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Enhanced membrane biofouling potential by on-line chemical cleaning in membrane bioreactor

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ABSTRACT

In MBR operation, on-line chemical cleaning is often conducted for maintaining a constant permeability. For this purpose, sodium hypochlorite (NaClO) has been widely used as a membrane cleaning agent. However, microorganisms are inevitably exposed to cleaning agents in the course of on-line chemical cleaning. So far, little information is available on the potential effects of NaClO on microorganisms especially from the perspective of biofouling re-development after membrane cleaning. In this study, activated sludge was exposed to NaClO with different concentrations, and treated sludge was used for study of subsequent fouling propensity in a crossflow microfiltration system. Results showed that NaClO could trigger bacterial lysis leading to a reduced sludge surface hydrophobicity and release of EPS and AI-2. Compared to the control, the membrane fouling rate of sludge exposed to NaClO was significantly increased especially at high NaClO concentration levels. Despite a decline in cell viability observed after NaClO exposure, live cells in suspension showed a greater tendency to attach onto membrane surfaces, leading to a faster fouling development. This may be due to the fact that under oxidizing stress imposed by NaClO, suspended bacteria tend to move onto membrane surface in order to mitigate the damage potential. Consequently, this study raised a serious concern on on-line chemical cleaning-induced membrane biofouling.

1. Introduction

Membrane bioreactor (MBR) by a combination of biological degradation and membrane filtration has gained increasing popularity in wastewater reclamation and reuse worldwide. Compared to the conventional activated sludge process, MBR has the advantages of smaller footprint, excellent effluent quality and less sludge production [1]. However, the inherent membrane biofouling is the biggest challenge encountered in the operation of MBR, resulting in a significant flux decline and increased operation cost [2,3]. Although several operation strategies including relaxation, backwashing, enzyme cleaning, etc. have been developed to mitigate or prevent membrane biofouling, chemical cleaning by sodium hypochlorite (NaClO) is still a major effective method for removing both reversible and irreversible membrane fouling in MBR process [4–6]. During the on-line chemical cleaning, cleaning agent, e.g. NaClO, is injected into membrane from the permeate side, while membrane modules are still soaking in bioreactor [7]. Compared to off-line cleaning, on-line cleaning is generally preferable due to its simplicity, low cost and effectiveness. Wei et al. [6] found that on-line chemical cleaning with a combination of NaClO, NaOH and HCl could achieve nearly 100% permeability recovery rate during first several runs in a pilot-scale MBR. Kweon et al. [8] also suggested water flux recovery could reach to approximately 100% during the first two cleaning in-place (CIP) runs when low turbidity feed water was used.

The principle of on-line chemical cleaning with NaClO is illustrated in Fig. 1. When NaClO solution is fed into membrane, it firstly passes through membrane pores and reacts with the foulants on membrane surface. The residual effective NaClO ends up in bioreactor and tends to oxidize soluble organic matters and microorganisms presented in MBR. After cleaning finished, membrane filtration restarts accompanied by fouling development again. This suggests that membrane and microorganisms in MBR are both exposed to cleaning chemical (e.g. NaClO) in the course of on-line chemical cleaning. In fact, it has been well known that NaClO may impair the surface integrity of various types of polymeric membranes. For example, Puspitasari et al. [9] conducted a

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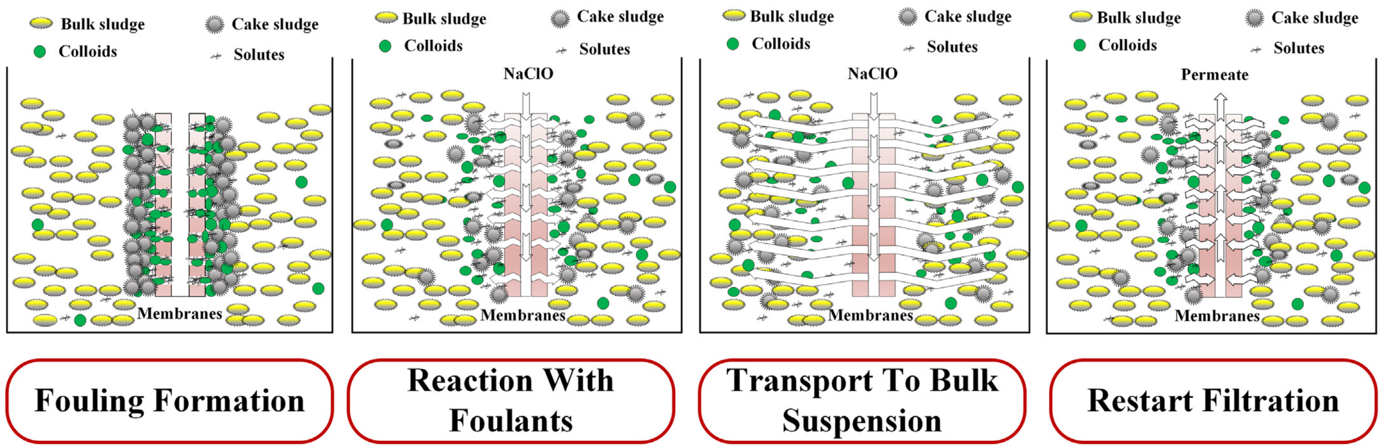

Fig. 1. Schematic illustration of on-line chemical cleaning.

series of continuous membrane cleaning studies and revealed that the surface modification substance on polyvinylidene fluoride (PVDF) membrane could be removed by NaClO, followed by membrane hydrophobicity increase and hydraulic resistance decline. Abdullah and Berube [10] also showed exposure to NaClO could increase the porosity and nominal pore size of commercial membrane, while significantly reduced its yield strength and intrinsic resistance. Comparatively, the effects of NaClO on microbial properties were less reported. Lee et al. [4] found the organic removal and nitrification performance in MBR were negatively affected by NaClO exposure, and serious foaming happened when 55 mg NaClO/g MLSS was applied in chemical enhanced backwashing (CEB). Moreover, the reduced microbial activity, degradation inhibition and cell lysis were also reported to occur during on-line chemical cleaning with various NaClO concentrations [11,12].

According to Fig. 1, it is known that the bulk suspension in MBR is exposed to the residual NaClO during on-line chemical cleaning of membrane, and several studies described above suggested this exposure could affect microbial properties. However, little information has been currently available about possible responses of microorganisms to NaClO especially from the perspective of membrane biofouling redevelopment after cleaning since activated sludge exposed to chemical agent can partially revert back onto membrane surface as foulants when membrane filtration restarts. Therefore, this study aims to investigate the impacts of on-line chemical cleaning with NaClO on microbial oxidation and subsequent biofouling behaviors. The results presented may offer different insights into the current practice of on-line chemical cleaning of membranes in MBR.

2. Materials and methods

2.1. Sludge treatment assay

Activated sludge collected from a local wastewater treatment plant was acclimatized with a synthetic substrate mainly consisted of 690 mg/L of sodium acetate, 313 mg/L glucose, 200 mg/L NH_4Cl, 60 mg/L K_2HPO_4 and other trace minerals for one month. The acclimated activated sludge was washed thrice with 10 mM phosphate buffered saline (PBS) solution before use. Different amounts of NaClO (Sigma-Aldrich) were added to a series of 1 L bioreactors with initial biomass concentration of 1000 mg/L for having the respective NaClO concentration of 0 mg/L, 2 mg/L, 5 mg/L, 10 mg/L, 20 mg/L. Dissolved oxygen concentration in the bioreactors were kept at quasi-saturation level through air aeration. The contact between activated sludge and NaClO in each bioreactor was controlled at 30 min, after which sludge samples were collected for further analysis.

2.2. Cross-flow microfiltration test

A standard crossflow microfiltration module was employed to evaluate the fouling potentials of activated sludge after exposed to NaClO with various concentrations. Flat-sheet hydrophilic PVDF membrane (GVWP2932A, Merck Millipore, Singapore) with nominal pore size of 0.22 μm and effective surface area of 42 cm^2 were embedded in the crossflow cell (CF042 Membrane Cell, Sterlitech). TMP changes during membrane filtration were monitored by two pressure sensors installed on both inlet and outlet of the filtration module, and readings were recorded with Labview software at the time intervals of 10 s (Fig. 2). A constant permeate flux of 30 L/(m^2 h) was maintained through automatic adjustment of peristaltic pump (Cole-Parmer, USA), which was also confirmed by measured permeate volume using a digital balance (Mettler Toledo, Switzerland). The circulation flowrate in the feed chamber was controlled at 0.2 L/min by a flowmeter (WF Waterflo). After exposed to NaClO with various concentrations for 30 min, activated sludge was harvested by centrifugation at 3000 rpm and resuspended in PBS solution at a MLSS concentration of 1000 mg/L for subsequent membrane filtration experiments.

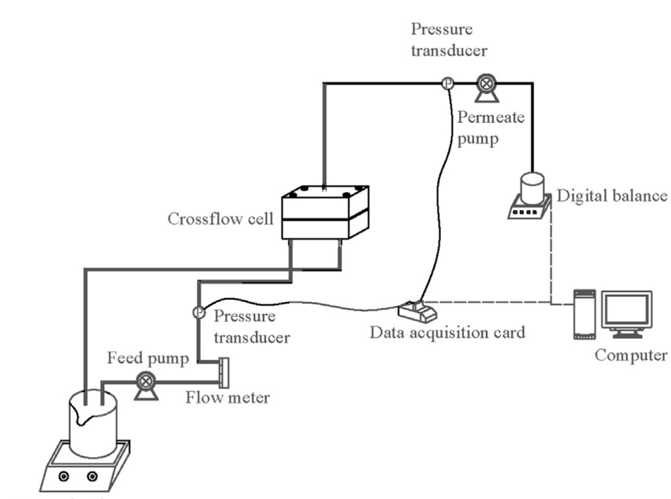

Fig. 2. The crossflow membrane filtration system.