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Evaluation of bubble flow properties between flat sheet membranes in membrane bioreactor

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ABSTRACT

To optimize membrane bioreactor (MBR) equipment specifications and operating conditions in order to reduce the aeration rate, we investigated effects of the flat sheet membrane clearance and the bubble diameter on the shear stress on the membrane surface. The results were obtained using an apparatus consisting of a visible-channel, simulated-flat sheet MBR, in which the membrane clearance and bubble diameter could be varied. The shear stress on the simulated membrane surface was measured directly. We found that large bubbles with two-dimensional amorphous shapes between the membranes could make the shear stress large in comparison to the case of bubbles smaller than the membrane clearance. Moreover, we determined how to get the local maximum shear stress in the case of large bubbles. We developed a dimensionless index, consisting essentially of the membrane clearance and the bubble diameter that can be applied to describe the condition for maximizing the shear stress. Because the parameters of this index are easily obtainable, it is of significant benefit for effectively designing the operating conditions and equipment specifications of MBRs to promote scouring.

1. Introduction

The membrane bioreactor (MBR) provides promising technology for wastewater treatment and water reclamation. The activated sludge is separated by a microfiltration or ultrafiltration membrane whose pores are smaller than the particle size of the activated sludge. Therefore, no activated sludge flows out, and the treated water quality is improved. Moreover, the MBR can be operated with a high concentration of mixed liquor suspended solid (MLSS), 4–10 times thicker than the conventional concentration, and there are advantages of reduced processing time and downsized facilities. However, membrane fouling has been a key problem preventing the wide spread application of the MBR [1,2].

Membrane fouling can be prevented by hydraulic effects. In external-module MBRs, whose membranes are located external to the bioreactors, a crossflow fluid provided by a recirculation pump reduces the membrane fouling. More recently, submerged MBRs have been developed. Their membranes are submerged in aeration tanks, and aeration bubbles not only supply oxygen to the activated sludge, but also scour the membrane surfaces. These bubble flows can suppress the membrane fouling effectively [3–5].

The use of gas bubbling to suppress membrane fouling has been studied. However, the fundamental nature of a flat sheet membrane module has not been investigated sufficiently in contrast to the large amount of fundamental research on a tubular membrane module [6,7]. To suppress fouling of the flat sheet membrane, Ozaki and Yamamoto [8] investigated the dependency of the sludge accumulation on the variation of hydraulic conditions resulting from the change of the crossflow velocity and clearance between flat membrane sheets. They showed that the scouring effect by bubbles depends on aeration intensity which was defined as air flow rate per cross-sectional area between flat membrane sheets, and can be explained by estimated shear stress. The shear stress on flat membrane sheets with fixed clearance was measured directly by Ducom et al. [9] using an electrochemical method, and by Nagaoka et al. [10] using a shear stress meter which can detect shear strain with a piezoelectric sensor. Both of these studies showed that the shear stress increased with the increase of aeration intensity.

In addition to aeration intensity, bubble size is also an important factor for MBRs. Fine bubbles have a large oxygen transfer efficiency due to their large surface area. Meanwhile, coarse bubbles are recognized empirically for their ability to scour the membrane effectively. Zhang et al. [11] showed that the shear stress on the flat membrane with fixed clearance of 20 mm increased with bubble size up to a value of 60 mL but was insensitive to size beyond that.

The shear stress is related to bubble flow, which is associated with not only bubble size, but also membrane clearance and the aeration intensity. However, little is known about the optimum bubble size, optimum membrane clearance, and optimum relationship among the bubble size, the aeration intensity, and the shear

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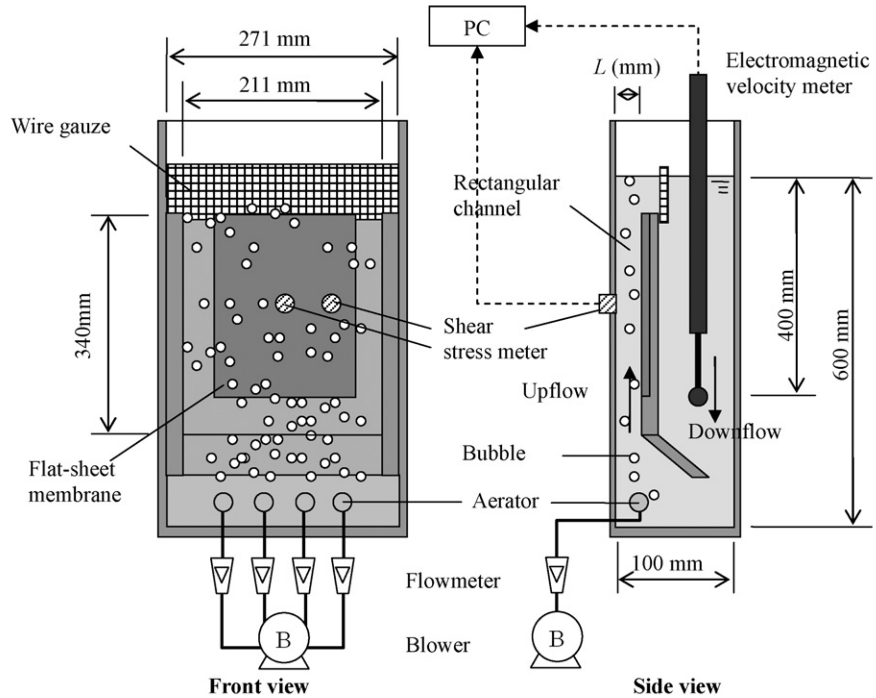

Fig. 1. Experimental apparatus.

stress on the membrane surface. In this study, we especially focused on the effects of the flat sheet membrane clearance and the bubble diameter, which are included among the MBR equipment specifications and operating conditions. To investigate optimization of the equipment specifications and operating conditions in order to reduce the aeration rate, we conducted an experiment with an apparatus having a visible-channel to simulate a flat sheet MBR. This apparatus could be aerated homogeneously on the membrane. Furthermore, we varied the membrane clearance and the bubble diameter and directly measured the shear stress on the simulated membrane surface.

2. Materials and methods

Activated sludge is mixed liquor. Viscosity of its filtrate is constant and nearly equal to that of water, but the viscosity of the mixed liquor, in general, increases with decrease of shear rate [5,12]. The hydraulic behavior of activated sludge mixed liquor and tap water are different; however, Ozaki and Yamamoto [8] showed that measurement results of hydraulic conditions during bubble-driven crossflow in tap water could be applied to summarize experimental results in activated sludge. This finding suggests that properties of bubble flow in activated sludge are qualitatively similar to those in tap water. In fact, similar bubble behaviors were observed between the flat sheet membranes in an experimental apparatus as described below. Small bubbles with spherical or hemispherical shapes flowed homogeneously. Large bubbles had two-dimensional amorphous shapes and larger bubbles were broken up. One objective of our study was to identify the optimum relationship among the bubble size, the aeration intensity, and the shear stress on the membrane surface. In tap water or activated sludge, bubbles can be observed. However, their diameters can be measured more accurately in tap water. Moreover, in activated sludge, shear stress values sometimes drifted improperly because activated sludge would flow into a small clearance of a shear stress meter as mentioned below. Therefore, we used tap water for the present study.

A visible single channel was used in an experiment to determine the bubble flow properties between the flat sheet membranes in an MBR. Fig. 1 shows the experimental apparatus. A 271 mm × 100 mm × 700 mm transparent vinyl chloride tank was filled with tap water (283 K) to a depth of 600 mm. Air was blown homogeneously through flowmeters from four aerators (i.e., nozzles or glass ball filters) in order to equalize the scouring effects on the membrane surface. The blown air became bubbles and flowed with the tap water into a rectangular channel, which had a width of 221 mm and a clearance of *L* (mm), where *L* was the membrane clearance between the flat sheet membranes. A flat sheet membrane (TC03A02, Yuasa Membrane Systems Co., Ltd.) was installed on one side of the channel, and its surface was kept flat by a suction pump. The tap water flowed upward through the rectangular channel then flowed downward through a downward channel (outside the rectangular channel), and circulation was established.

The experimental parameters were the air flow rate *Q* (L/min), the membrane clearance *L* (mm), and the aerator, as listed in Table 1. The aerator was a nozzle or a glass ball filter (501G1, Kinoshita-Rika Inc.). The nozzle diameter was 6 mm, while the diameters of the glass beads in the glass ball filter were 100–120 μm.

The shear stress due to the bubble flow on the flat sheet membrane was measured with a shear stress meter (S10W-02, SSK Inc.). This has the small clearance around the measured surface on a piezoelectric element, and can detect shear distortion caused by shear force on the measured surface. The shear stress meter was attached to the front surface of the tank opposite the membrane surface. The surface of the meter and the membrane was regarded as having the same properties with respect to the measured quan-

Table 1
Experimental parameters.

Air flow rate *Q* (L/min)	Membrane clearance *L* (mm)	Aerator
1.2, 2.4, 4.8, 9.6	5, 7, 10	Nozzle (Ø6 mm) or glass ball filter