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Changes in characteristics of soluble microbial products and extracellular polymeric substances in membrane bioreactor coupled with worm reactor: Relation to membrane fouling

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HIGHLIGHTS

- ▶ A membrane bioreactor coupled with a new worm reactor was proposed.
- ▶ Effective membrane fouling mitigation in the MBR–SSBWR was obtained.
- ▶ The SMP generated by worm predation was degraded by the sludge in the MBR.
- ▶ The fouling mitigation resulted from content decrease and structural change of EPS.
- ▶ The EPS in MBR with predated sludge recycle had a lower fouling potential.

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ABSTRACT

The study focused on the membrane fouling mitigation observed in a membrane bioreactor (MBR) coupled with worm reactor system. During the operation time of 100 days, the transmembrane pressure (TMP) in the combined system was maintained less than 5 kPa, while the final TMP in the Control-MBR increased to 30 kPa. The changes in properties of soluble microbial products (SMP) and extracellular polymeric substances (EPS) after worm predation were investigated by means of various analytical techniques. It was found that due to the worm predation, the reduced amount of EPS was far more than the increased amount of SMP leading to a significant decrease of protein-like substances which were dominant in the membrane foulants. Except for the content decrease, worm predation destroyed the functional groups of simple aromatic proteins and tryptophan protein-like substances in EPS, making them have lower tendency attaching to the membrane in the combined system.

1. Introduction

Municipal waste water treatment is mainly performed by the activated sludge process in which up to 50% of the organic material in the waste water is converted into biological sludge (Hendrickx et al., 2010). With the strictly enforced environmental and legislative requirements on the discharge of excess sludge, sewage sludge treatment and disposal represents a rising challenge for wastewater treatment plants (WWTPs). This has provided considerable impetus to develop strategies for reducing excess sludge production in the biological wastewater treatment processes. Several mechanical, physical and chemical methods are available, such as thermal, ultrasonic, mechanical, alkaline, and oxidative technologies (Odegaard, 2004). Compared with other strategies, worm predation can provide an ecological way for excess sludge reduction in WWTPs (Rensink and Rulkens, 1997). The principle of this strategy is to extend the food chain in biological wastewater treatment which starts with the conversion of pollutants into bacterial biomass by introducing higher organisms that feed on the bacterial biomass. Initially, aquatic worms were inoculated into the aeration tanks, and the sludge yield in the activated sludge system with worms was 0.15 g mixed liquor suspended solids (MLSS)/g chemical oxygen demand removed ($COD_{removed}$) as compared to 0.4 g MLSS/g $COD_{removed}$ without worms (Rensink and Rulkens, 1997; Rensink et al., 1996). Despite many attempts had been carried out to control worms growth and maintain high densities of these worms within the sludge, free-swimming aquatic worms still seem uncontrollable and that their effects on treatment processes are unclear, which makes stable application in wastewater treatment

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for sludge reduction difficult (Elissen et al., 2006). Further research therefore focused on separate worm reactors where the aquatic worm was used to reduce biological excess sludge produced by WWTPs, and the sludge reduction percentages reached promising 45–60% over long operating times (53–102 days) (Guo et al., 2007; Wei and Liu, 2006). Recently, an increasing attention has been paid to the combination of worm reactor with wastewater treatment process to obtain better results on both wastewater treatment efficiency and excess sludge reduction. A complete-mixed activated sludge reactor combined with a worm reactor was adopted to determine the effects of the recycled non-consumed sludge on the performance of the activated sludge system (Hendrickx et al., 2009). It was found that the removal efficiency of the COD by the activated sludge system connected with the worm reactor (88%) was similar to that of the system without a worm reactor (87%), meanwhile, total suspended solids (TSS) reduction of 16–26% by the worms was achieved (22–30% volatile suspended solids (VSS) reduction).

In this study, a membrane combined system consisting of a membrane bioreactor (MBR) and a worm reactor was proposed, where the excess sludge produced in the MBR was fed to the worm reactor and majority of the predated sludge was returned to MBR system. Compared with other wastewater treatment processes, MBR combined with worm reactor appealed to us much for the following advantages: (1) the combination of MBR and worm reactor has the great potential for simultaneous wastewater treatment and sludge reduction. Generally, the excellent effluent quality with 98% total organic carbon (TOC) removal and 99% ammonia (NH_4^+-N) removal can be obtained in the MBR (Judd, 2008; Pan et al., 2010). Additionally, based on mechanisms of maintenance metabolism and predation on bacteria, the sludge production rate of the combined system, which is reduced by 28–68% in MBR (Xia et al., 2008), may be further reduced by 20–30% (Tian et al., 2010). (2) With the advantages of low sludge production, the footprint and volume of worm reactor for sludge predation can be minimized. Under the conditions described in Elissen et al. (2006), a worm reactor with $61 \times 10^3\ m^2$ surface area would be required to deal with a waste sludge production from a 100,000 population equivalent WWTP. In comparison, combined with the MBR system, the required footprint of the worm reactor may reduced by 28–68%. Despite the advantages mentioned above, the effect of predated sludge recycle on membrane fouling in the combined system was not clear. The high MLSS concentration in the MBR has negative effect on membrane fouling, which was supported by the observation that the MLSS concentrations increased from 14 to 18.2 g/L with a 10% permeability decline (Trussell et al., 2007). The combination of worm reactor with MBR can keep an optimal range of sludge concentration in the MBR reactor, and thus eliminate the potentially adverse effects of high MLSS on its membrane fouling. However, it should be also noted that worm predation induced the release of soluble microbial products (SMP) and the change of extracellular polymeric substance (EPS) properties. Wang et al. (2011) reported that during operation time of 40 days, the released rate of SMP was approximately 0.125 mg TOC/g VSS d in the MBR with aquatic worms. Tian et al. (2010) demonstrated that worm predation had influence on EPS properties, including EPS content and carbohydrates/proteins (C/P) ratios. It was well known that the SMP and EPS played important roles in the formation of biological foulants and cake layer on membrane surfaces (Flemming et al., 1997; Ramesh et al., 2007). Therefore, an insight into the impact of worm predation on SMP and EPS is helpful to understand the effects of the predated sludge recycle on membrane fouling in the MBR coupled with Static Sequencing Batch Worm Reactor (MBR–SSBWR) system. In this article, based on the transmembrane pressure (TMP) observation and resistance analysis, EPS and SMP were critically examined by the evaluation of Fourier transform infrared (FTIR) spectroscopy and three-dimensional excitation–emission matrix (EEM) fluorescence spectroscopy, and their relations to the evolution of membrane fouling were considered. The characteristics of the foulants extracted from the fouled membrane were then analyzed and compared with those of the EPS in the MBRs. Specific attention in these analyses was given to the polysaccharides and proteins, clarifying the relative importance of these constituents to the membrane fouling.

2. Methods

2.1. MBR–SSBWR system

Two bench scale MBRs, with and without SSBWR (S-MBR and C-MBR, respectively), were operated to study the influence of the variational characteristics of EPS and SMP due to worm predation on membrane fouling (Fig. 1). The two MBRs, each having a working volume of 40 L, were fed with synthetic wastewater (glucose 200 mg/L; starch 200 mg/L; $NaHCO_3$ 300 mg/L; $CO(NH_2)_2$ 32.1 mg/L; NH_4Cl 95.5 mg/L; KH_2PO_4 47 mg/L; $MgSO_4$ 40 mg/L; $CaCl_2$ 5 mg/L), and a water level sensor was used to keep a constant liquid level in each reactor. One membrane module was immersed in each MBR, which was made of hollow fibers of polyvinylidene fluoride (PVDF) with a surface area of 1 m^2 and a mean pore size of 0.2 μm (Motimo, China). An aeration system was placed at the bottom of each MBR to maintain desired dissolved oxygen (DO) concentration. The hydraulic retention times (HRT) and sludge

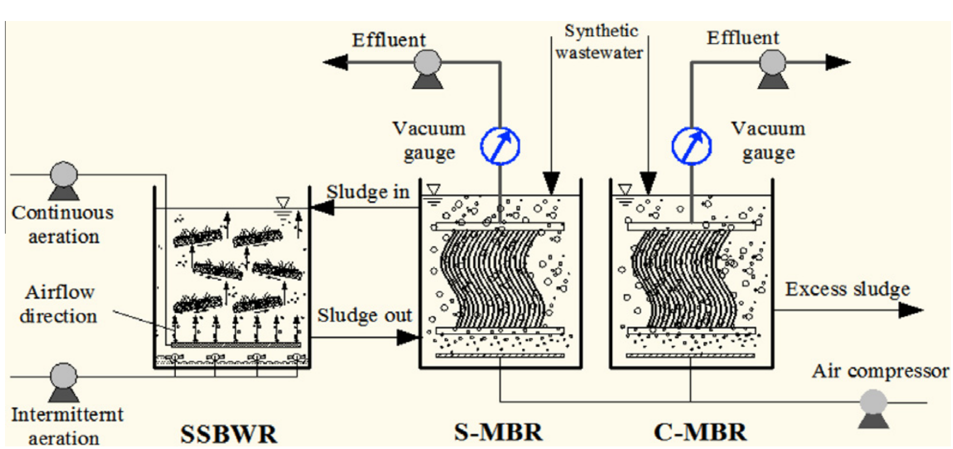

Fig. 1. A schematic representation of the Control-MBR and MBR–SSBWR.