assessing biological performance in MBR.
- Correlation between the BRP and TTC–DHA was established.
- BRP test was feasible for assessing biological performance in MABR.

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ABSTRACT

In order to quantify the activity of heterotrophic microorganism in membrane bioreactor (MBR) for drinking water treatment, biomass respiration potential (BRP) test and 2,3,5-triphenyl tetrazolium chloride–dehydrogenase activity (TTC–DHA) test were introduced and modified. A sludge concentration ratio of 5:1, incubation time of 2 h, an incubation temperature that was close to the real operational temperature, and using a mixture of main AOC components as the substrate were adopted as the optimum parameters for determination of DHA in drinking water MBR. A remarkable consistency among BDOC removal, BRP and DHA for assessing biological performance in different MBRs was achieved. Moreover, a significant correlation between the BRP and DHA results of different MBRs was obtained. However, the TTC–DHA test was expected to be inaccurate for quantifying the biomass activity in membrane adsorption bioreactor (MABR), while the BRP test turned out to be still feasible in that case.

1. Introduction

In developing countries, some water sources have been seriously polluted by domestic and industrial wastewater, which often leads to a high level of organic matter and ammonia in water source (Li and Chu, 2003) and threatens the safety of the conventional drinking water treatment process. On the other hand, the water quality standard becomes increasingly stringent. For bridging the gap between the deteriorated water source and the stringent water quality standard, advanced water treatment technologies, especially the biological treatment processes, have been developed and widely employed in drinking water treatment.

Biological activated carbon (BAC) filtration, the most commonly used biological process, has been extensively employed in potable water production for the removal of organic matter and ammonia (Xu et al., 2007). However, due to the restriction of oxygen supply, BAC filtration seems to be limited for the removal of ammonia at high concentration (Tian et al., 2009a). Besides, the release of colonized carbon fines from filters could deliver bacteria to distribution systems (Morin and Camper, 1997), which would increase the microbial risk of treated water.

In order to effectively remove the high concentration of ammonia and avoid the leakage of microorganism into the treated water, MBR, which combines membrane rejection and microorganism

Abbreviations: MBR, membrane bioreactor; BRP, biomass respiration potential; TTC, 2,3,5-triphenyl tetrazolium chloride; DHA, dehydrogenase activity; MABR, membrane adsorption bioreactor; BAC, biological activated carbon; DOM, dissolved organic matter; PAC, powder activated carbon; AOC, assimilable organic matter; BOM, biodegradable organic matter; BDOC, biodegradable dissolved organic matter; SS, suspended solids; VSS, volatile suspended solids; ATP, adenosine triphosphate; OUR, oxygen uptake rate; DO, dissolved oxygen; TMP, trans-membrane pressure; HRT, hydraulic retention time; DOC, dissolved organic matter; BOD, biochemical oxygen demand; THOD, theoretical oxygen demand; TF, tripenyl formazan; MAOCC, mixture of main AOC components; SRT, sludge retention time.

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biodegradation in a single reactor, has been developed and investigated for drinking water treatment (Li and Chu, 2003; Ravindran et al., 2009; Sagbo et al., 2008). For MBR, excellent removal of ammonia has been achieved (Ma et al., 2012), but the removal of dissolved organic matter (DOM) was reported to be fairly low (Tian et al., 2009c). In order to improve the DOM removal in MBR, pre-ozonation and adsorption by powder activated carbon (PAC) have been involved. Pre-ozonation increases the biodegradability of DOM (Treguer et al., 2010), and thus its combination with MBR enable an excellent elimination of assimilable organic carbon (AOC) and total aldehydes (Williams and Pirbazari, 2007). Addition of PAC to the MBR can obtain a high removal of DOM (Dosoretz and Böddeker, 2004). But if the PAC is not duly added, the adsorbability of PAC would be rapidly exhausted and the DOM removal would be decreased (Williams and Pirbazari, 2007). Therefore, PAC needs to be continuously or intermittently added to the reactor for keeping a sustaining adsorbability in MBR, and the MBR operated in this way could be regarded as MABR (Guo et al., 2008; Tian et al., 2008b). MABR was a widely accepted upgrading form of MBR in drinking water treatment.

In MBR, the removal of DOM can be attributed to the biodegradation by microorganism, rejection by membrane, and adsorption by PAC (only in MABR). However, the biodegradable organic matter (BOM) is mainly removed by the heterotrophic microorganism through biodegradation. Therefore, like in the other bioprocess, biomass and biomass activity of heterotrophic microorganism are important parameters for MBR. In drinking water MBR, the removal of BOM (AOC and biodegradable dissolved organic carbon (BDOC)) is usually measured for assessing its biological performance. However, measurement of these indexes can only reflect the biological properties of the MBR indirectly, and one cannot obtain detailed information on the biomass and biomass activity of the MBR by these measurements. Whereas, up to the authors' knowledge, study on the direct measurement of biomass and biomass activity in drinking water MBR have not been reported.

In drinking water MBR, exogenous sludge or PAC is usually used as the carrier for microorganism. Therefore, suspended solids (SS) and volatile suspended solids (VSS), which are usually used for quantification of biomass in wastewater treatment process (Ali et al., 1985), are not suitable for quantification of biomass in drinking water MBR. Although some advanced methods have been developed for measuring biomass in water and wastewater bioprocess, such as phospholipid analysis (Seredynska-Sobecka et al., 2006) and adenosine tri-phosphate (ATP) analysis (Velten et al., 2007), the precise determination of biomass of heterotrophic microorganism in drinking water MBR is currently almost impossible because these methods cannot differentiate the biomass of heterotrophic microorganism from that of autotrophic microorganism. As a result, the certain biomass that directly associates with the BOM removal cannot be quantified, neither can the corresponding bioactivity (i.e. bioactivity represents as unit heterotrophic microorganism biomass). Similarly, bioactivity expressed in terms of unit sludge mass may be meaningless as well. However, due to the MBR is a complete-mixing reactor with constant volume of mixed liquor in it, it would be reasonable to represent the bioactivity as unit volume of mixed liquor, and the BOM removal by the MBR could be associated with the obtained biomass activity value.

Techniques for the measurement of biomass activity, including oxygen uptake rate (OUR) (Jørgensen et al., 1992), BRP test (Urfer and Huck, 2001), fluorescein diacetate hydrolysis (Seredynska-Sobecka et al., 2006), DHA test (Fonseca et al., 2001) and ATP analysis (Magic-Knezev and van der Kooij, 2004), have been widely employed in biological water and wastewater treatment processes. Among these methods, it has been proved that BRP has a high sensitivity allowing the quantification of activity of low amount of biomass (Urfer and Huck, 2001), and TTC–DHA test is a very sensitive and simple methodology for determination of bacterial activity as well (Lazarova and Manem, 1995). Therefore, in this study, the BRP and TTC–DHA tests were selected for the determination of biomass activity in drinking water MBR.

BRP test was developed by Urfer and Huck (2001) for measuring the biomass activity in drinking water biofilters. In their study, the BRP test was based on the consumption of dissolved oxygen (DO) resulting from the aerobic respiration of the microorganism for the BOM biodegradation. However, tap water added with BOM was adopted to serve as the substrate in their study, thereby the concentrations of carboxylic acids and aldehydes needed to be analyzed by ion chromatography and gas chromatography, respectively. These analyses were time consuming, and the advanced equipments involved might not be available in some laboratories. Therefore, the method for determination of BRP was modified in this study.

TTC–DHA test is a commonly used method for quantification of biomass activity of activated sludge. The procedure for measurement of TTC–DHA has been developed by Lenhard (1968), and test parameters have been optimized by Klapwijk et al. (1974). After that, an optimal procedure has been put forward by Zhou and Yin (1996) based on the previous studies. However, these studies are all based on the activated sludge of the wastewater bioprocess, where large amount of biomass can be available. In drinking water MBR, due to the oligotrophic characteristic of raw water, the biomass of heterotrophic microorganism is far below that in wastewater bioprocess. Besides, the components of organic matter in raw water are completely different from that in wastewater. Therefore, the procedure for measuring the TTC–DHA needs to be modified for its application in drinking water MBR.

This study focused on the modification of BRP and TTC–DHA tests for quantifying biomass activity of heterotrophic microorganism in drinking water MBR. Moreover, the feasibility of the modified methods for assessing the biological performance and the correlation between the BRP and DHA were investigated. Furthermore, the feasibility of the modified methods for assessing the biological performance in modified MBR (i.e. MABR) was discussed.

2. Methods

2.1. Experimental setup

A bench-scale submerged MBR was constructed and operated in this investigation. As shown in Fig. 1, the MBR (effective volume of 1 L) was fed with raw water through a constant level tank and permeate was extracted from the membrane module by a peristaltic pump. The peristaltic pump was also used for backwashing by altering the running direction. The UF membrane module (Litree, China), which was made of polyvinylchloride, had a nominal pore size of 0.01 μm and a total membrane area of 0.06 m^2. A manometer was set between the membrane module and the peristaltic pump to monitor the trans-membrane pressure (TMP). Constant air flow was pumped to the bottom of the reactor to provide oxygen for microorganism metabolism and generate strong turbulence for mitigating membrane fouling.

2.2. Simulated raw water

The raw water was prepared according to the method described by Tian et al. (2008a). Concretely, domestic sewage was added to the local (Harbin, China) tap water with a ratio of 1:30. Meanwhile, 1 mg/L of humic acid (Jufeng, China) was added to the raw water. The prepared raw water was stabilized for at least 24 h in laboratory. Then, 2 mg/L of NH_3-N and 30 mg/L of sodium bicarbonate (for adjusting the alkalinity) were added before it was filled