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Performance of a flat-sheet submerged membrane bioreactor during long-term treatment of municipal wastewater

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ABSTRACT

A pilot-scale submerged membrane bioreactor (SMBR) with anoxic and oxic tanks was operated in an attempt to reduce the problems concerning effective removal of organic matter and nutrients from municipal wastewater. A flat type membrane with a pore size of 0.038 μm and having a total surface area of 3.60 m^2 was used in the experiments. During the operation, MLSS concentration in aeration (oxic) tank of SMBR was maintained at about 5–7 g/l. Influent and effluent pH in the SMBR also changed between 7.3–8.4. Raw wastewater with average chemical oxygen demand (COD): total nitrogen (TN) ratio of 12:2 was treated at various temperatures (10–30 °C) over an interval of about 160 d. When average influent nutrient mass ratio (COD:TN:TP) was 100:8.2:1.2 and BOD_5:COD ratio was 0.5, removal efficiencies of COD, BOD_5, TSS, TN and TP were 99.1%, 99.3%, 99.4%, 43.4% and 68.2%, respectively. Nitrification occurred in the aerobic reactor with NH_4^+–N removal efficiency ranging from 88.7 to 99.7% averaging at 97.8%. Nitrogen removal in the SMBR was limited not by nitrification but by denitrification. Increase in the concentration of TN in the treated water can be explained by increases in the concentration of NO_3^-–N.

Keywords: COD; Municipal wastewater; Pilot scale SMBR; Total nitrogen; Total phosphorus

1. Introduction

Membrane bioreactor (MBR) has become a more and more attractive technology in the wastewater treatment field. Compared with conventional activated sludge (CAS) processes, MBR process has many prominent advantages including a smaller footprint, less sludge production and superior effluent quality, etc. The development of submerged membrane bioreactors (SMBRs) has significantly reduced operational energy consumption and increased its potential application in wastewater treatment [1]. Feature of SMBR is that uprising air/liquid mixture generated by aeration creates turbulence for membrane surfaces cleaning [2].

The treatment capacity of small-scale wastewater treatment plants (WWTPs) for the two nutrients nitrogen and phosphorus is often limited. Nitrification and denitrification may occur to a certain degree in biological treatment plants, depending on the plant layout and the operating conditions. In contrast, phosphorus is only removed to a substantial extent with the aid of chemical precipitation [3]. Nutrient removal in

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small-scale decentralized MBRs has been studied by several researchers who showed that high levels of both nitrogen and phosphorus removal can be obtained by biological systems [4,5]. All these reactor systems are designed for 100–1000 PE and rely on continuous water flows and pretreatment. There is limited study on two-chamber SMBR to treat the domestic wastewater of a four-person household [3]. The aim of this study is to investigate the long-term performance of a two- chamber SMBR which is designed to treat the household wastewater. The reactor configuration studied included an anaerobic/anoxic tank followed by an SMBR.

2. Materials and methods

2.1. Experimental setup and operating conditions

The pilot-scale submerged membrane bioreactor (SMBR) was located in municipal wastewater treatment plant (WWTP) of Kayseri, Turkey (Fig. 1). SMBR system consisted of an anoxic tank (2000 l) and an aeration (oxic) tank (1800 l). Nine flat sheet membrane modules within a cassette (MCB 1-Hans Huber incorporated, Germany) were mounted vertically located in the oxic tank. The membranes were made of polyether-sulfone (PES) membrane with a mean pore size 0.038 μm. The effective filtration area for each module was 0.4 m^2. Air was supplied through two axial perforated tubes which were below the membrane modules in order to supply oxygen demanded by the microorganisms and to prevent fouling effects by scouring along the membrane surface [6]. Raw wastewater from the WWTP was supplied into the anoxic zone then flowed into oxic zone by gravity. The influent pump was controlled by a water level sensor to maintain a constant water level in the bioreactor over the experimental period. The membrane-filtered effluent was then obtained by suction using a pump connected to the modules. The effluent flow rate and the transmembrane pressure (TMP) were monitored by a flow meter and a pressure gauge, respectively.

Filtration flow rates were between 50–90 l/h in the SMBR. Intermittent filtration (8 min filtration and 2 min pause) was also carried out. Sludge recycling from oxic zone to anoxic zone was controlled at 3 times of influent flow rate. The MLSS concentration of sludge was about 5–7 g/l in the bioreactor and the sludge retention times (SRT) were kept infinite. The TMP was also in the range of 0.1–0.5 bar.

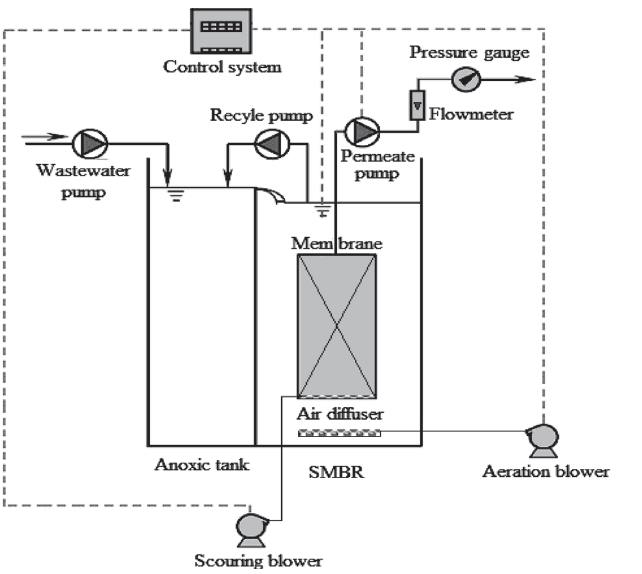

Fig. 1. Schematic flow diagram of the SMBR.

2.2. Analytical methods

The COD, BOD_5, total nitrogen (TN), ammonium nitrogen (NH_4^+–N), and nitrate-nitrogen (NO_3^-–N), total phosphorus (TP), pH and mixed liquor suspended suspended solids (MLSS) in the bioreactor were analyzed according to standards methods [7]. The COD, TN, NH_4^+–N, NO_3^-–N and TP were measured using Thermo-Spectronic Aquamate model spectrophotometer. HACH COD reagent (Cat No. 21258-51) for COD, Ammonia salicylate (Cat No. 23953-66) reagent powders and Ammonia cyanurate (Cat No. 23955-66) for ammonium nitrogen, Nitriver reagent (Cat No. 14065-99) and Nitraver reagent (Cat No. 14119-99) for nitrate, TN acid solution reagent (Cat No. 26721-45) and Hydroxide reagent set (Cat No. 27140-45) for TN and total phosphorous reagent set (Cat. No. 27672-45) for TP measurements were used.

3. Results and discussion

3.1. Biological degradability of real wastewater

The data presented here is associated with the initial 160 d of operation of the pilot-scale MBR unit. Influent and effluent pH in the SMBR also changed between 7.3–8.4. In the present study, the COD:TN:TP of 100:8.2:1.2 and BOD_5:COD of 0.5 for the real wastewater confirmed that of the commercial WWTP [4]. In municipal wastewater, limited COD availability results in a competition between denitrification and phosphorus removal. For conventional nutrient removal process (A^2O, AO, et al.), phosphorus removal efficiency has a sharp decrease when COD/TN ratio is below 7–9 [8]. The removals of COD, BOD_5, and total suspended solids (TSS) were quite successful as their efficiencies were 99.1%, 99.3%, and 99.4%, respectively (Table 1).

Total coliform organisms were taken as good indicators of water quality. The number of total coliform

Table 1
Measured influent and effluent values and removal efficiency of SMBR

Parameters*	Influent (raw ww)	Effluent (treated water)	Removal (%)
COD (mg/l)	729.5 ± 119.5	6.9 ± 6.8	99.1
BOD_5 (mg/l)	343.3 ± 42.8	2.3 ± 1.8	99.3
TN (mg/l)	60.0 ± 6.3	33.9 ± 6.4	43.4
NH_4^+–N (mg/l)	31.4 ± 0.6	0.6 ± 0.6	97.8
TP (mg/l)	9.0 ± 1.5	2.8 ± 1.5	68.2
TSS (mg/l)	438.3 ± 98.2	2.5 ± 2.2	99.4
pH	7.9 ± 0.2	7.6 ± 0.2	–

*Values are given ± standard deviation.

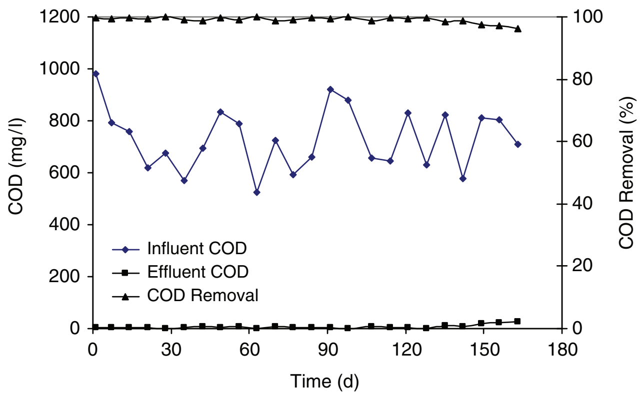

Fig. 2. Variation of influent and effluent CODs.

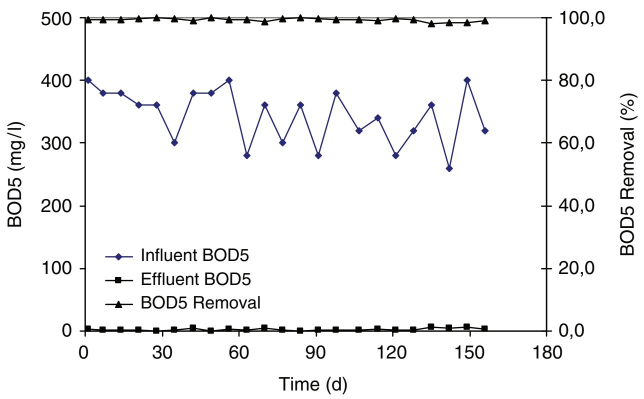

Fig. 3. Variation of influent and effluent BODs.

was measured during the experiments and the effluent from the SMBR contained between 72 and 112 total coliform/100 ml. Similar results were obtained in the literature [4,9,10]. The influent COD ranged between 524 and 983 mg/l during the study. Effluent COD concentration was frequently below 26 mg/l (Fig. 2). The fluctuations observed in the effluent COD can be

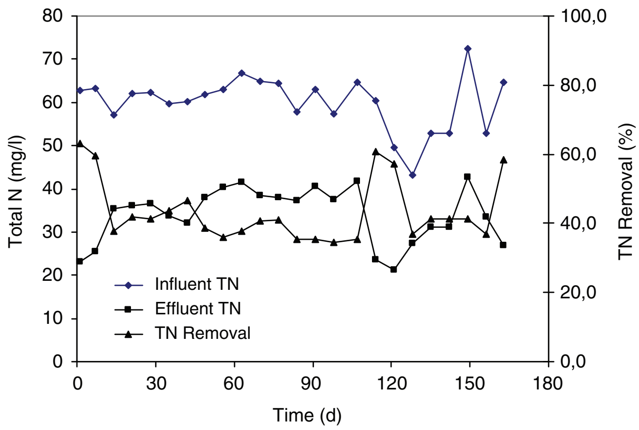

Fig. 4. Influent and effluent Total N concentrations.

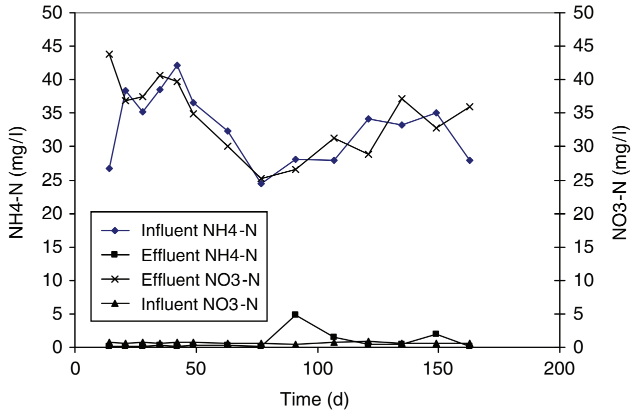

Fig. 5. Variation of NO_3–N with NH_4–N concentrations in the MBR.

explained by the dissolved oxygen concentration employed in the aeration tank. While the influent BOD_5 ranged between 260 and 400 mg/l, lower effluent BOD_5 values were obtained (Fig. 3). The influent and effluent concentrations of the suspended solids (TSS) were also found 230–662 mg/l and 0–8 mg/l, respectively (Table 1).

3.2. Removal of Nitrogen and Phosphorous in the SMBR

Figs. 4 and 6 show changes in concentrations of TN and TP in raw wastewater and treated water, respectively. The average removals of TN and TP were obtained 43.4% and 68.2%, respectively (Table 1). Fig. 5 shows changes in the concentrations of NH_4^+–N and NO_3^-–N in raw wastewater and treated water. The average influent NH_4^+–N concentration to the system following 160 d was 32.9 ± 5.0 mg/l while the effluent NH_4^+–N concentration averaged 0.8 ± 1.3 mg/l. The stability of nitrification is remarkable since increase of influent ammonia concentration to 42.1 mg/l on Days 35–42 did not cause significant increases in effluent concentrations.

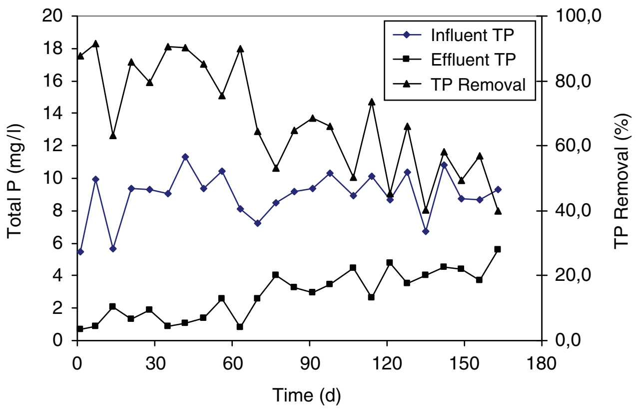

Fig. 6. Influent and effluent Total P concentrations.

Nitrification occurred in the aerobic reactor with nitrification efficiency ranging from 88.7 to 99.7% averaging at 97.8%. Nitrogen removal in the SMBR was limited not by nitrification but by denitrification. Increase in the concentration of TN in the treated water can be explained by increases in the concentration of NO_3^-–N (Fig. 5). Quality of feed wastewater for the SMBR inevitably fluctuated to some extent. The deterioration in denitrification in the SMBR may have caused this fluctuation. It is widely known that the carbon-to-nitrogen ratio (C:N) in wastewater affects the biological denitrification process. 43.4% TN removal by nitrification-denitrification obtained in this study is very close to value of 46.9% reported by Kimura et al. [10], who examined nitrogen removal in the baffled MBR.

The occurrence of denitrifying phosphorus-accumulating organisms (DPAOs) is a great progress in treating carbon-deficient influent. Differing from phosphorus-accumulating organisms (PAOs), DPAOs can utilize nitrite or nitrate instead of oxygen as electron acceptors to remove phosphate under anoxic condition [11,12]. Following Day 70, a shortage of electron acceptors made negative effect on anoxic phosphate uptake and TP removal efficiency decreased to 40% at that time. Similar result was also reported by Zang et al. [8].

4. Conclusions

This study examined removal of organic matter and nutrients from municipal wastewater in a flat-sheet submerged membrane bioreactor. During 160 d of the operation, MLSS concentration in aeration (oxic) tank of SMBR was maintained at about 5–7 g/l. Influent and effluent pH in the SMBR also changed between 7.3–8.4. Wastewater is characterized as COD:TN:TP of 100:8.2:1.2 and BOD_5 :COD of 0.5. The removals of COD, BOD_5, and total suspended solids (TSS) were quite successful and their efficiencies were 99.1%, 99.3%, and 99.4%, respectively. The number of total coliform in the effluent of the SMBR was measured between 72 and 112 total coliform/100 ml. The average removals of TN and TP were obtained 43.4% and 68.2%, respectively. Nitrification occurred in the aerobic reactor with NH_4^+–N removal efficiency ranging from 88.7 to 99.7% averaging at 97.8%. While good TP removal was achieved in the first 70 d, a shortage of electron acceptors made negative effect on anoxic phosphate uptake and TP removal efficiency decreased to 40% after 160 d.

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