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ORIGINAL RESEARCH PAPER

Municipal Wastewater Treatment Using a Hollow Fiber Membrane Bioreactor

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ABSTRACT: A bioreactor equipped with hollow fiber microfiltration membranes was applied for wastewater treatment. Removal of chemical oxygen demand (COD) and biochemical oxygen demand (BOD_5) was investigated. The experimental setup consisted of influent and effluent tanks, and membrane modules using Polyvinyl Di–Fluoride (PVDF) hollow fibers. The operation program included suction and backwash steps which were lasted three and one minutes, respectively. The performance of MBR was monitored for a period of 120 days. The average removal for COD and BOD_5 was over 99.5% and 88.9%, respectively. Results indicated that the MBR system can be applied to treat high–strength wastewaters. Also, it may have sustainable performance during the quantity fluctuations of influent wastewater.

KEYWORDS: *Hollow Fiber, Membrane Bioreactor, Microfiltration, Municipal Wastewater, Polyvinyl Di–fluoride, Submerged Membrane, HF–MBR*

Introduction

Membrane bioreactor (MBR) is a combination process of a biological reactor with a membrane separation device. Mostly, it is employed to treat industrial and domestic wastewater [1].

It was introduced for treating municipal wastewater by Dorr–Oliver in the 1960s [2]. In comparison to conventional wastewater processes, membrane bioreactors propose multiple privileges such as less environmental footprint, better effluent, and no need for effluent disinfection. Also, a higher biomass concentration up to 20 g/L provides a higher rate of BOD and COD removal and a smaller sludge yield which tends to noticeable cost saving during the sludge disposal [3].

Membrane bioreactor (MBR) separates biomass from wastewater effluent via a membrane layer. So, the characteristics of the activated sludge precipitation have no effect on the effluent quality. Concentrated activated sludge generates problems such as high viscosity, decreasing membrane flux, and altering the oxygen transfer rate [3].

The MBR system can be designed based on microfiltration (MF) or ultrafiltration (UF) modules. Usually, the MBR units can be installed instead of the secondary sedimentation basin in wastewater treatment plants to produce the effluents with very low turbidity content (<0.5 NTU) and almost free of bacteria [4].

Besides the above–mentioned advantages, the MBR technology has some limitations. The main complicated issue is the interaction status between membrane layer and mixed liquor. Therefore, the polarization phenomenon, internal clogging, and the external deposit reduce the filtrate flux and thus, increase the required membrane area.

During the recent years, various experiments have been focused on the most obvious understanding of MBR process to perform the better design approaches and more effective operation methods [4].

Two types of membrane bioreactor system are commercially available which have been considered for the treatment of almost readily biodegradable wastewaters originated from domestic or industrial sources [5]. As shown in Fig. 1a, the first type consists of the membrane modules which can be installed on the outside of the aerated basin. Usually, the modules have been equipped with tubular membranes and can be fed with mixed liquor that is pumped continuously. The high shear stress is necessary to obtain the acceptable filtrate flux values. Therefore, the velocity of circulation flow inside the tubular modules is generally up to 4 m/s which can produce a high head loss and the noticeable power consumption. In the second type, as shown in Fig. 1b, the membrane module is immersed in the aerated basin and the filtrate liquid sucked through the membrane wall [6].

This research aimed to peruse the efficiency of the pilot scale of membrane bioreactor (MBR), the immersed hollow–fiber microfiltration type, for domestic wastewater treatment. The experiment was performed in southern wastewater treatment plant of Isfahan metropolitan (ISWTP), Iran.

Materials and methods

Experimental Setup

Fig. 2 illustrates the experimental setup employed in this study. It was constructed to treat the effluent from primary sedimentation basin of ISWTP. The system was consisted of three separated tanks with the total volume of 2.2 m^3. The first

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tank was considered for equalization proposes which have 1 m^3 volume. The second tank with a total volume of 1 m^3 was designed in dual parts and contained the membrane bioreactor module and functioned as biological reaction. The third tank was designed for solid – liquid separation and can be denoted as secondary sedimentation basin with the effective volume of 0.2 m^3.

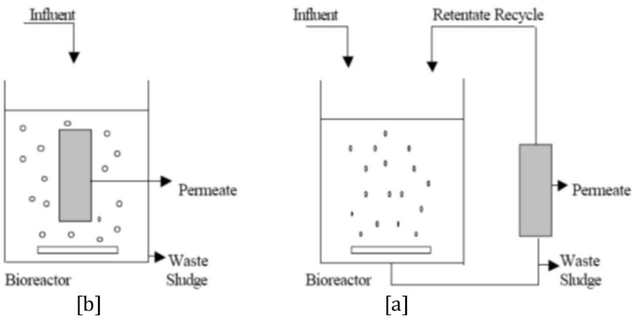

Fig. 1. Two types of membrane bioreactor which are commercially available for wastewater treatment: [a] external re–circulation, [b] submerged membrane bioreactor.

As shown in Fig. 2, the inlet flow was delivered to equalization tank by the pipe A. The wastewater constant level was obtained by floating valve D. The pressure was controlled by pressure gauges G installed at the inlet and outlet parts of the membrane. Both membrane inlet flow rate and permeate flow rate were measured with flow meters H. Mixture of water and sludge was transferred from bioreactor to the membrane module pipeline by the suction pump I. Filtrated liquid as effluent, which flowed through the shell of the membrane module and supplied in the third tank K, was used for membrane backwash.

Wastewater characteristics

The MBR inlet flow was received from the effluent line of primary sedimentation tank which was originated from the municipal wastewater. The characteristics of the wastewater are indicated in Table 1.

Membran module

Characteristics of the membrane (Polyvinyl Di–fluoride was manufactured by EcoFILL™) are given in Table 2.

System Operation

Treatment was performed in an aerobic condition with sludge aeration via porous tubes installed on the bottom of the bioreactor. Initially, the membranes were washed with water and exposed to 0.076 m^3 of ethanol (96%) for 12 h. Then, the bioreactor was filled with wastewater.

The membranes were operated at an intermediate suction rate and were periodically backwashed using permeate flow. Before the operation day of 30, multiple operation modes including the suction–backwash and coarse bubble aeration duration were assessed with the goal of diminishing the fouling of membranes. On day 31, the operation mode was determined as following protocol: Continuous operation mode including 3 min for filtration using suction pump followed by 1 min for stop the suction.

After the first 15 days, which was intended for seeding and start–up phase, the MBR system was operated and monitored continuously for 120 d. The HRT of MBR tank was adjusted at 24 h. Some details of operation condition are shown in Table 3.

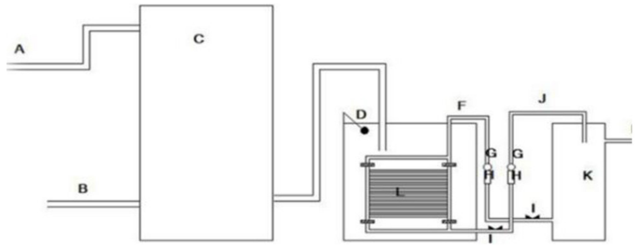

Fig. 2. Schematic diagram of the MBR system for domestic wastewater treatment; A: influent from primary sedimentation treatment; B: sludge; C: equalization tank; D: liquid level control valve; E: membrane bioreactor; F: membrane backwash pipe; G: pressure gauge; H: flow meter; I: suction and backwash pump; J: suction liquid; K: backwash tank (effluent tank); L: permeate liquid.

Table 1. Characteristics of the raw wastewater.

Parameter	Range
BOD_{5avg} (mg/L)	88.46 – 645.97
COD_{avg} (mg/L)	192.02 – 1127.96
TSS_{in} (mg/L)	428 – 1559
BOD_{avg}/COD_{avg}	0.41 – 0.57
VSS/TSS	0.73 – 0.79

Table 2. Main characteristics of the hollow fiber membrane.

Characteristic parameter	Membrane module
Material	high crystalline PVDF
Hollow fiber (OD×ID)	1.3 m×0.8 mm
Pore size	0.1 µm
Max transmembrane pressure (TMP)	300 kPa
Filtration pressure	30–80 kPa
Backwash pressure	<160 kPa
Max operation temperature	40 °C
pH range	1 – 10
pH range at activated sludge	6 – 8
Operation cycle:	
Filtration	9 min
Backwash	1 min
Scouring air rate	12.5 L/m^2

Control, analysis and monitoring

Pressure, DO, and flow rates were recorded daily using online controllers. The concentration of dissolved oxygen (DO) was measured by the titration method of Winkler and maintained higher than 3.0 mg/L in the membrane tank. All the examinations were done according to the standard methods issued by DC, USA: American public Health association, 2005 [7]. The influent and effluent of the membrane tank were sampled two or three times per week.

Table 3. MBR pilot plant operating conditions.

Item	Value/range
Equalization tank volume (m^3)	1
Membrane tank volume (m^3)	1
Backwash tank (effluent tank) volume (m^3)	0.2
Membrane tank HRT (h)	24
SRT (d)	25 – 35
F:M ratio of membrane tank (kg COD/kg MLSS.d)	0.11 – 4.23
Volumetric loading rate of Membrane tank (kg COD/m^3.d)	2.66 – 16.61
Volumetric loading rate of Membrane tank (kg BOD_5/m^3.d)	1.35 – 7.44

The analysis was comprised biochemical oxygen demand (BOD), chemical oxygen demand (COD), mixed liquid volatile suspended solids (MLVSS), mixed liquid suspended solids (MLSS), and turbidity. COD concentration was measured by the titration method of potassium dichromate. Mixed liquor suspended solids (sludge concentration) were measured by weight method after drying.

Result and discussion

Performance of MBR system

Fig. 3 illustrates the COD values obtained from the influent and effluent flows of the MBR system. As revealed from Fig. 3, the effluent COD was stable and the removal efficiency was around 90%.

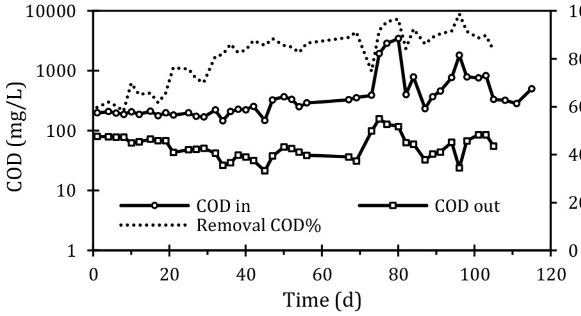

Fig. 3. Variations and removal of COD.

According to Fig. 3, at the beginning of operation phase, the removal efficiency of COD was about 76%. This relatively low removal efficiency may be due to lack of complete formation of gel layer on the membrane surface [3]. According to Fig. 3, the efficiency of COD removal was gradually increased up to 96% after a 100–day operation time. The results are in agreement with those of Palupi et al. [6]. Palupi et al. performed their experiment based on polyacrylonitrile hollow fiber membrane with a pore diameter of 0.01 – 0.1 µm. The HRT was 5 h and no sludge disposal occurred. The operation relied on the intermittent pattern and the optimum condition was acquired at a transmembrane pressure (TMP) of 1.45 bar. The Palupi et al. showed that removal of approximately 98% was obtained for both COD and BOD using the MBR system for domestic wastewater treatment. Also, the MLSS and MLVSS degradation were 98.6% and 98%, respectively [6].

According to Fig. 3, the most of COD loadings had occurred in the third month, between 72nd and 82nd days. During this period, sludge discharge system of primary sedimentation tank was interrupted. So, the MLSS, BOD_5, and COD values were dramatically increased in the MBR inlet flow which can be denoted as a biological shock and this condition of the membrane operation was checked.

As shown in Fig. 2, the COD loading rate in the above–mentioned period was 9.34 – 16.61 kgCOD/m^3.d. Also, the COD removal efficiency was measured as 91% – 96%. The most removal amount of COD was 96% that was obtained in the loading rate of 5.54 kg COD/m^3.d and the influent COD of 3453.41 mg/L. The results support those of Zhang et al. [8] which studied the wastewater treatment of a beer factory. According to the findings of Zhang et al., the MBR system has the enough tolerance to afford the shocks occurred with the inflow organic matters. Also, according to Yuang et al. [9], the MBR system can be considered as an appropriate alternative to treat the high–strength wastewaters, especially those with high fluctuations in organic content.

Fig. 4 illustrates the MBR performance on the removal of BOD_5. As shown, the BOD_5 values measured in the system inflow have the noticeable fluctuations. However, the BOD_5 values reported in the system outflow were closed to the laboratory detection limits. The average BOD_5 removal was more than 99% and the BOD_5 removal up to 100% was also achieved.

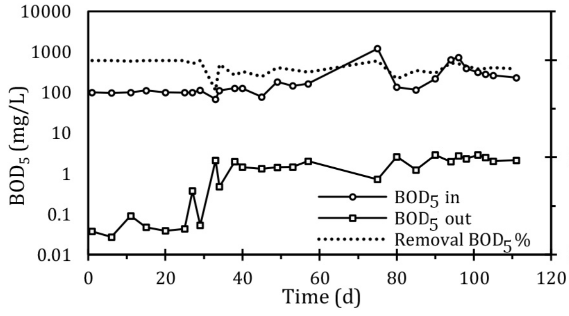

Fig. 4. Variations and removal of BOD_5.

Variation of MLSS

Fig. 5 shows that the wastewater treatment plant can be operated with a high biomass concentration using the MBR as sludge separation system. The MLSS concentration in MBR tank was maintained in the range of 9000 – 10,000 mg/L. The excess sludge was discharged according to the sludge growth rate of 25 – 35 days. As inferred from Fig. 5, the variations of the MLSS values can be classified into two stages. The first stage was between 1st and 68th days that the MLSS amounts were increased gradually. The second stage located between 76th and 120th days that the MLSS values were increased with a steep slope but after a sharp peak around 100th day, it tend to a decreasing pattern followed by a sharp increase during the second stage.

In the third month, the aeration pipes of the MBR system were blocked and became an emergency system was not predicted, we were forced to empty the MBR tank and repair bluer then re–start the system. This may be attributed to the influent COD concentration during stage 2 which was reported higher than those of stage 1. Furthermore, stage 1 can be related to an adaptation and acclimation phase of the biomass to the operating conditions, but stage 2 can be inferred as a stabilized stage where the biomass can be considered as an acclimated to an operating condition. Although the MLSS concentration was measured higher than 9000 mg/L, the treated water was almost free of suspended solids. It was due to the complete separation that was done by the membrane.

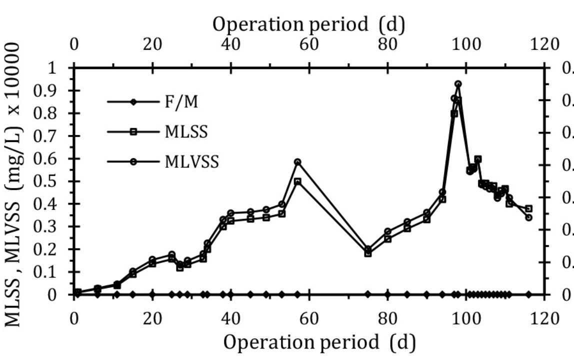

Fig. 5. The inflow and outflow values of MLSS, MLVSS and F/M during the MBR operation period.

Conclusion

This study demonstrated the field operation of municipal wastewater treatment using MBR experimental setup. It was concluded that the MBR system has the capability of removing

96% and 100% of COD and BOD_5, respectively. Also, the results indicated that the MBR system has a noticeable potential in the treatment of municipal wastewater because it has the stable operation and satisfactory removal performance.

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