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The Influence of Short Values of Hydraulic and Sludge Retention Time on Performance of a Membrane Bioreactor Treating Sunflower Oil Refinery Wastewater

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ABSTRACT

In this work, the performance of organic pollutant removal, membrane fouling and sludge morphology in a submerged membrane bioreactor (MBR) treating sunflower oil refinery wastewater (SORW) containing high oleic content was studied during 52 days' operation at short values of 18 h and 10 days for hydraulic retention time and sludge retention time, respectively. The removal efficiencies of chemical oxygen demand (COD), oil and grease (O&G) and turbidity were found to be 73.2±6.6%, 75.1±2.5%, and 99.7±0.1%, respectively and the need for membrane cleaning never rose. The results showed a statistically significant linear correlation between the mixed liquor O&G with soluble microbial products and extracellular polymeric substances (EPS) (r_P=0.792; p-value=0.034 and r_P=0.920; p-value=0.003, respectively). Additionally, increase in MLVSS concentration which was due to an increase in cell concentration and was not related to accumulation of O&G and biopolymers inside the bioreactor, increased specific oxygen uptake rate. The trend of changes in sludge volume index (SVI) and supernatant turbidity (ST) with EPS_{total} was also found to be statistically significant (r_P=0.736; p-value=0.037 and r_P=0.773; p-value=0.024, respectively). The results of SVI, ST, EPS, particle size distribution and microscopic observation showed change in sludge morphology to flocs of smaller size (unimodal, with mode of 20 µm) with high compressibility (SVI=44.0 mL g^{-1} MLSS) and bioflocculating ability (ST=20.4±3.3 NTU). The results of the present study were indicative of a very good potential of the MBR for treatment of SORWs.

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1. INTRODUCTION

The main problem of activated sludge process (ASP) in biological treatment of municipal and industrial wastewater is its poor ability to separate biomass from the effluent [1]. A membrane bioreactor (MBR), in which a membrane separation process is combined with biological processes, is an efficient alternative approach for wastewater treatment and reuse. The advantages of the MBR toward the conventional ASP treatment include excellent effluent quality due to membrane, good disinfection capability, higher volumetric loading, compact foot-print, process flexibility towards influent changes and reduced sludge yield by maintaining higher biomass concentration in the MBR [2-4]. However, the major process disadvantage of MBR in its full-scale applications for wastewater treatment plants is membrane fouling due to the physicochemical interactions between the constituents of the mixed liquor such as extracellular polymeric substances (EPS) and soluble microbial products (SMP) and membrane material [5-7].

Hydraulic retention time (HRT) and sludge retention time (SRT) are two main significant operating parameters affecting the MBR performance as well as membrane fouling [6]. Also, in MBRs, the physicochemical and morphological characteristics of the mixed liquor, have important effects on both the removal performance and membrane fouling rates [8].

The flocculation ability of microbial aggregates and the compressibility of the activated sludge flocs are the keys to the achievement of an ASP effluent having low turbidity and high quality [9-11]. One of the main

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factors contributing to biomass loss through the effluent of ASP is filamentous bulking. Filamentous microorganisms play a predominant role in the bacterial community of the activated sludge and can function as "backbones" for flocs. To form strong flocs, floc-forming bacteria attach by means of EPS. However, overgrowth of filamentous microorganisms is the main factor for poor settling of filamentous flocs [1, 2].

According to the previous researches, the value of EPS can affect the bioflocculating ability of the bacterial population in the activated sludge as well as the compressibility of the flocs. It also accelerates the microbial aggregates formation through close binding cells [9, 10, 12, 13]. It is reasonable to assume that the quantity and quality of produced EPS is dependent on sludge characteristics. Therefore, for evaluating the performance of MBR, special attention should be given to the sludge morphology and EPS matrix.

To the knowledge of the authors, there are only two previous reports on the treatment and reuse of vegetable oil wastewaters (VOWs) using MBR technology [14, 15]. This wastewater generally contains high organic content, including large amounts of oil and grease (O&G), chemical oxygen demand (COD), free fatty acids, phospholipids and lipoproteins and inorganic contents including sulphates and phosphates and it also has offensive smell and dark color [14, 16, 17]. In the study of Ma et al. [14], a submerged MBR employing a hollow-fiber polyvinylidene fluoride (PVDF) membrane was considered for the treatment of VOW and good removal performance was achieved at the optimum HRT of 18 h. However, in that study complete sludge retention has been employed and the mixed liquor characteristics were not studied. Also, as a result of complete sludge retention and subsequent increase in mixed liquor suspended solids (MLSS) concentration, the rate of membrane fouling was high. In another study by Abdollahzadeh Sharghi et al. [15], biological treatment of real sunflower oil refining wastewater using a submerged MBR in terms of organic pollutant removal performance and membrane fouling at a moderate SRT (20 days) and relatively high HRT (48 h) was investigated. The results of their study showed that the MBR had a very good potential for the treatment of VOW of Kourosh vegetable oil factory compared to the combined system of conventional ASP and moving bed bioreactor used in that factory, both in terms of removal performance and membrane fouling.

Therefore, a lack of knowledge of the performance of MBR in terms of variations in characteristics of influent VOWs, operating parameters, microbial communities responsible for VOW degradation and membrane fouling of MBR exists.

The present work aims to evaluate the effect of short SRT (10 days) and relatively short HRT (18 h) on the organic pollutant removal performance, membrane fouling and activated sludge mixed liquor morphology in a submerged MBR treating real sunflower oil refinery wastewater containing high oleic content during 52 days of MBR operation.

2. MATERIALS and METHODS

2. 1. Vegetable Oil Wastewater and Sludge Used

The VOW samples used in this study were collected from a high oleic acid containing sunflower oil refining plant located in Alborz (Kourosh vegetable oil factory, Alborz, Iran). Sampling was carried out after the preliminary treatment which consisted of a CPI (corrugated plate interceptor) oil separator, bar screen, grit chamber, aeration, mixer 1 (alum + lime + polyelectrolyte), mixer 2 and sedimentation. The samples were then stored at 4°C. All samples were equilibrated to room temperature before feeding. Analysis of the VOW was carried out several times and the average composition is shown in Table 1.

The COD/N/P ratio of the medium was adjusted to approximately 100:10:1 by the incorporation of suitable concentrations of NH_4Cl and KH_2PO_4 into the VOW. The activated sludge used as the inoculum for the MBR, was also collected from the aeration tank of the Kourosh VOW activated sludge treatment plant.

2. 2. Experimental Set up and Operating Conditions

The bioreactor used in the present study, consisted of a 5 L acrylic tank, in which a PVDF flat-sheet ultrafiltration (UF) membrane (Shanghai SINAP Membrane Tech Co., Ltd., China) with a pore size of <0.1 μm and area of 0.1 m^2 was immersed (Figure 1). Details of the experimental setup and mode of operation have been described elsewhere [18].

The bioreactor temperature was kept constant at 30±1°C and controlled by a heater. The pH of the MBR throughout its operation was within 6-8. The VOW was fed to the MBR via a feed tank equipped with a mixer rotated at 120 rpm.

TABLE 1. Physicochemical characteristics of high oleic sunflower oil refinery wastewater used in this work.

Parameter	Concentration
pH (-)	8.4 ± 0.7
Turbidity (NTU)	277±145
Conductivity (μS cm^{-1})	4454±707
Salinity (mg L^{-1})	2373±407
TDS (mg L^{-1})	2326±394
COD (mg L^{-1})	946±246
O&G (mg L^{-1})	73.5±7.5

At the start of operation, the MBR system was inoculated with the activated sludge and the concentration of initial MLSS and mixed liquor volatile suspended solids (MLVSS) were 3130±444 mg L^{-1} and 2292±610 mg L^{-1}, respectively. The MBR system operated over a period of 52 days with SRT, HRT and organic loading rate equal to 10 days, 18 h and 1.26±0.33 Kg COD m^{-3} d^{-1}, respectively.

2. 3. Chemicals and Analytical Methods All chemicals were of analytical grade obtained from Merck Company (Merck, Germany). The COD of the samples of the MBR mixed liquor, influent and effluent were determined according to closed reflux, colorimetric method (5220D) of APHA Standard Methods [19]. MLSS and MLVSS were determined according to 2540D and 2540E of APHA Standard Methods, respectively [19]. Total dissolved solids (TDS), pH, conductivity and salinity were measured with a Hach apparatus (Hach, HQ 40D). The O&G of the feed and effluent were measured according to the United States Environmental Protection Agency (USEPA) Method 1664, which is a modified version of 5520F in Standard Methods [19]. The O&G of the mixed liquor samples were determined according to method described by Abdollahzadeh Sharghi and Bonakdarpour [20].

SMP and EPS were measured by utilizing the method described by Chang et al. [21]. The protein, humic acids and carbohydrate concentrations of the EPS (EPS_p, EPS_h and EPS_c) and SMP (SMP_p, SMP_h and SMP_c) were determined as described previously [18].

The SMP_{total} and the EPS_{total} were estimated as the sum of these three components. Specific oxygen uptake rate (SOUR) was determined according to Standard Methods [19].

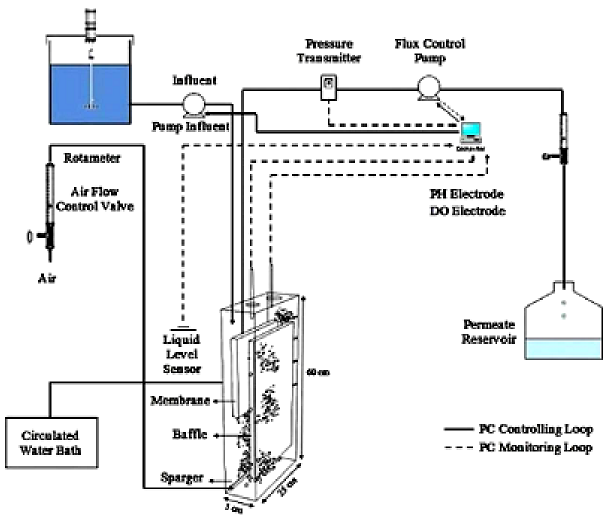

Figure 1. Schematic of the laboratory MBR setup

All analyses were performed in triplicate and error bars in figures represent standard deviations of three replicates.

Sludge volume index (SVI) was also determined according to Standard Methods [19]. Sludge supernatant turbidity (ST), which is a measure of sludge flocculating ability, was determined by measuring the turbidity of the supernatant at the end of the SVI test. All turbidity measurements were performed with a portable turbidity meter (Aqualytic AL450T-IR). Microscopic analysis was carried out using an Olympus CX21 microscope (model CX21FS1, Japan). A drop of the mixed liquor sample was placed on a slide glass and observed at 400x magnification. The particle size distribution (PSD) of the mixed liquor in the reactor was determined by a laser particle sizer ANALYSETTE 22 NanoTec (Fritsch GmbH, Germany) with a detection range of 0.01–2100 µm.

2. 4. Statistical Analysis In order to determine when steady state conditions with regard to MLSS and MLVSS were obtained during the MBR operation, the MLSS and MLVSS data were subjected to one-way ANOVA analysis. It was assumed that steady state conditions were achieved when there was no statistically significant difference between the values in succeeding days at $p<0.05$. Univariate linear correlation analysis was performed to identify the presence or absence of a statistically significant linear correlation between the trend of changes of various parameters during the operation of the MBR [18]. All analyses were performed using Minitab version 16 (Minitab Inc., State College, PA, USA). Correlations were considered statistically significant when $p < 0.05$.

3. RESULTS AND DISCUSSION

3. 1. MLSS, MLVSS and Chemical Composition of the Mixed Liquor In MBR studies of oily wastewaters, MLSS reflects both the inorganic and organic compounds of the mixed liquor, whereas MLVSS reflects the adsorbed oil, biopolymers and bacterial biomass [20]. Figure 2 shows the variation of MLSS, MLVSS and the MLVSS/MLSS ratio during 52 days of MBR operation at HRT and SRT of 18 h and 10 days, respectively. The results of one-way ANOVA analysis (data not presented here) showed that at the significance level of 5%, steady state conditions with regard to MLSS and MLVSS were attained after day 50 and 43, respectively. During the MBR operation, the average value of MLSS and MLVSS concentration increased from 3130±444 mg L^{-1} and 2292±611 mg L^{-1} to 4313±135 mg L^{-1} and 2340±35 mg L^{-1}, respectively. The increasing trend of MLSS and MLVSS with operation time after day 20 revealed that the wastewater under study had no toxic effect on the microbial growth and the net growth rate was higher than the rate of biomass removal being necessary to maintain the SRT at 10 days. Nevertheless, the decreasing trend of MLVSS/MLSS ratio during MBR operation from 0.73 to 0.54 (Figure 2) demonstrated that accumulation of inorganic matter inside the MBR that came from the pretreatment step using coagulants, might have occurred.

The question is: Are there any possible relations between MLVSS with mixed liquor O&G and biopolymers? To answer this question, the concentration of mixed liquor O&G, COD and SMP_{total} during MBR operation is presented in Figure 3. Univariate correlation analysis revealed the presence of a statistically significant linear correlation between mixed liquor O&G and SMP_{total} (r_P = 0.792; p-value = 0.034, where r_P is the Pearson's correlation coefficient) throughout the operation of the MBR, but the correlation between MLVSS with mixed liquor O&G, COD and SMP_{total} were not statistically significant. These results revealed that increase in MLVSS concentration was due to an increase in cell concentration and was not related to the accumulation of O&G and biopolymers inside the bioreactor.

3. 2. Removal Performance of the MBR Increasing the concentration of biomass can enhance the organic compounds removal efficiency and increased oxygen uptake rate (OUR) by aerobic metabolic activity of microorganisms [22].

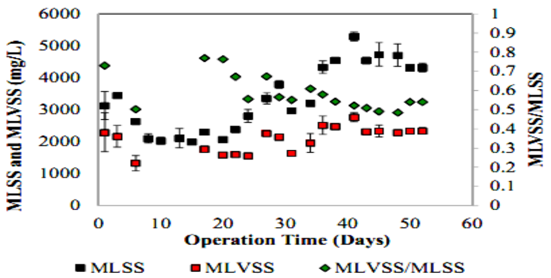

Figure 2. Variations of MLSS and MLVSS concentration and MLVSS/MLSS ratio during MBR operation

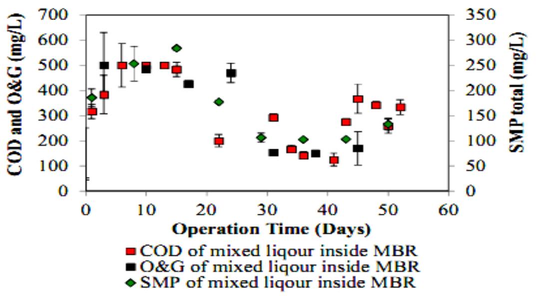

Figure 3. Variations of COD, O&G, and SMP_{total} in the mixed liquor inside the MBR during operation time of 52 days

The concentration of MLVSS, feed to microorganisms (F/M) ratio, OUR and SOUR during MBR operation is presented in Table 2. As it is shown, despite decreasing F/M ratio during MBR operation time, with increasing MLVSS concentration, the concentration of SOUR increased. The increase in SOUR concentration might be explained by the increase in OUR at high MLSS values for biodegradation of oily pollutants.

The trend of changes of COD and O&G removal efficiency, and the concentration of COD and O&G in the influent and effluent of the MBR system, during MBR operation at HRT and SRT of 18 h and 10 days, are presented in Figures 4a and 4b, respectively. As it is shown, the average COD and O&G removal efficiency as well as the effluent COD and O&G concentration in the present study were 73.2±6.6% and 75.1±2.5%, and 252.6±100.4 mg L^{-1} and 18.2±1.7 mg L^{-1}, respectively. In previous study by Abdollahzadeh Sharghi et al. [15] the COD and O&G removal efficiency from the sunflower oil refinery wastewater using MBR at SRT of 20 days and HRT of 48 h, were 85.0±1.3% and 82.7±1.4%, respectively. The better removal performance observed in the previous study compared to the present work was found to be related to relatively high used HRT as well as difference in the nature of wastewater. The results of the present study exhibited almost similar performance of MBR system in term of COD and O&G removal in treating VOWs compared to common biological systems. A COD removal efficiency of 72% has been reported by Ozturk et al. [23] using an ASP. Degenaar et al. [24] also achieved an average COD removal capacity of 84% using an ASP process at SRT of 15 days. Azbar and Yonar [25] used an ASP system with a HRT of 24 h and their results were indicative of COD removal efficiencies of 82% and 74-82% in lab and full scale operations, respectively. However, due to lack of filamentous growth and subsequent poor floc formation in the ASP, the high concentration of suspended solids in the effluent was a persistent problem.

Variations of turbidity removal efficiency and influent and effluent turbidity during MBR operation are presented in Figure 4c. Free oil in VOW successfully eliminated by a primary gravity separation treatment, but emulsified oil as a part of the influent turbidity remains a challenge for a secondary treatment stage.

TABLE 2. The concentration of MLVSS, F/M ratio, OUR and SOUR during MBR operation at SRT of 10 days

Operation Time (days)	8	28	38	45
F/M (kg COD kg $MLVSS^{-1}$ d^{-1})	1.15	0.70	0.53	0.58
MLVSS (mg L^{-1})	1328	2200	2475	2336
OUR (mg O_2 h^{-1})	14.04	20.40	22.36	26.67
SOUR (mg O_2 g $MLVSS^{-1}$ h^{-1})	10.57	9.27	9.04	11.42

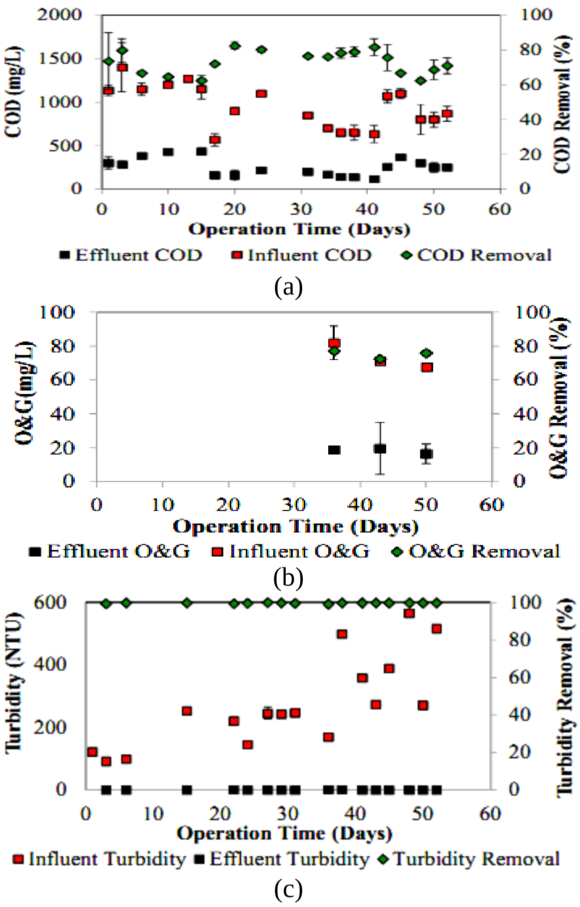

Figure 4. Variations of (a) COD, (b) O&G, and (c) turbidity removal efficiency, and the influent and effluent concentration during MBR operation

Membrane technology has been suggested as an alternative treatment capable of high effluent purification and recovery of the oily retentate, but its fouling rate is high when used alone [26]. An MBR, the combination of a membrane process with a suspended growth bioreactor, is an efficient alternative approach to the treatment of this type of wastewater and allows microorganisms to efficiently biodegrade the oily retentate by the membrane inside the reactor. The results of present work showed that despite high turbidity in the VOW influent (277.5±144.7 NTU), the effluent turbidity was consistently less than 1.4 NTU and turbidity removal efficiency was more than 99% during the entire MBR operation, which revealed a very good performance of the UF membrane in terms of turbidity removal especially for the oily industrial wastewaters.

3. 3. Fouling of Membrane during the MBR Operation Evaluation of fouling during the MBR operation in the present work was performed through monitoring of transmembrane pressure (TMP). The membrane fouling rate during the 52 days operation of the MBR was very low and the TMP remained in the range 0.22–1.02 kPa (date not presented here), therefore, the need for membrane cleaning never rose. In the study of Ma et al. [14] using combined system of aerobic reactor and submerged MBR with infinite SRT and optimum HRT of 18 h, as a result of complete sludge retention and subsequent increase in MLSS concentration (up to 11000 mg L^{-1}), the membrane module was significantly fouled every 40 days and the need for membrane cleaning was essential. However, in present work, as a result of low SRT, the concentration of MLSS had a slight increase and finally stabilized at the average concentration of 4313±135 mg L^{-1}.

3. 4. Morphological Characterization of the Activated Sludge Mixed Liquor during MBR Operation In the present study, morphology of the activated sludge inside the MBR during the MBR operation was characterized through monitoring both ST and SVI throughout the 52 days of operation (Figure 5). ST can be a measure of the population of dispersed bacteria as well as that of oil droplets whereas SVI value represents the activated sludge floc compressibility [9, 11]. As can be seen in Figure 5, ST increased from 27.8.3±0.4 NTU at the first day to 82.3±1.7 NTU at day 22 and then decreased and remained almost constant at the average value of 20.4±3.3 NTU in the last days of MBR operation. Part of the changes of ST was related to the suspended oil particles inside the reactor (Figure 3) while the other part was related to the dispersed bacterial populations. Univariate correlation analysis revealed the presence of a statistically significant linear correlation between average concentration of mixed liquor O&G and ST throughout the operation of the MBR (r_P=0.772; p-value=0.042). This finding showed that during MBR operation, bioflocculating ability of the bacterial population changed and improved in the last days of MBR operation. Decrease in SVI values from 76.7 mL g^{-1} MLSS in the first day to 44.0 mL g^{-1} MLSS at the end of the operation, furthermore, indicated that the structure of sludge flocs changed to flocs with higher compressibility.

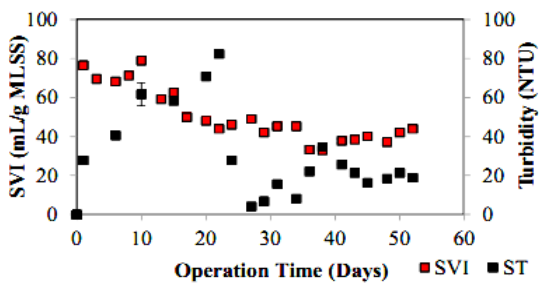

Figure 5. Variation of SVI and ST during MBR operation

Generally, sludge bulking (SVI more than 150 mL g^{-1} MLSS) is characterized by an imbalance between floc-forming and filamentous bacteria in the microbial aggregates of sludge and occurs when aggregates do not compact and form a loose, low density floc [11].

In order to understand the effect of EPS and its components as major structural components of flocs on morphological changes, the concentration of EPS and its components was monitored throughout the operation of the MBR (Figure 6). Statistical analyses of experimental data using univariate linear correlation analysis indicated that the correlation between total EPS and its components with mixed liquor O&G was statistically significant (Table 3). These results demonstrated that a probable explanation for change in EPS production could be the change in the mixed liquor O&G concentration that induced microorganisms to secret EPS to the cell surfaces.

The trend of changes in total EPS and its components with ST (except EPS_h) and SVI (except EPS_p) were found to be statistically significant (Table 4). The direct correlation between total EPS with SVI and ST has also been reported in previous studies [9, 10, 12, 13, 27]. This effect has been partly explained through the corresponding effect of EPS on surface charge of flocs (due to stronger electrostatic repulsion between negatively charged floc components as described by the DLVO theory) [12] and partly by steric forces that EPS may create when EPS molecules extend out from cell surfaces and physically prevent the cells from forming close contact [2, 9].

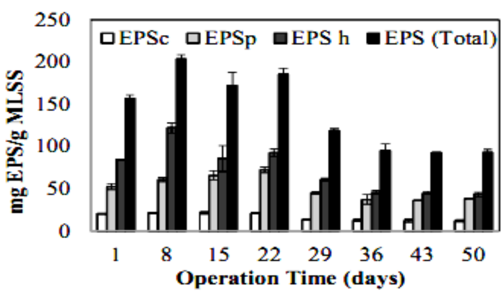

Figure 6. Variation of the concentration of total EPS and its components (EPSp and EPSc) during the operation of MBR

TABLE 3. The results of univariate linear correlation analysis (r_p and p-value) between the trend of changes of total EPS and its components with that of mixed liquor O&G during MBR operation

Chemical constituent	mixed liquor O&G (mg L^{-1})	
	r_p	p-value
EPS_c (mg EPS g^{-1} MLSS)	0.979	0.000
EPS_p (mg EPS g^{-1} MLSS)	0.839	0.018
EPS_h (mg EPS g^{-1} MLSS)	0.884	0.008
EPS_{total} (mg EPS g^{-1} MLSS)	0.920	0.003

3. 5. Microscopic Observation Microscopic observation was used to visualize the microbial morphology of activated sludge flocs during the MBR operation. Microscopic analysis (Figure 7) on day 1 of MBR operation revealed the presence of two size flocs with loosely structures, filamentous sludge and also dispersed bacteria. It has been hypothesized that filamentous microorganisms serve as a backbone for the flocs to provide more binding sites for the attachment of free cells or smaller aggregates by EPS [2]. But, microscopic evaluation of the activated sludge on day 52 of the MBR operation revealed dramatic shifts in floc structure to smaller flocs size with higher compressibility (SVI=44.0 mL g^{-1} MLSS) and also higher bioflocculating ability (Figure 5).

3. 6. Sludge PSD Analysis Generally, foc size is a parameter that specifies sludge morphology. In MBRs, floc size is strictly related to the stability of sludge flocs and the applied shear force [3]. The results of PSD analysis (based on volume) presented in Figure 8 showed a wide range of particle sizes from below 3 µm to 425 µm for day 1 of MBR operation.

TABLE 4. The results of univariate linear correlation analysis (r_p and p-value) between the trend of change of total EPS and its components with that of ST and SVI during MBR operation

Chemical constituent	ST (NTU)		SVI (mL g^{-1} MLSS)	
	r_p	p-value	r_p	p-value
EPS_c (mg EPS g^{-1} MLSS)	0.780	0.023	0.804	0.016
EPS_p (mg EPS g^{-1} MLSS)	0.893	0.003	0.537	0.170
EPS_h (mg EPS g^{-1} MLSS)	0.666	0.072	0.779	0.023
EPS_{total} (mg EPS g^{-1} MLSS)	0.773	0.024	0.736	0.037

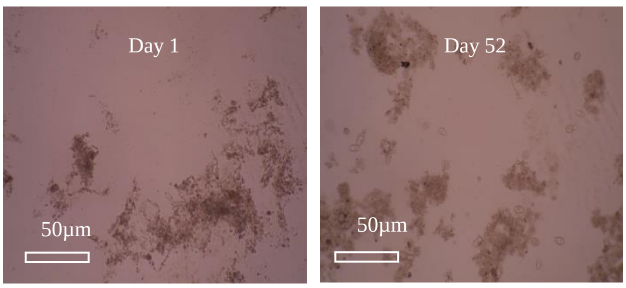

Figure. 7. Microscopic observations of mixed liquor samples during the MBR operation

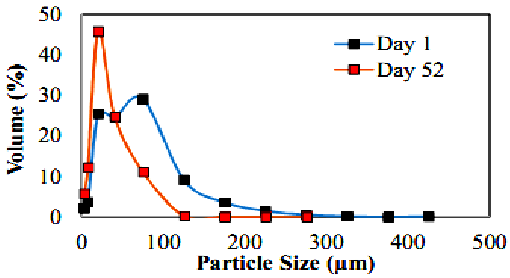

Figure. 8. Mixed liquor PSD (based on volumetric values) at the start and the end of MBR operation

However, PSD analysis of samples from day 52 showed a significant decrease in the range of particle sizes with the biggest particles having size less than around 125 µm. According to Figure 8, the PSD of mixed liquor sample from day 5 of MBR operation is bimodal (with modes of 20 µm and 75 µm) whereas that from day 52 is unimodal (with mode of 20 µm). Also, the PSD curve at day 52 had a higher left hand area compared to the corresponding curve at day 1. This could be due to dramatic shifts in floc structure to smaller flocs size (Figure 5 and 7). These results further confirm the shift to compact floccular morphology at the end of MBR operation.

4. CONCLUSIONS

In the present study a submerged MBR was evaluated for the treatment of sunflower oil refinery wastewater containing high oleic content, and the performance of organic pollutant removal, membrane fouling and sludge morphology was studied at short values of 18 h and 10 days for HRT and SRT, respectively. During 52 days operation of the MBR, high turbidity and fairly good COD and O&G removal efficiencies were achieved and the rate of membrane fouling was negligible. The results showed a statistically significant linear correlation between the mixed liquor O&G with SMP and EPS. Additionally, despite decreasing F/M ratio during MBR operation time, increase in MLVSS concentration which was due to an increase in cell concentration and was not related to accumulation of O&G and biopolymers inside the bioreactor, increased OUR and SOUR. The trend of changes in SVI and ST with EPS was also found to be statistically significant. The results of SVI, ST, EPS, PSD and microscopic observation showed change in sludge morphology to flocs of smaller size with high compressibility and bioflocculating ability. The results of the present study were indicative of a very good potential of the MBR in terms of removal performance and membrane fouling, for treatment of sunflower oil refinery wastewater containing high oleic content.

5. ACKNOWLEDGEMENT

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The Influence of Short Values of Hydraulic and Sludge Retention Time on Performance of a Membrane Bioreactor Treating Sunflower Oil Refinery Wastewater

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چکیده

در این تحقیق، عملکرد حذف آلاینده های آلی، گرفتگی غشا و مورفولوژی لجن یک بیوراکتور غشایی (MBR) غوطه ور برای تصفیه پساب پالایش روغن آفتابگردان حاوی اسید اولئیک بالا (HOSORW) در طول ۵۲ روز عملیات در مقادیر پایین ۱۸ ساعت و ۱۰ روز برای زمان ماند هیدرولیکی و زمان ماند لجن به ترتیب، مطالعه شد. بازده حذف اکسیژن مورد نیاز شیمیایی (COD)، روغن و گریس (O&G) و کدورت از پساب به ترتیب ۷۳/۲±۶/۶٪، ۷۵/۱±۲/۵٪ و ۹۹/۷±۰/۱٪ بود و نیاز به شستشوی غشا هرگز دیده نشد. نتایج یک رابطه خطی معنی دار آماری بین O&G با محصولات محلول میکروبی و مواد پلیمری خارج سلولی (EPStotal) نشان داد (به ترتیب، rP =۰/۷۹۲؛ p-value=۰/۰۳۴ و rP =۰/۹۲۰؛ p-value=۰/۰۰۳). همچنین افزایش غلظت MLVSS که به دلیل یک افزایش در غلظت سلول بوده و به تجمع O&G و پلیمرهای زیستی در داخل راکتور مربوط نبوده، نرخ ویژه مصرف اکسیژن را افزایش داده است. روند تغییرات شاخص حجمی لجن (SVI) و کدورت رویی (ST) با EPStotal از نظر آماری معنی دار بود (به ترتیب، rP =۰/۷۳۶؛ p-value=۰/۰۳۷ و rP =۰/۷۷۳؛ p-value=۰/۰۲۴). نتایج حاصل از SVI، ST، EPS، توزیع اندازه ذرات و مشاهده میکروسکوپی نشان دهنده تغییر در مورفولوژی لجن به لخته هایی با اندازه کوچکتر (تک قله ای، با قله20 μm) با تراکم پذیری (mL g–1 MLSS 0/44=SVI) و توانایی لخته شدن بیولوژیکی (NTU 3/3±4/20=ST) بالاتر بود. نتایج حاصل از این مطالعه نشان دهنده پتانسیل بسیار خوب MBR در تصفیه HOSORWs است.

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