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A submerged membrane bioreactor with pendulum type oscillation (PTO) for oily wastewater treatment: Membrane permeability and fouling control

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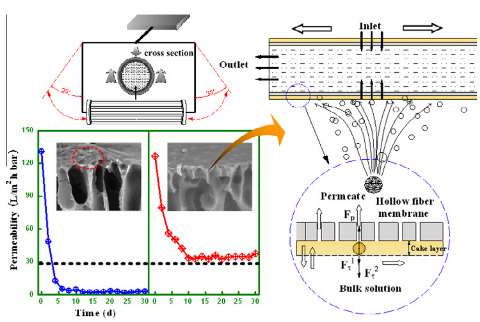
HIGHLIGHTS

- A novel submerged MBR system with pendulum model oscillation modules was set up.
- Enhanced shear stress had significant effect on characteristics of sludge flocs.
- Dynamic membrane filtration was sensitive to the oscillation orientation and frequency.
- The optimized PMO system exhibited 11 times higher permeability than control system.
- PMO modules offered better fouling control ability than conventional module.

GRAPHICAL ABSTRACT



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ABSTRACT

In this study, a novel submerged membrane bioreactor (SMBR) with pendulum type oscillation (PTO) hollow fiber membrane modules was developed to treat oily wastewater and control the problem of membrane fouling. To assess the potential of PTO membrane modules, the effect of oscillation orientation and frequency on membrane permeability was investigated in detail. The forces exerted on sludge flocs in the oscillating SMBR were analyzed to evaluate the impact of membrane oscillating on the cake layer resistance reduction. Results showed that the optimized PTO SMBR system exhibited 11 times higher membrane permeability and better fouling controllability than the conventional MBR system. By hydrodynamic analysis, it was found that the cooperative effect of bubble-induced turbulence and membrane oscillation in PTO SMBR system generated strong shear stress at liquid-membrane interface

Abbreviations: bEPS, bound extracellular polymeric substance (mg-TOC/g-MLVSS); COD, chemical oxygen demand (mg/L); d, equivalent diameter (m); DO, dissolved oxygen (mg/L); du/dy and du/dx, velocity gradient; FOG, fat, oil and grease; F_τ^1 and F_τ^2, pull force (N); F_p, permeation drag force (N); F_s, net force (N); HRT, hydraulic retention time (h); J_p, permeate flux (L/m^2 h); L_p, permeability (L/m^2 h kPa); MF, microfiltration; MLSS, mixed liquor suspended solids (mg/L); MLSS$_i$ and MLSS$_e$, concentration of MLSS in the aqueous phase before and after extraction (mg/L); MLVSS, mixed liquor volatile suspended solids (mg/L); n, flow behavior index; NH_3–N, Ammonia–nitrogen (mg/L); PTO, pendulum type oscillation; PVDF, polyvinylidene fluoride; r, revolutions; R_c, cake resistance (m$^-$); Re, reynolds number; R_f, membrane fouling resistance (m^{-1}); RH, relative hydrophobicity (%); R_{if}, inorganic fouling resistance (m^{-1}); R_m, initial clean membrane resistance (m^{-1}); R_{of}, organic fouling resistance (m^{-1}); R_t, total membrane filtration resistance (m^{-1}); SEM, scanning electron microscope; sEPS, soluble extracellular polymeric substance (mg/L); SMBR, submerged membrane bioreactor; SRT, solid retention time (day); SVI, sludge volume index (mL/g); TMP, transmembrane pressure (kPa); TOC, total organic carbon (mg/L); v, cross flow velocity (m/s); VHFM, vibrating hollow fiber module; Δp_{TM}, transmembrane pressure (bar); η, plastic viscosity (Pa·s); ρ, solution density (kg/m^3); τ_y and τ_x, yield stress (Pa); τ^1 and τ^2, shear stress (Pa).

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Fouling control
Oily wastewater

in vertical and horizontal direction and effectively hindered the particles from depositing on membrane surface.

1. Introduction

With the rapid development of economy and society, oily wastewater has become one of the most common pollutants all over the world, which derived from the various industries and domestic life everyday (Jeganathan et al., 2006; Ma et al., 2009; Yang et al., 2012). It is reported that million tons of oil containing wastewater from food industry and kitchens has been discharged into rivers every year. The urgency to treat oily wastewater has emerged since the presence of fat, oil, and grease (FOG) and chemical surfactant in water can not only lead to serious environmental pollution, but also represent a significant hazard to our health. Recently, various methods such as advanced oxidation, adsorption, biological degradation, and membrane separation have been applied for oil wastewater treatment, but these treatment processes are often costly and less effective (Guo et al., 2009; Lebedeva and Fogden, 2010). Alternatively, membrane bioreactor (MBR), as one of most promising technologies, has been widely used in dealing with refractory contaminants including textile, landfill leachate, and oily wastewater, which perfectly combines the biological degradation with membrane separation (Scholz and Fuchs, 2000; Ravindran et al., 2009).

However, the membrane fouling as a major disadvantage restricts the widespread application of MBR, especially in oily wastewater treatment. In order to control the membrane fouling and reduce the cost during the MBR process, most of previous researches have focused on the development of new MBR types (Qin et al., 2012a; Zhang et al., 2013; Deng et al., 2014), the hydrophilic modification of the membrane surface (Meng et al., 2009), the optimization of operational parameter (Chang et al., 2002), and addition of adsorbents and surfactant (Qin et al., 2012b). In recent years, dynamic or shear-enhanced membrane filtration using a moving membrane module to mitigate membrane fouling, as an effective strategy for efficient fouling control and significant energy saving, has attracted more and more attention (Jaffrin, 2008; Altaee et al., 2010). In conventional submerged MBRs, membrane fouling is limited mainly depending on the aeration to generate shear rate. Comparatively, the reduction in membrane fouling via air bubbling is less effective than cross flow operation. The fact maybe due to that vibrated membrane filtration would maintain a high shear-rate only at the liquid-membrane interface, and not in the whole bulk, which would be beneficial to achieve an efficient filtration. The performances of shear-enhanced membrane filtration systems such as rotating membrane module (flat-sheet plates and hollow rotating axis) (Rector et al., 2006; Jiang et al., 2012), vibrating hollow fiber module (VHFM) (Beier and Jonsson, 2009; Genkin et al., 2006) and magnetically induced flat sheet membrane (Bilad et al., 2013) on membrane fouling alleviation have been investigated by the previous referred studies. Experimental results indicated that around 3–6 times lower filtration resistances were observed for the shear-enhanced membrane filtration systems, compared with the traditional MBR system.

In this work, we first introduce a novel pendulum type oscillation (PTO) hollow fiber membrane bioreactor. Our strategy is developed to treat non-biodegradable oily wastewater and control the membrane fouling. The PTO system is chosen because of the following rationales: (1) oscillating system has been applied to a wide range of oscillation angle and frequencies. In comparison with traditional vibrated membrane module, the oscillation amplitude can be greatly increased; (2) a cross-flow interface on the vertical and horizontal orientations is provided due to oscillation of membrane module and aeration at the bottom of reactor; (3) the periodical oscillation of module can make the membrane and mixed liquid be surrounded by a alternating shear flow field; (4) the operation is easy to control and the energy consumption can be obviously reduced. To our best knowledge, such system in SMBR process has not been reported so far.

Based on this new idea, the objective of this study is focused on evaluating the effectiveness of PTO hollow fiber membrane module on the performance of emulsified oil degradation and membrane fouling control in SMBR system. In order to better investigate the feasibility of novel membrane module oscillation, the main interests will be taken in exploring the effect of the enhanced shear stress on the properties and characteristics of sludge flocs, such as EPS, SVI, hydrophobicity, particle size distributions and related microstructure.

2. Methods

2.1. Activated sludge and synthetic oily wastewater

Activated sludge was taken from the sedimentation tank of Hangzhou Municipal Wastewater Treatment Plant. In each stage, the mixed liquor suspended solid (MLSS) of the activated sludge was set at 4000 mg/L. It was well known that the emulsified oil in water solution is always considered as the most difficultly degradable contaminant during the treatment. In this study, waste frying oil (70 mg/L) collected from the restaurant was mixed with commercial detergent (chemical surfactant) in order to enhance oil molecule dispersion in aqueous phase. Except carbon, trace elements and nutrient substance were also provided for biodegradation stimulation. The components of synthetic oily wastewater as well as their concentration are shown in Table S1 (see Supplementary material).

2.2. Experiment setup

A schematic diagram of the experimental setup is shown in Fig. 1. The configuration of the bioreactor was similar to that of the conventional SMBR, except for the addition of the pendulum type oscillation (PTO) module (Fig. 1b).The working volume of the bioreactor was 30 L, and a self-made polyvinylidene fluoride (PVDF) hollow fiber membrane module with membrane pore size of 0.2 μm and the effective membrane area of 0.2 m^2 was applied in each reactor. The SMBR system was operated under constant flux (4.5 L/m^2 h) mode with 8 min suction followed by 2 min relaxation. The transmembrane pressure (TMP), which was an indicator of the extent of membrane fouling, was continually monitored. Air was supplied continuously to each reactor at the same flow rate (0.1 m^3/h) in order to provide dissolved oxygen and eliminate the effect of mixing intensity on membrane permeability. The hydraulic retention time (HRT) and solid retention time (SRT) was controlled at 42 h and 30 d.

In the PTO system, pendulum type oscillation of the membrane was used to provide shear stress at the liquid-membrane interface. As depicted in Fig. 1b, the PTO module consisted of a vibration engine, an eccentric axis, disk, coupling, and the actual oscillating module. The disks mounted on axis was capable of imparting vari-