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Indigenous somatic coliphage removal from a real municipal wastewater by a submerged membrane bioreactor

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ABSTRACT

The membrane bioreactor (MBR) features many advantages, such as its excellent effluent quality and compactness. Moreover, the MBR is well known for its disinfectant capacity. This paper investigates virus removal performance for municipal wastewater using a submerged MBR and the operational conditions affecting the virus removal using indigenous somatic coliphages (SC) as an indicator for viruses. The results revealed that the municipal wastewater acquired by the Qinghe Municipal Wastewater Treatment Plant, Beijing, contained an SC concentration of $(2.81 \pm 1.51) \times 10^4$ PFU ml^{-1}, which varies seasonally due to spontaneous decay. In the MBR system, the biomass process dominates SC removal. Membrane rejection is an essential supplement of biomass process for SC removal. In this paper, the relative contributions of biomass process and membrane rejection during the start-up and steady operational periods are discussed in detail. The major factors affecting SC removal are biodegradation, membrane pore size, and gel layer formation on the membrane. During long-term experiments, it was demonstrated that high inoculated sludge concentration, long hydraulic retention time, moderate fouling layer, and non-frequent chemical cleaning are favorable for high SC removal in MBR systems.

1. Introduction

Disposal and reclamation of inadequately treated municipal wastewater is one of the main sources of pathogens in the environment. Pathogen removal in municipal wastewater treatment and reclamation has received much attention due to its epidemiological significance and diverse range in human waste (Ottoson et al., 2006). As a promising and efficient technology, membrane bioreactors (MBRs) have been increasingly applied to municipal wastewater treatment and reclamation (Yang et al., 2006). MBRs give significant advantages over conventional activated sludge processes (CAS) by applying membrane separation instead of gravitational sedimentation. These advantages include a high quality effluent, and high concentration of mixed liquor suspended solid (MLSS) leading to small footprint. In addition to these features, micro-filtration mostly applied in MBRs is capable of complete retention of all bacteria, parasitic protozoa, and metazoa, which reduces the risks of pathogens in the effluent without producing harmful disinfectant by-products with respect to

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conventional chlorine added processes. Considerable research has demonstrated that the effluent of MBR carries a wide range of reclamation purposes for which coliforms are an indicator of pathogens (Arrojo et al., 2005; Ueda and Horan, 2000; Ottoson et al., 2006; Oota et al., 2005).

However, outbreaks of waterborne diseases associated with the enteric virus have recently raised public concern. The capacity to remove the enteric virus using MBR began to receive more attention because of its significant disinfectant ability. Due to the difficulty in examining viruses, bacteriophages have been suggested as viral indicators because they closely resemble enteric viruses in terms of their structure, morphology, size, and behavior (Melnick, 1984). Few studies have recently been conducted on employing bacteriophage as the indicator of viruses. Ottoson et al. (2006) found that MBR achieved a phage removal of 3.08 $\log_{10}$ with somatic coliphages (SC) as indicators in practice, which was higher than the phage removal of 2.32 $\log_{10}$ achieved by CAS. Zhang and Farahbakhsh (2007) used somatic and F-specific coliphages as indicators and obtained similar results with the phage removals of 5.8 $\log_{10}$ by MBR and 5.7 $\log_{10}$ by CAS with advanced tertiary treatment. Shang et al. (2005) reported that phage removal by MBR was subject to MLSS concentration, sludge retention time (SRT), and ratio of food to microorganisms (F/M). Zheng and Liu (2006) reported two additional parameters affecting phage removal: membrane pore size and permeate flux.

However, most of the recent investigations mentioned above were undertaken by seeding the synthesized wastewater with cultured coliphages at the phage concentrations of 10^7 PFU ml^{-1}, which was different from the general phage concentration in sewage of about 10^4 PFU ml^{-1} (Lucena et al., 2004). The deviation may lead to inaccurate results. In addition, the biological activity present in MBR and the resulting role of biomass could not be neglected during the study of virus removal by MBRs.

As a result, the aim of this study is to better understand MBR behavior in virus removal for real municipal sewage by applying an indigenous bacteriophage (SC), which has been proved to be an ideal tracer for the enteric virus (Anonymous, 2000). Firstly, the concentration of SC and its spontaneous decay in municipal wastewater in Beijing were investigated. The roles of biomass and membrane in SC removal were then explored, during which the effects of MBR operational conditions on SC removal were also studied.

2. Materials and methods

2.1. Somatic coliphage culture assay

SC concentrations were enumerated using the double agar layer method with *E. coli* (ATCC 15597) as their host cells. In order to examine the active host cells, they were first cultivated for 4–6 h at 37 °C in the medium and quickly mixed with an appropriate amount of soft agar and water sample. The mixture was gently poured onto the surface of the hard agar, which had already been aseptically concreted in Petri dishes. After incubation at 37 °C overnight, immobilized plaques developed in a semi-transparent circle (plaque forming unit or PFU), which could be counted to indicate the quantity of SC present in a given volume of the sample (Anonymous, 2000; Mooijman et al., 2001).

2.2. Somatic coliphage removal evaluation

SC removal efficiency could be expressed as $\log_{10}$ removal value (LRV). LRVB and LRVM were applied to represent the SC removal efficiencies using biomass and membrane respectively. They can be calculated by Eqs. (1) and (2) (Zheng and Liu, 2006):

$$\mathrm{LRVB} = \log_{10}\left(\frac{C_i}{C_s}\right) \quad (1)$$

$$\mathrm{LRVM} = \log_{10}\left(\frac{C_s}{C_e}\right) \quad (2)$$

where C_i, C_s and C_e represent the SC concentrations in the influent, supernatant, and effluent for an MBR system, respectively.

2.3. Experimental MBR systems

Fig. 1 shows a diagram of the bench-scale submerged MBR system. The bioreactor, with a size of 30 × 12 × 70 cm and an effective volume of 19 l, was divided into two parts by an internal baffle. A polyethylene hollow fiber membrane module (Mitsubishi Rayon Corporation, Japan), with a surface area of 0.2 m^2 and nominal pore size of 0.4 μm, was installed in one section. The bioreactor was filled with activated sludge, which was aerated with an airflow of 0.8 m^3 h^{-1} through a perforated pipe located beneath the membrane module to supply oxygen to microorganisms and prevent sludge particles from depositing on the membrane surface. The aeration also induced re-circulated flow and resulted in the formation of riser and down-comer zones in the bioreactor. The effluent was withdrawn at an intermittent mode (10 min on/2 min off) by a pump (Pulsafeeder Chem-Tech series 100) connected to the membrane module. A pressure gauge was placed on the

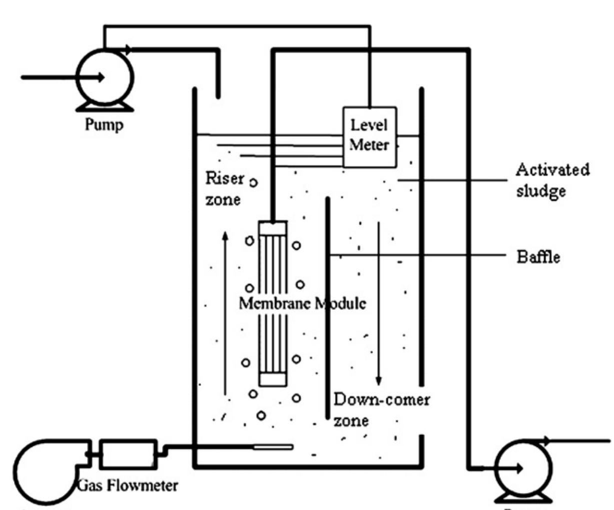

Fig. 1 – Diagram of the experimental MBR.