*Vietnam Journal of Science and Technology* ***55*** *(4C) (2017) 258-263*

# MEMBRANE FOULING IN ANOXIC-OXIC MBR SYSTEM OPERATED AT LOW DISSOLVED OXYGEN

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Received: 13 July 2017; Accepted for publication: 17 October 2017

**ABSTRACT**

Membrane fouling in a lab-scale anoxic-oxic MBR operated at low dissolved oxygen (DO) was investigated in this study. The system includes an anoxic, an oxic and a membrane basin with the working volumes of 73 L, 124 L, and 68 L, respectively. A hollow fibre membrane module with a pore size of 0.2 µm and with total filter area of 1.44 $m^2$ was submerged in the membrane basin. The system was operated at various low DO concentrations of 2.0; 1.5; 1.0; and 0.5 mg/L. The results shown that at DO higher than 1.0 mg/L, COD and TN removal efficiencies were higher than 90 % and 60 %, respectively. However, low DO (less than 1.0 mg/L) lead to poor sludge flocculation which deteriorate the membrane filterability. The TMP increased dramatically at different DO levels. There was a significant increase of TMP during first 15-days experiment at DO 2.0 mg/L. After that the TMP was increased slowly and lower than 16 kPa to until 30-days. In contrast, when DO was reduced to 1.5, 1.0, and 0.5, the TMP was increased sharply almost from 1 to over 20 kPa within about 15 days.

*Keywords:* filterability, fouling, low dissolved oxygen, membrane bioreactor, wastewater.

## 1. INTRODUCTION

Membrane bioreactor (MBR) which combines biological treatment and membrane separation is an increasingly attractive option for the treatment and reuse of industrial and municipal wastewater [1, 2]. Compared to the conventional activated sludge (CAS) process, MBRs have various distinct advantages such as lower sludge production, prolonged biomass retention, smaller footprint and better effluent quality [3]. Normally, the land and space requirements for MBR systems are about 30 % of the space required for conventional systems designed to meet the same treatment goals [4]. Despite the advantages described above, the high running cost is one of the current challenges for application of MBRs [5]. The power requirements in MBRs came from pumping feed water, mixing, sludge circulation pumping, permeate pumping and aeration [6]. The energy demand of the MBRs in municipal wastewater treatment is reported to be a factor of 1.5 to 3 times higher, compared to the CAS [7]. Overall, it is shown that the energy demand of municipal MBRs could be about 0.4-1.0 kWh/$m^3$ [6], which is higher than 0.3-0.4 kWh/$m^3$ for treated water by conventional wastewater treatment [8]. The aeration requirements in MBRs are higher than that in CAS because of the lower oxygen transfer rate in the former due to its highly concentrated biomass [7]. As known, dissolved oxygen (DO) deficiency is one of the most typical factors responsible for most filamentous bacteria proliferation in activated sludge process. The effective method to avoid filamentous bulking due to low DO is increasing the DO concentration, usually up to approximate 2 mg/L or even more [8]. Additionally, membrane cleaning is needed in submerged MBRs by air scouring, which consumes a significant amount of energy [6]. The energy demands for oxygen supply and for fouling prevention comprise from 50 % to over 70 % of the total energy used in the treatment plant, accounting for about one third of the overall operating costs [9]. So, energy saving achieved by operating MBR processes under low dissolved oxygen would be an interesting approach. However, low DO could lead to poor flocculation of sludge which could affect the membrane filterability and membrane fouling.

This study, therefore, was aimed to conduct a lab-scale anoxic-oxic membrane bioreactor (AO-MBR) operated at low DO. The effects of low DO on the membrane fouling and the treatment efficiencies of the AO-MBR system, specially on COD and nitrogen removal, were examined.

## 2. MATERIALS AND METHODS

### 2.1. The experimental system

A lab-scale anoxic-oxic membrane bioreactor (AO-MBR) consisting of an anoxic compartment (73 L) and an aeration compartment (124 L) and a membrane tank (68 L) was used in this study (Fig. 1). A hollow fibre microfiltration (MF) membrane, made of polyvinylidene fluoride, was submerged inside the membrane tank, and its effective membrane surface area was 1.44 $m^2$ with a nominal pore size of 0.2 μm.

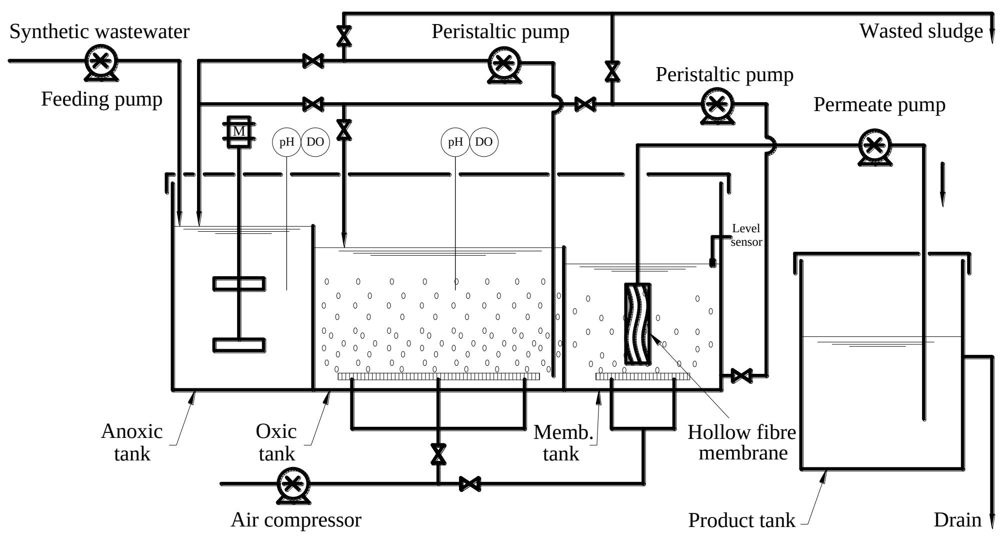


*Figure 1.* Schematic diagram of a lab-scale AO-MBR system used in this study.

The system was inoculated with the seed sludge taken from the MBR process in the Ulu Pandan water reclamation plant (Singapore). Aeration in oxic compartment was supplied by air injection through five-round plates placed at the bottom of the reactor. This injection provided oxygen mainly for organic oxidation and nitrification processes. Besides, under the membrane module, another air injection was applied to create turbulence around the submerged membrane module for the fouling prevention purposes. Two peristaltic pumps with flow rates of 6 L/h and 12 L/h, respectively were used to connect the membrane and oxic tank, and connect the oxic and the anoxic tank as an internal recycle. The anoxic tank was provided with a low speed mixer to keep the sludge in suspension. The flux was maintained at 20 LMH by a peristaltic pump. During operation, sludge concentrations of 6000-7000 mg/L was maintained in the oxic tank through periodic sludge wastage. The dissolved oxygen (DO) concentration in the oxic tank was maintained at four different levels of 2.0 mg/L (for 30 days), 1.5 mg/L (for 20 days), 1.0 mg/L (for 20 days), and 0.5 mg/L (for 20 days). The system was placed in the Environmental Laboratory II at Nanyang Technological University. Temperature was maintained in the reactor at respectively stable value of $25 \pm 2\ ^{o}C$.

### 2.2. Wastewater source

Synthetic wastewater was used in this study to simulate domestic sewage. Its chemical compositions basically consist of glucose ($C_6H_{12}O_6$) as the source of carbon, phosphate (sodium phosphates, $Na_2HPO_4$, $NaH_2PO_4$) and nitrogen (urea, $(NH_2)_2CO$, $NH_4Cl$). The wastewater characteristics include COD of 605-782 mg/L; $NH_4$-N of 48-79 mg/L; TN of 54-86 mg/L; TP of 8.0-9.3 mg/L and pH of 7.2-7.8. The influent was prepared daily in a 120 L plastic tank.

### 2.3. Analytical methods

In this study, the parameters including pH, DO, and temperature were measured online and automatically recorded using a data logger. The transmembrane pressure (TMP) was monitored automatically using a digital pressure gauge. The flowrate and other operational parameters were set-pointed and controlled by the SCADA (Supervisory Control And Data Acquisition) control system. The MLSS, SVI, COD, $NH_4$-N, TN were measured based on the Standard Methods [10].

## 3. RESULTS AND DISCUSSION

### 3.1. Aeration flowrate and DO level in the system

DO was a key operational parameter which related directly to the biological processes and the air supply. In this study, the DO levels (2.0, 1.5, 1.0, and 0.5 mg/L) in the oxic tank were controlled by a DO sensor which was setpointed and monitored by the SCADA control system. Fig. 2 shows the variation of DO and air flow during operation. From the figure, it could be seen that the DO values were varied around the DO setpoints. It should be noted that when DO value recorded by the DO sensor reached the setpointed value (e.g. 2.0 mg/L), the air valve will be closed and stopped air supply. And when it went down to lower 2.0 mg/L, the air valve will be opened and supply air to increase DO up to 2.0 mg/L as setpoint. However, it was observed that during aeration ON, the DO was still come down, lower 2.0 mg/L. Also, during aeration OFF, the DO was raisen over 2.0 mg/L, somehow, it could be 2.3 mg/L. The observation pointed out that the sensitivity of controlling sensor played an important role in maintaining DO at fixed value. During operation, the DO in the anoxic tank was also monitored and mostly less than 0.1 mg/L for all operational conditions.

### 3.2. Effect of DO on transmembrane pressure (TMP)

Membrane fouling is a major concern for optimization of membrane bioreactors (MBRs) technologies as it is usually encountered in MBR operation [10]. Membrane fouling results in the reduction of the permeate flux and in the increase of the TMP [5]. As shown in Fig. 3, in different DO levels the TMP increased dramatically. However, the rate of TMP increase was much different at DO levels. When the system was operated at the DO of 2.0 mg/L, the TMP was increased slowly and lower than 16 kPa during 30 days. In contrast, when DO was reduced to 1.5, 1.0, and 0.5, the TMP was increased sharply almost from 1 to over 20 kPa within about 15 days.  It should be note that air scouring can be used to remove foulants from the membrane surface. With respect to aeration, bubbling requirements for MBRs are typically split into fine bubbles for aeration and larger coarse bubbles for fouling control [11]. In addition, it should be noted that low DO conditions could lead to poor flocculation of individual activated sludge, so that the number of small particles under the low DO conditions is greater than that of the high DO conditions. The smaller particles increase the specific cake resistance, and thus, it deteriorates the membrane filterability. Besides, the aeration rate directly controls the quantity and composition of total soluble microbial products and extracellular polymer substances in the biological flocs and ultimately the ratio of protein/carbohydrate deposited on the membrane surface [3].

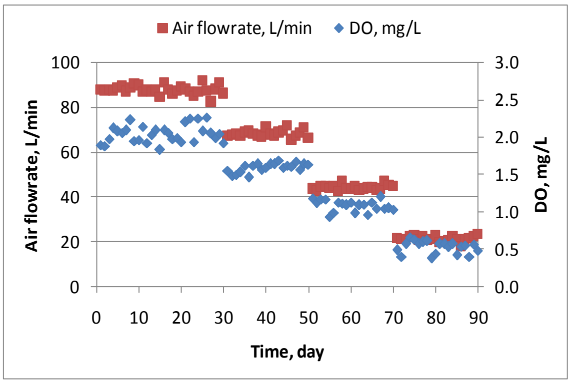


*Figure 2.* Variation of air flow and DO levels.

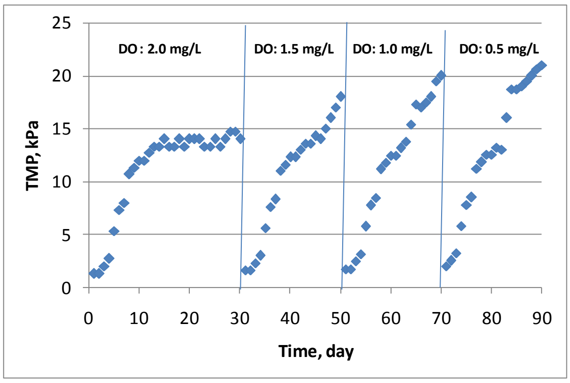


*Figure 3.* Effect of DO levels on TMP variation.

### 3.3. COD removal at different DO levels

Figure 4 shows the COD removal efficiency at different DO levels. Initially, DO was maintained at 2.0 mg/L, and COD removal was averaged at 98 %, then DO was decreased to 1.5 mg/L and the mean COD removal was 95 %. When DO was kept at 1.0 mg/L and 0.5 mg/L, respectively, COD was removed by average of 91 % and 88 %. It can be observed that COD could be biodegraded significantly in the reactor at DO in the range of 0.5-2.0 mg/L. Regardless of DO concentration, greater than 90 % COD removal was achieved with effluent COD concentrations in the range of 30 mg/L, indicating that biodegradation was not significant limited by DO concentration higher than 1.0 mg/L. However, when DO was at 0.5 mg/L, COD removal was reduced to about 88 %. Wang et al. [12] reports the COD removal efficiency of a full-scale wastewater treatment plant treating municipal wastewater operated at low DO level, i.e. 0.8 mg/L, for a period of 60 days could achieve 80 %.

### 3.4. TN removal at different DO levels

The influent ammonia has to be first nitrified to either nitrite or nitrate in the oxic tank before it can be further reduced to nitrogen gas in anoxic tank. Nitrification requires high DO and is usually seen as the limiting step of the nitrification-denitrification process. For that reason, the DO concentration of more than 2.0 mg/L is usually recommended for nitrification [5]. The $NH_4$-N removal at different DO levels was presented in Fig. 5. At the DO setpoint of 2.0 mg/L, NH4-N was always about 2.5 mg/L in the effluent, and the removal was in the range of 96 %. At the following DO setpoints, it was found that the removal of $NH_4$-N was decreasing. At the DO of 0.5 mg/L, $NH_4$-N removal was only about 70 %. Under this condition, $NH_4$-N in the effluent increased to over 18 mg/L. It was found that nitrification was inhibited at low DO of 0.5 mg/L. It has been confirmed from this test that DO should not be below 0.5 mg/L for nitrification, otherwise the process will be inhibited. It is evident in Fig. 6 that DO has a slight effect on TN removal. At the DO of 2.0 mg/L, average removal for TN was 64 %. Then DO was decreased to 1.5 mg/L, 1.0 mg/L, the corresponding removals for TN decreased to 60 % and 61 %. However, when DO reduced to 0.5 mg/L, the TN removal was increased to about 72 %. It seems that DO can penetrate into sludge flocks, resulted in the anoxic zone in the inner part of flocs, hence the lower denitrification took place. It should be noted that in order for the denitrification function properly, the DO in the anoxic tank should be lower than 0.5 mg/L [2]. Besides, for a highly concentrated sludge could be maintained in MBR, anoxic zone may be formed in sludge flocks at a high DO, so partial denitrification could take place in MBR [3].

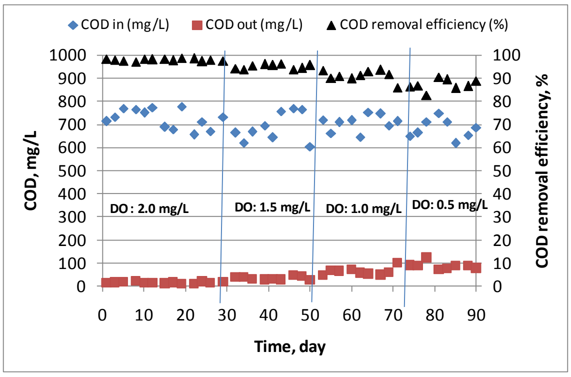


*Figure 4.* Effect of DO on COD removal efficiency in the AO-MBR.

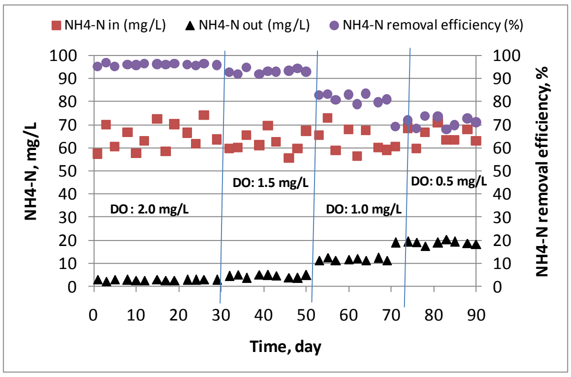


*Figure 5.* $NH_4$-N removal at different DO levels.

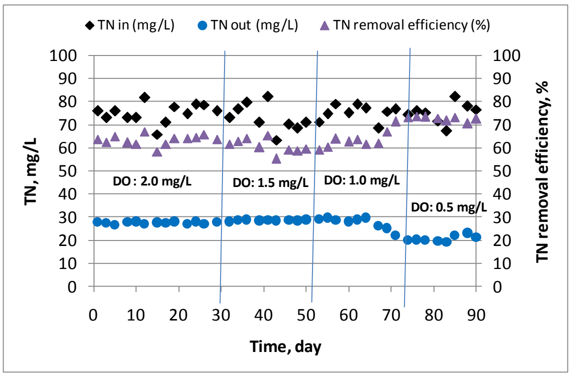


*Figure 6.* TN removal at different DO levels.

## 4. CONCLUSIONS

The findings in the present study showed that the DO levels have strongly affect on membrane fouling. However, the rate of TMP increase was much different at DO levels. Low DO levels lead to poor flocculation of activated sludge, resulted in small sludge sizes. The smaller sludge sizes increase the specific cake resistance, and thus, it deteriorates the membrane filterability and caused faster membrane fouling. COD removal was achieved higher than 90 %, showing that COD removal was not significant limited by DO concentration higher than 1.0 mg/L. However, when DO was at 0.5 mg/L, COD removal was reduced to about 88 %. $NH_4$-N removal increased with DO when DO was higher than 1.0 mg/L. Nitrification was inhibited at low DO of 0.5 mg/L. DO level has a slight effect on TN removal. At a low DO of 0.5 mg/L, the anoxic zone may be formed in sludge flocks, so partial denitrification could take place in MBR. In conclusion, the countered effect of DO on membrane fouling, COD and TN removal in a lab-scale AO-MBR was seen clearly in this study. Therefore, DO control is an important factor to ensure low membrane fouling rate and high COD and TN removal efficiency.

***Acknowledgements.*** The financial support from Nanyang Technological University (Singapore) was acknowledged.

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