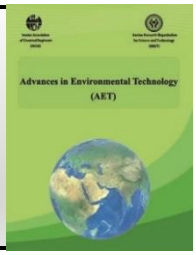
DOI: http://dx.doi.org/10.22104/aet.2015.369 Advances in Environmental Technology 3 (2015) 105-111

Advances in Environmental Technology

journal homepage: http://aet.irost.ir



Efficient treatment of baker's yeast wastewater using aerobic membrane bioreactor

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ARTICLE INFO

Article history:
Received 25 February 2016
Received in revised form
16 May 2016
Accepted 13 June 2016

Keywords:
Baker's yeast wastewater
Hollow fiber membrane
Membrane bioreactor
Membrane fouling
Wastewater treatment

ABSTRACT

A 0.15 µm dead-end immersed hollow fiber membrane and filamentous fungus *Aspergillus oryzae* were used in a membrane bioreactor (MBR) for treatment of baker's yeast wastewater. The fungus was adapted to the wastewater in the bioreactor for two weeks before continuous process. Average organic loading rate of 4.2 kg COD/m^3.d was entered the bioreactor. COD and BOD_5 of the wastewater were reduced to 488 and 70 mg/L, respectively, over a period of 45 days, while the turbidity of the wastewater reduced from 134-282 NTU to less than 2.5 NTU in the permeate stream. Critical flux and a suitable operating flux were determined as 6.7 and 5 L/m^2 h, respectively. The system was able to efficiently reduce the turbidity and suspended solid by 99.4% and 98.3%, respectively, resulting in a clear effluent.

1. Introduction

Baker's yeast is nowadays widely produced and used in breading of bread industries worldwide [1]. The wastewater of the baker's yeast factory is one of the high strength wastewaters that contain high concentrations of slowly biodegradable organic materials [2]. High load of organic compounds such as sugars, carbohydrates, and fermented products is one of the main characteristics of the wastewater [3, 4]. Molasses, a by-product of sugar manufacturing factories, is the main raw material for baker's yeast production [5]. It contains 45-50% residual sugars that is easily consumed by yeast, while the rest of molasses is non sugary compounds (15-20% non-sugar organic substances, 10-15% ash that is mineral compounds and around 20% water) [4]. A major part of non- sugary compounds are not converted by yeast and released to the wastewater [3]. Thus, the wastewater contains the non-sugar compounds, yeast metabolites, and chemicals added during the fermentation [3]. Antioxidant properties of melanoidines cause their recalcitrance to biodegradation [5]. Various processes such as carbon adsorption [6], electrocoagulation [7] and biological degradation with ozonation [8] have been investigated on molasses wastewater.

Membrane technology, nowadays, are used in many water and wastewater treatment processes [9, 10]. Membrane bioreactor is one of the efficient technologies for wastewater treatment that received significant attentions in the last two decades [11-15]. The combination of common activated sludge wastewater treatment and physical filtration by membrane called membrane bioreactor. Unlike common biological treatments, membrane bioreactors do not need a downstream stage [16]. Membrane bioreactor has some advantages in comparison with common biological treatment, e.g., less sludge production, less footprint, higher quality of effluent, treatment with different hydraulic retention and sludge retention times, and high performance in disinfection [17, 18].

The purpose of this study is to investigate treatment of baker's yeast wastewater by *Aspergillus orayze* in a membrane bioreactor (MBR). *A. orayze* is a non-pathogenic

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fungus widely used in many food industry wastewater treatment processes because of appropriate cultural status and absence of harmful by-product [19, 20]. During 45 days of experiment changes in mixed liquor suspended solid (MLSS), chemical oxygen demand (COD), biological oxygen demand (BOD) and turbidity was investigated, also membrane operational factors such as, critical flux and membrane resistance distribution was determined.

2. Material and methods

A baker's yeast wastewater was obtained from Shahr-e-kord baker's yeast factory (Shahrekord, Iran). Main characteristics of wastewater are given in Table 1.

Table 1. Wastewater characteristics

Parameter	Unit	Value
COD	mg/L	2550-5070
BOD_5	mg/L	460-1460
Turbidity	NTU	134-282
SS	mg/L	500-1200
pH	-	5.4-6.7

A membrane bioreactor (Plexiglas) with 50 cm long, 15 cm wide, 50 cm high, and 30 L working volume was used in all treatments (Pars Polymer, Isfahan, Iran). The wastewater was continuously fed to the reactor using a diaphragm pump (ROUltraTec, USA). Continuous aeration was provided by an air pump (Aco-208, Hailea, china) through the spargers located at the bottom of the reactor. A circular sparger was contrived exactly at the beneath of the membrane module (Fig. 1).

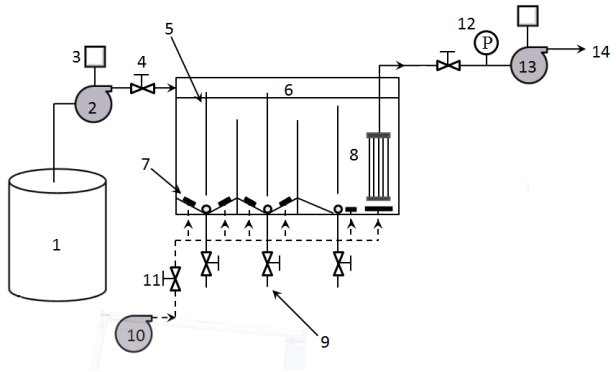

Fig. 1. Experimental membrane reactor setup. The numbers on the figure indicate: (1) feed tank, (2) feed pump, (3) feed pump controller, (4) feed valve, (5) Compartment wall, (6) bioreactor, (7) sparger, (8) membrane module, (9) sludge drain valve, (10) aeration pump, (11) air regulation valve, (12) pressure indicator, (13) effluent pump, (14) permeate stream

Besides providing the oxygen for the system, aeration had a role in agitation and cleaning of the membrane surface [21, 22]. The bottom of reactor was designed gradient to ease the sludge discharge. Hollow fiber, dead-end membrane module was used in the MBR that submerged in the bioreactor. Membrane characteristics are presented in Table 2.

A peristaltic pump was used for MBR effluent (Etaron DS, Italy). After each 5.5 minute of operation, effluent suction pump turned off for 30 seconds. This have done to mitigate cake layer formation and membrane fouling. In case of drastic fouling that occurred time to time, membrane module was removed from the reactor and physically washed by tap water for few minutes. Physical washing effectively removed the cake layer from membrane surface. Occasionally when physical washing was not enough, membrane was soaked in 8% solution of NaOCl for 4 h. After chemical washing, permeability of membrane was mostly recovered. Membrane before and after chemical washing are demonstrated in Fig. 2.

Table 2. Membrane module characteristics

Membrane substance	polypropylene
Fiber length(cm)	12.5
Fiber outer diameter(mm)	0.35
Fiber inner diameter(mm)	0.25
Mean pore size(μm)	0.15
Membrane total area(m^2)	0.3

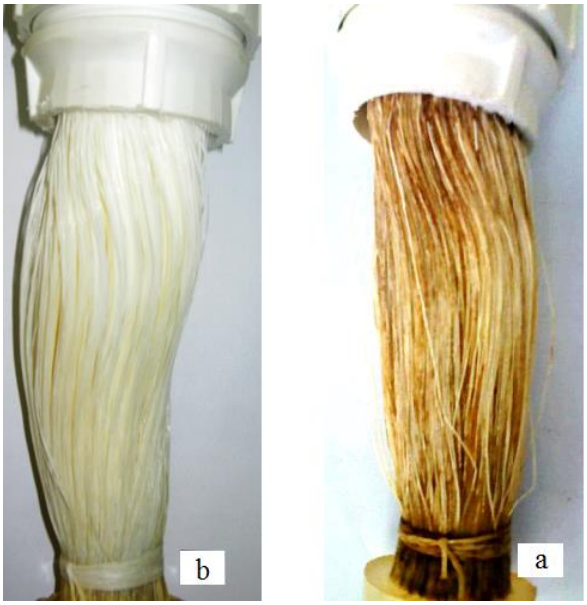

Fig. 2. Membrane before (a) and after (b) chemical washing

2.1. Micro-organism preparation

Filamentous fungus *Aspergillus orayze* PTCC 5163 purchased from Persian Type Culture Collection was used in all treatments. The fungi was cultivated on a solid medium containing 20 g/L malt extract, 20 g/L glucose, 1 g/L peptone and 20 g/L agar. Then, the fungal biomass was prepared in a liquid medium containing 50 g/L glucose for 4 days. The fungus was adapted to the wastewater for two weeks. In the beginning of adaptation, glucose was given to microorganism as a carbon source. During the adaptation,

the carbon source of the feed was gradually substituted by the wastewater in a two weeks process.

2.2. Factors affecting the membrane flux

Flux of filtration, an important factor that determines the performance of filtration, depends on different factors such as operational conditions and membrane fouling. Factors affecting the fouling are membrane characteristics such as material, hydrophobicity, and porosity, biomass characteristics such as mixed liquor suspended solid (MLSS), soluble microbial product (SMP), extracellular polymeric substances (EPS), floc size and structure, and operating conditions such as configuration, solid retention time (SRT), hydraulic retention time (HRT), and trans-membrane pressure (TMP) [23-26]. Equation 1 shows the relationship between TMP and flux according to Darcy's law [17]:

$$J = \frac{TMP}{\mu R_t} \quad (1)$$

$$R_t = R_m + R_c + R_f \quad (2)$$

Where R_m is the membrane resistance when the membrane is clean. R_m is a constant depending on the membrane characteristics. R_f is the fouling resistance that is resistance after cake removing minus membrane resistance. R_c is the parameter related to the cake formation and is the difference between total mass transfer resistance before and after the cake removal.

2.3. Critical flux

Membrane fouling leads to significant increase in the hydraulic resistance that causes the reduction of flux in the case of constant TMP or increment in TMP if the flux was kept constant. Principally, submerged membrane bioreactor works in constant flux conditions [27]. Critical flux is an important operating parameter that can help to avoid membrane fouling. Several parameters such as soluble chemical oxygen demand (COD), sludge concentration, aeration rate and even initial flux can affect critical flux of membrane [28]. At fluxes below the critical flux, fouling do not happens. Although there is no accurate approach to determine the critical flux, step flux method can be useful. In this method, two TMP value must be measured that is TMP after sudden increase in flux (TMP_i) and TMP at the end of step (TMP_f). TMP_i usually measured after 30 seconds from flux change. Initial TMP increment (ΔP_0) represents difference in TMP caused by step increase in flux [29].

$$\Delta P_0 = TMP_i^n - TMP_i^{n-1} \quad (3)$$

Rate of TMP increase and average TMP presented in equations 4 and 5, respectively [29]

$$\frac{dP}{dt} = \frac{TMP_f^n - TMP_i^n}{t_f^n - t_i^n} \quad (4)$$

$$P_{ave} = \frac{TMP_f^n + TMP_i^n}{2} \quad (5)$$

Permeability can be calculated as [29]

$$K = \frac{J}{P_{ave}} \quad (6)$$

2.4. Sampling and analytical methods

Duration the experiments, liquid samples were taken daily from the bioreactor influent, mixed liquor, and membrane effluent at the same time. All samples were taken at least twice and the averages of the results were reported. COD, BOD, turbidity, TSS, and MLSS concentrations were analyzed. COD was determined according to standard methods [30] using a COD reactor (HACH, Germany) and a UV-Vis spectrophotometer (6305, JENWEY, UK). Turbidity of the samples was analyzed using a turbidimeter (AN-2100, HACH, Germany). For DO analysis, a DO meter was used (YSI-55, YSI, USA). Hydraulic retention time (HRT) was calculated theoretically. Dissolved oxygen concentration stabilized in 2 to 4 mg/L. Table 3 represents other operating conditions.

Table 3. MBR operating conditions

Factor	Unit	Value
HRT	h	22
MLSS	mg/L	4100-9100
Organic mean load	kg COD/m^3.day	4.2
Permeate flux	l/m^2.h	5
Effluent rate	l/h	1.5
Dissolved oxygen	mg/L	1.7-3.7
pH	-	7.3-8.4
Temperature	^{0}C	25-28

Step flux method was used for critical flux determination. Initial flux was 3.3 L/m^2.h and increased every 30 min until it reached to 10 L/m^2.h. At each flux, TMP change was recorded.

3. Results and discussion

3.1. Critical flux

The rate of fouling and permeability are represented in Fig. 3. The permeability decreased by increasing the flux. Furthermore, the higher TMP was required for the higher flux, accompanying with higher fouling. The reason for higher fouling was accumulation of suspended solid on the membrane surface. TMP was increased as result of pore size reduction during the constant flux operation.

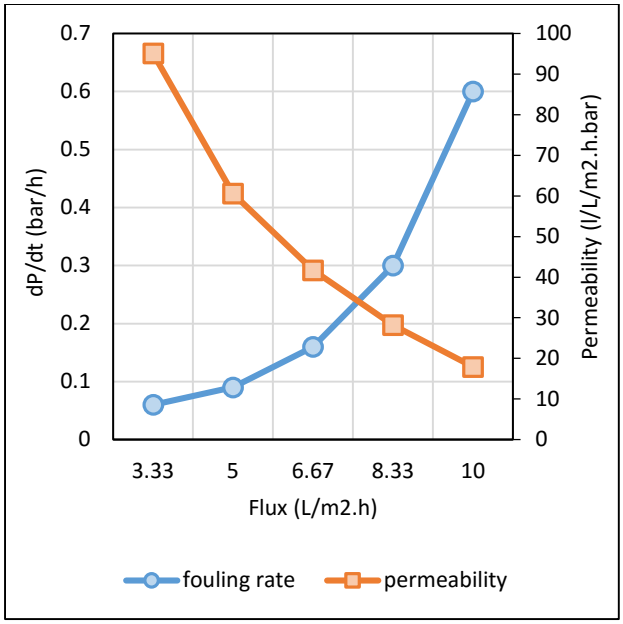

Fig. 3. Fouling rate and permeability of the membrane as a function of the flux rate

According to Fig. 3, critical flux was 6.7 L/m^2.h. Both TMP and fouling were extremely increased in fluxes higher than 6.7 L/m^2 h. When the flux was increased from 6.7 to 8.3 L/m^2 h, the fouling rate was increased from 0.16 to 0.3bar/h, whereas reduction of flux from 6.7 to 5 L/m^2 h led to reduction of fouling rate from 0.16 to 0.09 bar/h. On the other hand, at fluxes equals to 5, 6.7, and 8.3 L/m^2 h the average TMP was 82.5, 160, and 295 mbar, respectively, that represented a significant increase in the average TMP by increasing the flux from 6.7 to 8.3 L/m^2 h. According to the results, the flux of 5 L/m^2 h had a low fouling rate and at the same time high permeability.

3.2. Membrane resistance distribution

Several resistances contributed in the membrane mass transfer. The cake resistance (R_c) had a major contribution in the overall resistance while the clean membrane resistance (R_m) showed the lowest impact (Table 4). This indicates that cake layer formation is the major mechanism of fouling. Significant effect of physical cleaning on fouling indicates that cake layer was attached to membrane quite loosely.

Table 4. Membrane resistances

Resistance	value×10^{-12} (m^{-1})
Overall resistance	8.333
Clean membrane resistance	0.837
Internal fouling resistance	1.674
Cake resistance	5.822

3.3. MBR effluent quality

3.3.1. COD removal

Fig. 4 represents the COD of the bioreactor influent, mixed liquor, and membrane effluent during the process. Operation was done for 45 days, and the results of COD removal in the bioreactor and overall process are summarized in Fig. 5.

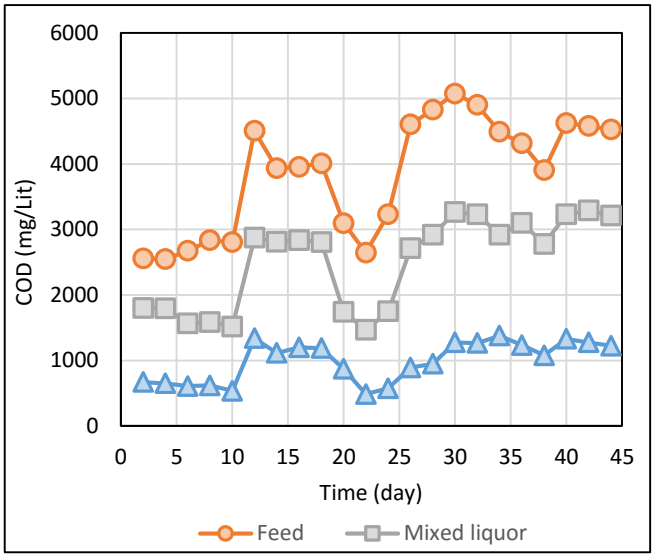

Fig. 4. COD of influent, mixed liquor, and effluent in different days of experiment

As can be seen in Fig. 4, the COD concentration of the influent at different times varied in the range of 2546 to 5074 mg/L, while the effluent had a concentration in the range of 488 to 1380 mg/L. In this situation, the maximum and minimum removal of COD were 82% and 69%, respectively. The concentration of COD in the effluent stream depended on the bioreactor influent concentration and biofilm characteristics formed on the membrane. Biofilm thickness was a factor that could affect the COD removal. The thicker the biofilm layer, the smaller particle were removed.

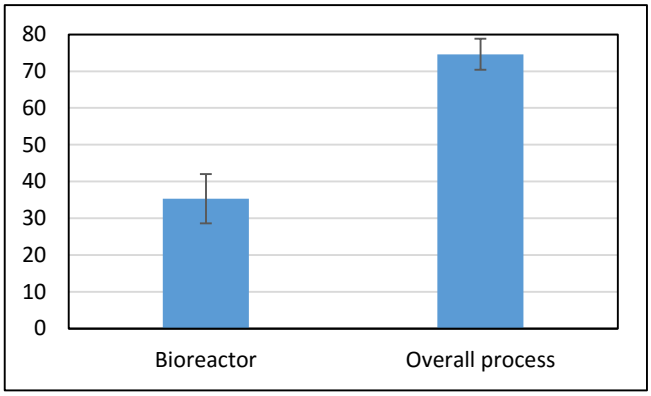

Fig. 5. COD removal in the bioreactor and overall process

3.3.2. BOD_5 removal

One of the important factors of wastewater quality is BOD_5. The BOD of bioreactor influent and membrane effluent was monitored during the experiments and is presented in Fig. 6.

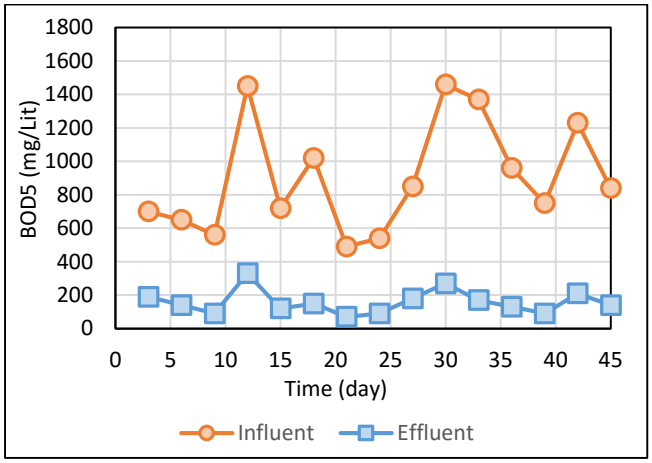

Fig. 6. BOD_5 of reactor influent and effluent

Influent BOD was varied from 540 to 1460 mg/L while the effluent BOD was varied from 70 to 330 mg/L. Fig. 7 shows that more than 72% of the initial BOD was removed. The maximum removal was 88% obtained after 39 days of operation**.**

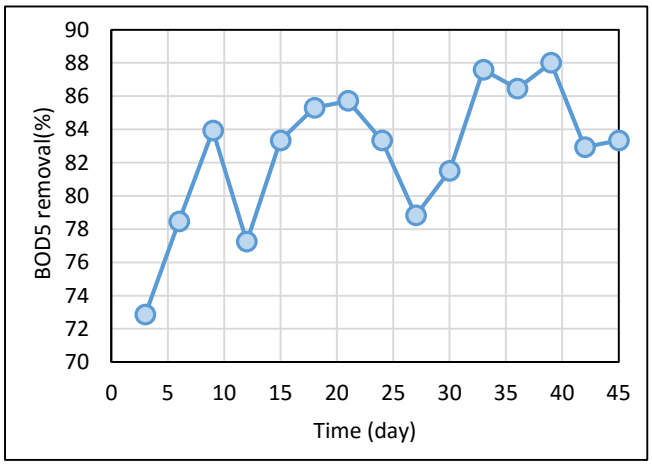

Fig. 7. BOD removal in bioreactor

3.3.3. Turbidity reduction

The turbidity of the wastewater mainly related to the organic materials. The backer's yeast wastewater used in this study had a high turbidity, in the range of 134 and 282 NTU. The turbidity in different days of operation is presented in Fig. 8

3.3.4. Suspended solid removal

The wastewater contained high level of suspended solids. The influent suspended solid concentration in different days was between 500 and 1200 mg/L whereas that of effluent was less than 30 mg/L and the least value was 5 mg/L (Fig. 10). 98.43±0.547 %of the suspended solid was removed during the experiment in the current work.

Effluent turbidity was reduced to less than 2.5 NTU, which was elimination of more than 98% of influent turbidity. Removal of the turbidity depends on the membrane pore size. Fig. 9 represents the turbidity removal percent at different days of operation.

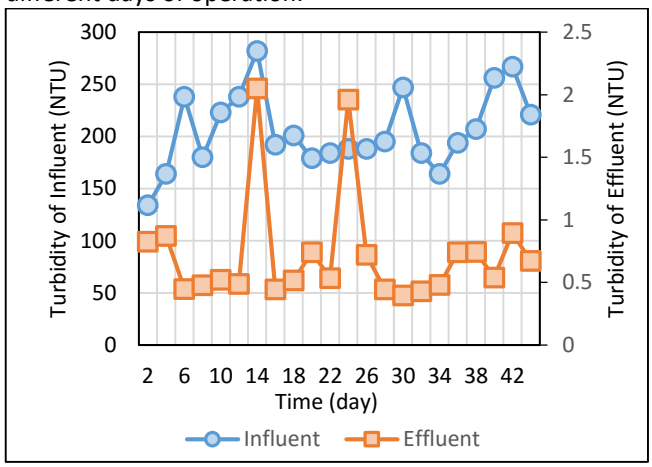

Fig. 8. Turbidity in influent and effluent during the experiment

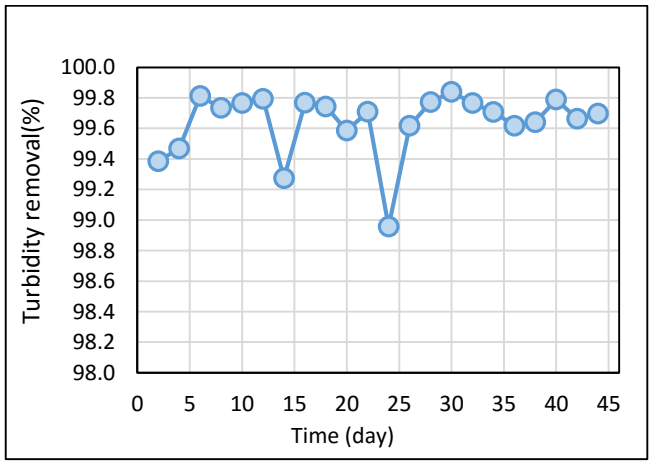

Fig. 9. Turbidity removal in bioreactor

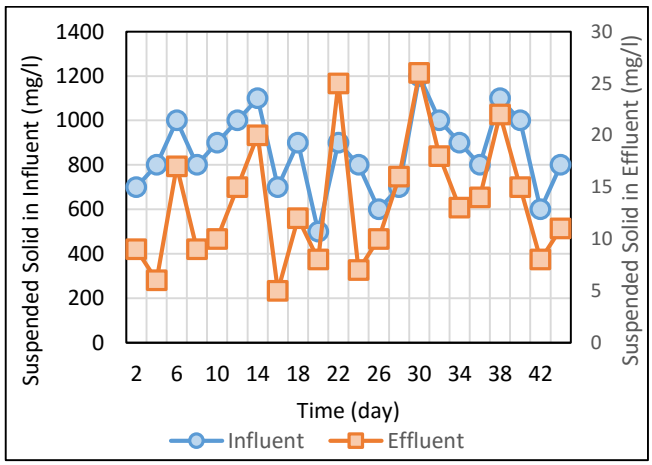

Fig. 10. Suspended solid in the Influent and Effluent

3.3.5. Mixed liquor suspended solid

MLSS concentration in the bioreactor features the active biomass concentration that consumes wastewater organic materials. Greater MLSS concentration accompanied with

better treatment of wastewater pollutants. Fig. 11 shows that MLSS in the first days of process was low while it sharply increased in the latter phase of the treatment. At the beginning of experiment, MLSS concentration was 4100 mg/L, while it increased to 7000 mg/L in 8th day of operation. The MLSS concentration increased up to 9100 mg/L. The changes in MLSS concentration at different days of the process was due to the changes in the feed and the fungal biomass concentrations.

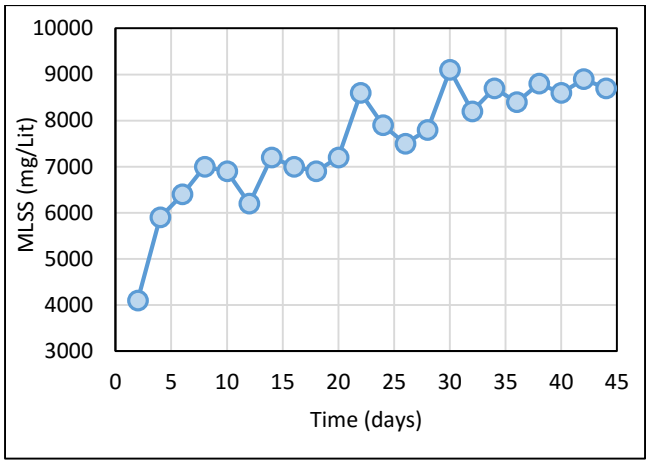

Fig. 11. MLSS concentration in bioreactor

3.3.6. Dissolved oxygen and pH

The bioreactor was continuously sparged with air to provide the aerobic conditions, and the DO concentration was monitored by a DO meter located in the bioreactor (Fig. 12). The maximum and minimum concentration of oxygen during the process were 3.7 and 1.7 mg/L, respectively.

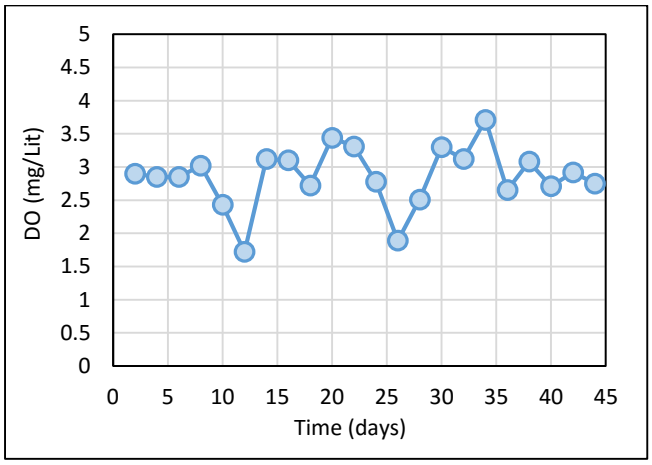

Fig. 12. Dissolved oxygen concentration in bioreactor

4. Conclusions

MBR technology using *A. oryzae* demonstrated a reasonable performance for baker's yeast wastewater treatment. Significant reduction in COD, BOD_5 and turbidity of bioreactor effluent were observed. Removing 98% of turbidity and reducing effluent to 488 mg/L in the best operation conditions, MBR demonstrates that it is a good solution for treatment of food industries wastewater. The cake resistance had the major part in membrane resistance. Sufficient back-washing protocol and aeration on membrane surface can mitigate cake resistance and fouling of membrane.

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