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Process Biochemistry 41 (2006) 299–304

PROCESS BIOCHEMISTRY

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Short communication

Virus removal performance and mechanism of a submerged membrane bioreactor

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Received 4 June 2005; received in revised form 5 June 2005; accepted 8 June 2005

Abstract

Responding to the worldwide outbreak of SARS in 2003, virus removal performance and mechanism of a SMBR were investigated by employing phage T4 as a model virus. Two membrane modules were compared in continuous operation for about 75 days. During stable operation, SMBR achieved almost complete phage removal for both membrane modules. For the 0.22 μm module, the cake layer, the gel layer and the membrane contributed 6.3 log, 3.1 log and 1.7 log, respectively to phage removal, confirming the importance of the cake/gel layer formed on the surface of membrane. The damage of the cake/gel layer resulted in the decrease of phage removal. As for the 0.1 μm one, the membrane alone played a major role in phage removal. Inactivation by activated sludge and adsorption by cake/gel layer contributed about 3.6 log to phage removal everyday so that there was no phage accumulation in bulk solution. The results demonstrated that SMBR was an efficient system and recommended for treatment of virus-bearing wastewater.

Keywords: Submerged membrane bioreactor (SMBR); Phage removal; Phage T4; Removal mechanism; Wastewater treatment

1. Introduction

Hospital wastewater often contains a wide variety of microbial pathogens and viruses. However, this wastewater has long been treated with the conventional wastewater treatment processes. Even in well-functioning biological plants, as many as 10^3 CFU ml^{-1} resistant coliform bacteria were found in its effluent [1–3], to say nothing of much smaller viruses.

As for other disinfection methods, such as chlorination, chlorine dioxide, ozone and UV radiation etc., the mutagenic/carcinogenic and toxic disinfection by-products, which are potentially harmful to humans and aquatic organisms, are often accompanied with the disinfection treatment [4]. Moreover, the presence of suspended solids and organic compounds in wastewater often lower disinfection efficiency drastically [5].

SMBR, which is characterized by its ability of complete suspended solids removal from effluent, low/zero sludge production, compact size and lower energy consumption, has gained more and more attention [6–9]. Some of above characteristics make SMBR have a potential ability to remove virus more effectively and safely. In last decades, several researches on viral removal by MBR had been carried out and gained some achievements, at the same time, present a few deficiencies. Chiemchaisri et al. [10] put forth that gel layer formed on the membrane surface could reject 4–6 log coliphage Qβ but did not gain the complete phage removal. Then Urase et al. [11] demonstrated that the cake/gel layer of membrane surface made a major contribution to reject virus in activated sludge by batch experiments. However, there was still 3–4 log of phages remained in effluent. Afterwards, Kawamura et al. [12] fulfilled the complete removal of phage Qβ and T1 by using ultramembrane unit but little phage removal mechanism was considered. Otaki et al. [13] also employed microfiltration and ultrafiltration process to the virus removal of the water supply. Recently, Wen et al. [8] investigated the performance of a SMBR for treatment of hospital wastewater but no considerations was given to rival removal. To date, however, more detailed and systematic

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doi:10.1016/j.procbio.2005.06.005

reports on viral removal efficiency and mechanism of SMBR are still scarce [14].

In this study, a SMBR for treatment of virus-bearing wastewater was investigated using phage T4 as a tracer focusing on: (1) the removal efficiency of well-running SBMR to virus that suddenly surged into wastewater; (2) the effects of pore size of membrane modules on viral removal performance; (3) the effects of cake/gel layer disintegration on rival removal efficiency; and (4) the mechanisms of viral removal by SMBR equipped with different membrane modules. Based on above experiments, the feasibility of SMBR to remove SARS coronavirus was evaluated.

2. Materials and methods

2.1. System description

A bench-scale SMBR with an effective volume of 12 l was applied to treat municipal wastewater (Fig. 1). Two different membrane modules (pore size of 0.22 μm and 0.1 μm) were mounted in each membrane compartment. The membrane flux was driven by the difference of water head between the liquid level in the bioreactor and the effluent pipe (8.5 kPa). Prior to the injection of phage T4 into wastewater, the SMBR had been continuously operated for 34 days to make it work well. Then, T4 was fed to wastewater and the removal efficiency of well-running SBMR to virus was estimated. The operation parameters of SMBR were as below: temperature 14.5 °C, pH 6.4, DO 7.4 mg l^{-1}, MLSS 4.5 g l^{-1}, COD load 1.05 kgCOD/m^3 d and HRT 10.8 h.

2.2. Preparation for phage T4

Phage T4 was selected as a model virus in this study because: (1) its size is similar to that of the SARS coronavirus [15]; (2) it is harmless to humans; (3) it can be seeded with a high concentration in tracer experiments; and (4) the assay method is relatively easy and simple [16]. T4 stock solution (10^{10} PFU ml^{-1}) was prepared in advance and it was added to wastewater to make the phage concentration in a range from 10^5 to 10^8 PFU ml^{-1}.

T4 in wastewater was viewed under Atomic Force Microscope (NanoScope IIIa Multimode Scanning Probe Microscopy Instruments, Digital Instruments, Santa Barbara, CA, USA).

The surfaces of a new membrane and a long-time used one were viewed under Scanning Electron microscope (FEI QUANTA 200).

2.3. Sample collection and analysis

The COD, NH_4^+–N, and suspended solids (SS) of effluent from 0.22 μm membrane were determined by methods described by the literature [17]. For phage assay, samples were taken from the influent tank and outlet of each module at the same time everyday. Phage concentration was assayed according to the double-layer-agar method described by Adams [18] with *E. coli* B as host bacteria. In order to estimate the role activated sludge played on viral removal, the phage concentration of bulk solution was sampled and assayed also.

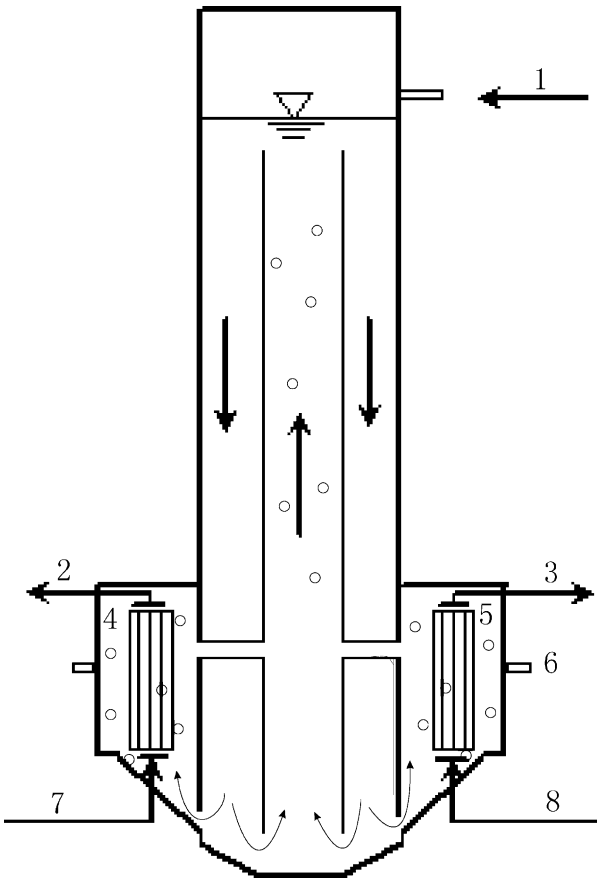

Fig. 1. Schematic diagram of the SMBR. (1) Influent; (2 and 3) effluent of 0.22 μm and 0.1 μm; (4) membrane module no. 1 (0.22 μm, hollow fiber membrane, PVDF, membrane area 0.18 m^2); (5) membrane module no. 2 (0.1 μm, hollow fiber membrane, PP, membrane area 0.18 m^2); (6) sampling outlet of bulk solution; (7 and 8) compressed air inlet.

2.4. Data presentation

$r_{overall}$, r_c, r_g, r_m were employed to represent the virus removal efficiency by overall membrane, cake layer, gel layer and membrane alone, respectively. The equations were as follows:

$$r_{overall} = \log\left(\frac{C_{in}}{C_{out}}\right) \quad (1)$$

$$r_c = \log\left(\frac{C_b}{C_{out}}\right) \quad (2)$$

$$r_g = \log\left(\frac{C'_{in}}{C'_{out}}\right) \quad (3)$$

$$r_m = \log\left(\frac{C''_{in}}{C''_{out}}\right) \quad (4)$$