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Fouling control of submerged hollow fibre membrane bioreactor with transverse vibration

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ABSTRACT

The present study further examines the effectiveness of transverse vibration for the fouling control of hollow fibre membranes in a submerged membrane bioreactor (SMBR) with real mixed liquor. The scope of the investigation included both short and long duration tests. The short duration tests incorporated both continuous and intermittent vibration in different concentrations of mixed liquor, and compared among longitudinal vibration, transverse vibration and combined transverse vibration and low aeration. The results indicated that continuous transverse vibration with low frequencies was very effective towards the fouling control, and was more so than longitudinal vibration. Intermittent vibration was somewhat less favourable, but it provided significant energy savings. With intermittent vibration, a short non-vibration time interval of less than 120 s was also found to be necessary to prevent irreversible fouling during this time interval when the permeated extraction continued. For the first time we found that transverse vibration can be more effective for fouling control when combined with low aeration due to the turbulence enhancement by the moving bubbles. The long duration tests confirmed that transverse vibration could be effectively used in the SMBR to control the membrane fouling and prolong the membrane filtration period without chemical cleaning, with high removal efficiencies of both organics and nutrients in the reactor. Higher frequencies of transverse vibration produced larger shear stresses on the membrane surface and enhanced the membrane filtration performance, at the same time the risk of fibre breakage also heightened with the increase in periodic stress cycles on the hollow fibres. The characteristics of the biosolids in the reactor were monitored during the long duration tests. The results showed that both soluble microbial products (SMP) and extracellular polymeric substances (EPS) affected the membrane filtration performance under transverse vibration, but SMP was found to be key membrane fouling contributor. Overall, the study demonstrated that transverse membrane vibration is practical and beneficial for fouling control in the SMBR.

1. Introduction

A submerged membrane bioreactor (SMBR) combines the conventional bioreactor and a submerged membrane filtration unit together as a treatment facility. It represents an advanced technology for wastewater treatment that can save operating space and also reduce the energy consumption of the process. The bioreactor can completely retain the bacteria and biomass [2,3] and, together with the membrane module separation, also produce a superior quality effluent. The submerged membrane filtration unit typically utilizes either ultra- or micro-filtration (UF/MF) membranes with a pore size of less than 0.2 μm.

With the above advantages, the SMBR has been widely adopted and studied over the past two decades. However, the main challenge in SMBR applications continues to be membrane fouling which can cause a significant reduction in membrane permeability as well as more frequent membrane cleaning and replacement, thus increasing the operational costs. Several approaches have been adopted to reduce membrane fouling in SMBRs, including: (i) pretreatment of the feed water; (ii) improvement of the membrane properties; and (iii) optimization of the hydrodynamic conditions by air sparging [4,5].

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Recently, the use of membrane vibration in SMBRs has been proposed as an alternative for fouling control of the membranes. Genkin et al. investigated the vibration of longitudinal membranes with transverse vanes and coagulant addition to improve the filtration performance of submerged hollow fibre membranes [6]. They observed that by using a longitudinal membrane vibration frequency of 1.7 Hz, the critical flux increased from 17 to 46 L/(m^2 h) with the coagulant addition of 34 mg/L aluminium chlorhydrate. With the additional transverse vibration of the vanes next to the membranes, a five-fold enhancement in critical flux to 86 L/(m^2 h) was also achieved. They attributed the effect of coagulation to the aggregation of fine particles and evacuation of aggregates away from the membrane surface due to inertial and gravitational forces, and the effect of vanes due to the intensified turbulence. Kola et al. found that the transverse vibration of submerged hollow fibre membranes induced less membrane fouling in treating secondary effluent from an anaerobic bioreactor (AnMBR) in comparison to gas sparging and crossflow [7]. They attributed the effectiveness to the fact that the vibrations produced enhanced shear stresses near the membrane surface that reduced the foulant deposition from the bulk feed. Mezohegyi et al. compared the usage of aerated and vibrated membrane filtration systems for the concentration of sewage from a municipal wastewater plant [8]. They concluded that the vibrated membrane filtration had a clear advantage over the aerated system in terms of both fouling control and energy consumption. In contrast, De Vrieze et al. found that membrane vibration in an AnMBR led to a sharp increase in trans-membrane pressure (TMP) and cake layer formation, and thus concluded that vibration alone without mixing was not as effective as the biogas recirculation in their anaerobic system [9]. However, our previous study confirmed that the use of transverse vibration with model feeds of Bentonite and yeast suspensions could effectively reduce membrane cake fouling and lead to an order of magnitude improvement in the fouling reduction [10]. We found that in addition to the generation of high shear stresses introduced by vibrating fibres, transverse vibration can also induce circulation in the reactor, which could further reduce membrane fouling. It should be noted that all of the above studies were conducted in short duration tests (generally less than one day). There is thus still a need to investigate over longer durations comparable to typical commercial SMBR operations.

The present study further examined the fouling control of SMBR by transverse vibration for wastewater treatment. The study included both short and long duration tests in laboratory reactors with real mixed liquor. The short duration tests were intended to examine the effects of intermittent vibration and feed concentrations under the action of vibrating hollow fibre membranes. The test duration was typically less than one day so that more combinations could be examined within a reasonable time frame. A comparison study between longitudinal vibration, transverse vibration, and combined transverse vibration and low aeration in mixed liquor was conducted with the short duration tests. Subsequently, experiments with long operating duration were performed to investigate the effectiveness of the vibration approach with a time scale of weeks which is more typical of commercial SMBR operations. The long duration tests included examining the impact of microbial parameters on the membrane filtration performance under vibrations. In particular, the influence of mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS), as well as SMP and EPS [11–13] in the reactor was closely monitored under transverse vibrations. In the following, the experimental setup and procedures are first described. The results will then be presented.

2. Materials and methods

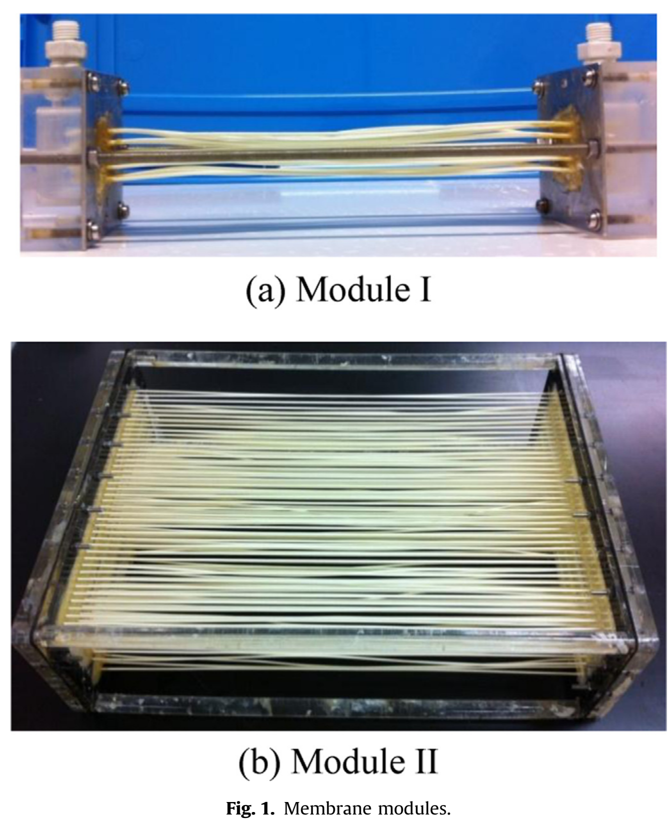
2.1. Hollow fibre membrane module

Polyacrylonitrile (PAN) hollow fibres made by Ultrapure Pte. Ltd. in Singapore were used in the present study. The nominal pore size of the membranes was 0.1 μm. Two different fibre sizes were used: inner/outer diameters of 1/1.7 mm and 1/2 mm. The performance of these two types of hollow fibres under longitudinal vibration has been reported in our earlier study [14].

Two types of membrane modules (Modules I and II) were used in the experiments: Module I for the short duration tests, and Module II for both the short and long duration tests. Fig. 1 shows the pictures of the two modules. Module I had a 5 × 5 membrane fibre bundle with a length of 18 cm and a fibre spacing of 5 mm. Module II can hold up to 200 fibres (arranged in 5 rows with 40 fibres each). The row spacing was 20 mm, and the fibre spacing within a row was 6.5 mm. The 1/1.7 mm and 1/2 mm fibres were utilized in Modules I and II, respectively. For both modules, the fibres were mounted with 1% looseness as we had found previously that a small fibre looseness could significantly improve the membrane filtration performance during vibrations [10,14].

2.2. Feed

In this study, the feeds included both real mixed liquor and synthetic wastewater. The real mixed liquor was collected from the Ulu Pandan Water Reclamation Plant (UPWRP) in Singapore. Two types of mixed liquor were obtained. The first type was collected from the aeration tank of the UPWRP, with MLSS concentrations of 4 ± 1 g/L, and average particle (floc) size of 52.5 μm. The second type was from the membrane tank of the UPWRP, with MLSS concentrations of 8 ± 1 g/L, and average particle size of 67.6 μm. Both represented typical mixed liquor produced in the water reclamation plants across Singapore. For the synthetic



(a) Module I

(b) Module II

Fig. 1. Membrane modules.