Use of Membrane Bioreactor for Medical Wastewater Treatment

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ABSTRACT

In this study, a lab scale modified Ludzack-Ettinger (MLE) type submerged membrane bioreactor (MLE-type MBR) system is studied to treat a hospital wastewater to remove organic matter as well as nitrogen. During the operation period, the BOD_5 and COD removal efficiency is higher than 98 and 90%, respectively regardless of the fluctuation in influent quality. In addition, the results show excellent removal of nitrogen, pathogen and TSS with average of 96, 98.33 and 99.5%, respectively. The MLE-MBR system produces high quality effluent which can achieve the Iraqi limits for irrigation purpose for all measured parameters.

Keywords: Membrane Bioreactor (MBR), Modified Ludzack-Ettinger (MLE), Nitrogen Removal and Hospital Wastewater.

استخدام الأغشية الغاطسة في المفاعل الحيوي لمعالجة مياه الصرف الصحي المطروح من المستشفيات

الخلاصة

في هذه الدراسة, تم اختبار نظام الأغشية الغاطسة في المفاعل الحيوي (هوائي محدد) لمعالجة مياه الصرف الصحي من المستشفيات من خلال إزالة المواد العضوية إضافة" إلى النتروجين. خلال فترة العمل كانت كفاءة الإزالة لكل من الأوكسجين المطلوب حيويا" والأوكسجين المطلوب كيميائيا" تزيد على 98 و 90% على التوالي, بغض النظر عن التذبذب في نوعية المياه الواردة. كما وأظهرت النتائج نسب إزالة ممتازة لكل من النتروجين, الأحياء المسببة للأمراض و المحتوى الكلي للمواد الصلبة وبمعدل نسبة إزالة تساوي96, 98,33 و 99,5% على التوالي. إن نظام الأغشية الغاطسة في المفاعل الحيوي (هوائي محدد) ينتج ماء بنوعية ممتازة يستطيع من خلالها تحقق حدود المواصفة العراقية الخاصة بالمياه المكررة لإغراض الري ولجميع المعايير المقاسة.

INTRODUCTION

Due to diminishing water supplies and increasing population, wastewater reuse is becoming necessary throughout the world to conserve natural water resources used for drinking water supply. The membrane bioreactor (MBR) is a leading edge technology currently being used in countries around the world for water reuse. Due to advances in technology and declining costs, the application of MBR technology for water reuse has sharply increased over the past several years [Naghizadeh et al., 2008].

Membrane bioreactor is a biological wastewater treatment process that uses membrane to replace the gravitational settling of conventional activated sludge process for the solid-liquid separation of sludge suspension. MBR, in which biomass is strictly separated by a membrane, offer several advantages over the conventional activated sludge process, including a higher biomass concentration, reduced footprint, low sludge production and better permeate quality [Van Dijk et al., 1997; Naghizadeh et al., 2008]. For this reason, MBR has been widely applied to remove organic pollutants as well as nutrient in wastewater [Cicek, 2003].

Oxygen demand and nitrogenous pollutants in wastewater are a potential threat to the aquatic environment and hence to public health. The oxygen demand and NH4-N can result in a DO (dissolved oxygen) depletion of the receiving water body; NO3 and NO2 are considered as the main cause of eutrophication and methemoglobinemia [Metcaf and Eddy, 1991]. Therefore, biological oxidation including nitrogen removal from wastewater became an essential treatment process to avoid organics and nitrogen contamination to the environment.

Biological nitrogen removal involves two successive processes, i.e., nitrification and denitrification. NH_4-N, the predominant form of nitrogen in untreated wastewater, can be oxidized to NO_3-N and NO_2-N by nitrification, which then converted to nitrogen gas in the subsequent denitrification process [Robertson et al., 1988]. The two processes require different conditions: nitrification occurs under aerobic conditions while gentrification prevails in the absence of oxygen [Sabalowsky, 1999]. Therefore, for the practical application, they are generally designed to occur in two or more reactors.

In MBR applications, biological nitrogen removal can be achieved by two types of MBR systems: the single-reactor-type MBR and the modified Luzack-Ettinger (MLE)-type MBR. The single-reactor-type MBR introduced the alternating aerobic and anoxic conditions to a submerged MBR by intermittent aeration in the aerobic tank. However, filtration operation in this type of MBR is limited during only the aeration period due to minimize fouling of the membrane. Therefore, the MLE-type MBR (a continuous aerated MBR together with a separated anoxic tank) was developed for continuous filtration operation, in which the mixed liquor is recycled continuously from aerobic zone to anoxic zone [Yeom et al., 1999; Yuan et al., 2008].

Iraq area is characterized by arid to semi arid climate with low rainfall. Wastewater reuse is an important approach to help overcome the water scarcity problem of Iraq. Moreover, since current local wastewater treatment units in various hospitals are not capable to meet Iraqi standards (especially in terms of nutrient and pathogen removal), this study is designed to evaluate the performance of MLE-type MBR technology to treat hospital wastewater through combined removals of organic and nitrogen to a level where it could be reuse for irrigation purpose.

MATERIAL AND METHODS

Laboratory-scale experiment

The experimental setup consisted of a MLE type submerged MBR (sMBR) process. Figure (1) shows the schematic diagram of the MLE- type MBR system used in this work. A photograph of this system shown in Figure (2). The system was composed of two reactors, an anoxic reactor for denitrification and an aerobic reactor where the flat-sheet ultrafiltration membrane module was installed for organic matter removal and nitrification. The effective volumes of these two reactors were 49L and 108L, respectively. For providing the best condition of denitrification and homogenization of mixed liquor, a two submersible pump was used in the anoxic zone. Oxygen demand was supplied by air compressor attached to the diffusers inserted at the bottom of the membrane. DO concentration in the aerobic zone was kept above 4.0 mg/L while in the anoxic zone it was generally below 0.5 mg/L. The operation temperature and pH were adjusted at 29∓3°C and 6.8-8.0. The constant flux of 13 $L.m^{-2}.h^{-1}$ was maintained and the transmembrane pressure was monitored. The membrane was operated intermittently to minimize membrane fouling; 12 min suction and 3 min rest. The ultrafiltration flat sheet membrane module used in this study manufactured by Ecologix Technologies Asia Pacific, Inc., Taiwan. Specifications of the membrane module are given in the Table (1). The membrane module was placed in the center of the aerobic reactor to ensure maximum contact with the coarse bubbles and for alleviating the fouling phenomenon commonly encountered in MBR.

Raw hospital wastewater obtained from the collection wastewater basin of Baquba Teaching Hospital as influent to the system is used in this study. The raw hospital wastewater is screened with a 0.75 mm opening screener. Table (2) shows the characteristics of the influent hospital wastewater.

Operation condition

The operation condition of the lab-scale experiment is listed in Table (3). The MBR system was operated with a flow rate of 312 L/d. The hydraulic retention time (HRT) of anoxic tank and aerobic tank were 3.7 and 8.3 h, respectively. For removal of nitrate and performing denitrification process the mixed liquor suspended solid (MLSS) was returned to the anoxic reactor at a rate of 300% of the influent flow rate. Activated sludge collected from the aeration tank of the existing conventional wastewater treatment unit of Baquba Teaching Hospital was used as microorganism seeding to the system used in this study. The activated sludge was concentrated by settling to about 5000 mg/L MLSS. Then the system is fed with wastewater until reaching the steady state (8000mg/L of MLSS).The work of the experiment extended from 15 Oct. 2012 to 4 Nov. 2012.

Analytical methods

Biochemical oxygen demand (BOD) is measured using the WTW OxiTop control system, Germany. Chemical oxygen demand (COD) is measured using CSB/COD-Reactor (AL32 AQUALYT- IC, Germany). Ammonium, nitrate, nitrite and ortho-P are measured using the spectrophotometer (WTW Photo Flex, Germany). Dissolved oxygen concentration and pH are measured using the Do meter (YSI, Model 556, and USA). The measurement of mass liquor suspended solids (MLSS) and total suspended solids (TSS) follow standard [APHA, 2005]. Each analytical parameter was analyzed three times a week. The samples collected from the sampling port were analyzed on the same days, two hour after sampling.

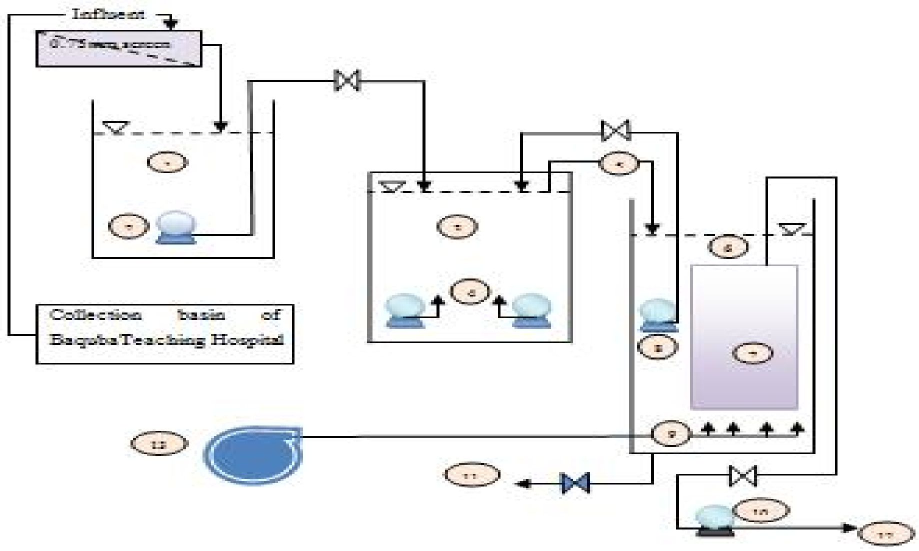

Figure (1) A schematic diagram of the MLE- type MBR system.

1	Influent tank	**5**	Sludge returning	**9**	Air diffuser
2	Submersible pump	**6**	Aerobic bioreactor	**10**	Suction pump
3	(Ax/An) bioreactor	**7**	FS membrane module	**11**	Sludge wasting
4	Submersible pump for homogenization	**8**	Submersible pump for recirculation	**12**	Permeate
				13	Air compressor

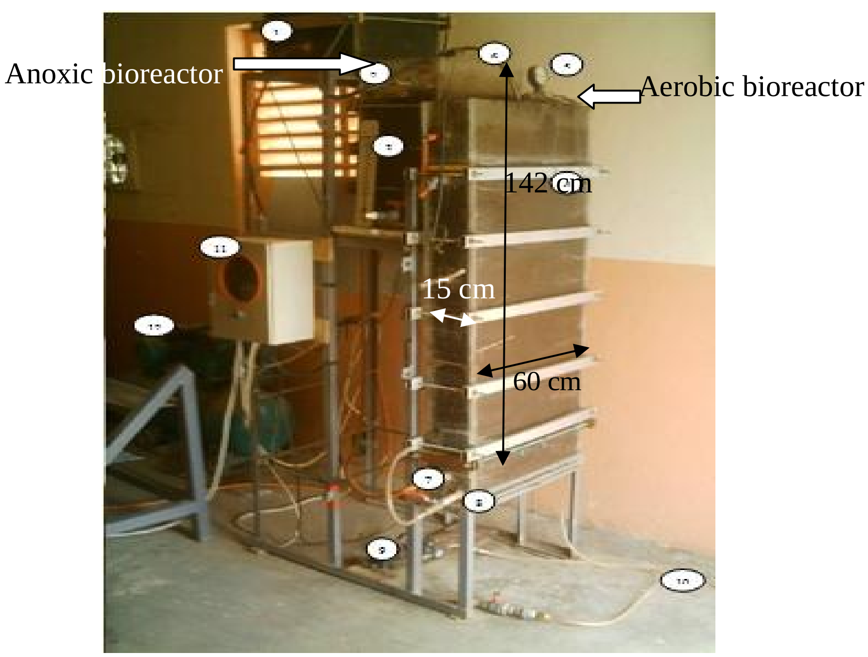

Figure (2) A photograph of the MLE-type MBR system

Table (1) Specifications of the membrane module.

Parameter	Specification
Membrane material	PVDF (Polyvinylidene fluoride)
Pore size	0.08 µm
Effective area	0.80 m^2
Transmembrane pressure (ΔP)	20 Kpa
Max. operation temperature (temp.)	40 °C
Design flux	0.4-0.85 $m^3/m^2/day$

Table (2) Typical composition of the influent wastewater

Parameters	Unit	Range	Average
Biochemical oxygen demand (BOD)	mg/l	440 - 840	620
Chemical oxygen demand (COD)	mg/l	558 - 980	750
Orthophosphate PO_4-P	mg/l	9.05 - 48	18.5
Ammonium NH_4-N	mg/l	76.3 – 232.8	154.7
Nitrate NO_3-N	mg/l	0 – 16.4	4.7
Nitrite NO_2-N	mg/l	0.1 – 0.58	0.33
Total suspended solid TSS	mg/l	100 - 254	170
pH		7.2 -7.68	7.4
Electric Conductivity	µS		2090
Fecal coliforms	MPN/100 ml	460 - 1100	780

Table (3) The operating conditions of the MLE- type MBR system

parameters	unit	Value
Flux	$L.m^{-2}.hr^{-1}$	15.12
HRT	hr	8.3
SRT	Day	95
MLSS	mg/L	8000 ± 300
Temperature	°C	29 ± 3
DO concentration	mg/L	4.2 ± 0.3
pH		6.8 – 8
VLR	$KgCOD.m^{-3}.d^{-1}$	2.929
COD/P		76.64
Operation time	day	22
internal recycle rate	L/hr	39

RESULTS AND DISCUSSION

Organic matter removal

Despite the fluctuation in the influent BOD_5 and COD (as shown in Figures (3, 4) and Table (4), the average removal efficiency of BOD_5 and COD was 98.41% and 90.76 %, corresponding to average effluent of 10.4 and 70.4 mg/L, respectively. The major part of influent organic matter was consumed during the anoxic period, as indicated by low effluent BOD_5 and COD concentration. These results were in agreement with previous study [Tadkaew et al., 2010], who reported that the removal of organic matter was varied between 90% and 99%.

Nitrogen removal

The influent and effluent value of NH_4-N were varied between 71 to 260 mg/L and 0 – 3 mg/L, respectively see Figure (5). From this figure, it can be seen that NH_4-N concentration in the effluent was 3 mg/L at the first day of experiment and became about 0 mg/L during all period of experiment (more than 99% of NH_4-N was oxidized). This indicates that the nitrification process was complete and all the influent ammonia entered in the aerobic reactor was completely oxidized into nitrate. The efficient removal of NH_4-N may be due to the retaining ability of the membranes, which increased the sludge age, allowed the combined process to maintain a large number of nitrobacteria, and ensured a good nitrification effect as being reported by Chen et al.,[2010]. From Figure (6) and Table (4), it seems that the effluent concentration of NO_3-N and NO_2-N was 12.7 and 4.09 mg/L, respectively at the first day of experiment and decreased significantly towards the end of the experimental run, giving effluent concentration of 2.4 and 0.25 mg/L respectively, this indicates high level of denitrification developed in the anoxic bioreactor, achieving average nitrogen removal efficiency of almost 96%. This is similar to the observations of Yoshimasa and Katsuki, [2006], who reported that the nitrogen removal efficiency exceeded over 95%.

Phosphorus removal

As shown in Figure (7), the biological phosphorus removal efficiency was significantly increased towards the end of the experimental run, achieving the removal efficiency in the range of 10 to 55%, with average value of 38.3%, corresponding to the average 5.6 mg/L in the effluent. These observations have indicated that the removal of phosphorus might result from the biomass synthesis rather than the biological phosphorus removal mechanisms of phosphate accumulating organisms (PAOs). That is, PAOs would not be the predominant due to the continuous introduction of nitrate into the anoxic zone by the internal recycle as supported by Ahn et al., [2003]; Puig et al., [2008]; Monclus et al., [2010].

Pathogen removal

The membranes serve as microbial barriers that can capture most of the biomass inside the bioreactor. Therefore, the MBR system produce excellent removal efficiency of pathogen (in terms of fecal coliforms) with 98.33%. This result is slightly less than that reported by Mahvi et al., [2009] who found that the rate of fecal coliforms removal had a percentage of 99.96% in Hamadan (west of Iran) hospital. This result is probably due to pollution of the system or due to experimental error in sampling, where the ultrafiltration membrane which has a pore diameter smaller than the size of bacteria and parasitic microorganisms.

Total suspended solids removal (TSS)

As shown in Table (4), the MBR system shows excellent removal efficiency of 99.5% for TSS with effluent values steady less than 1 mg/L. This result is in a good agreement with previous study [Noah et al., 2009].

Satisfaction of environmental limitations

To find out the compliance of effluent water quality from the anoxic MBR system with the irrigation limits, the measured parameters were compared with the maximum permissible concentrations according to the Iraqi limits for wastewater reuse for agricultural irrigation No. 3, 2012 (ILWRA no.3, 2012). As shown in Table (5), the anoxic MBR system is well to meet the requirements of the ILWRA no. 3, 2012 for all measured parameters and provides appropriate treatment technology that is available to produce high quality effluent to be reused for irrigation purpose (restricted agriculture) which can significantly reduce the demand for fresh water.

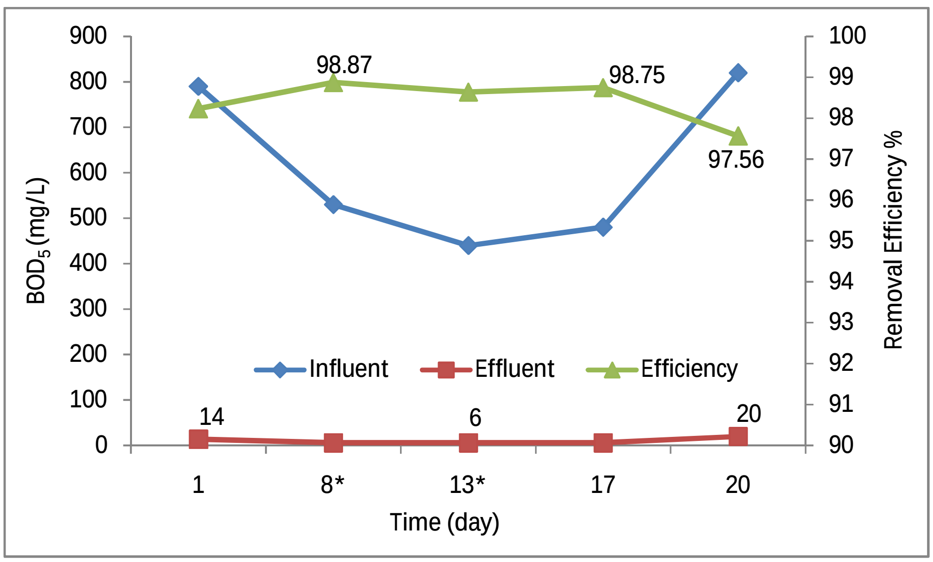

Figure (3) The influent, effluent and removal efficiency of BOD_5 for MLE-type MBR system. (*) means rainy day.

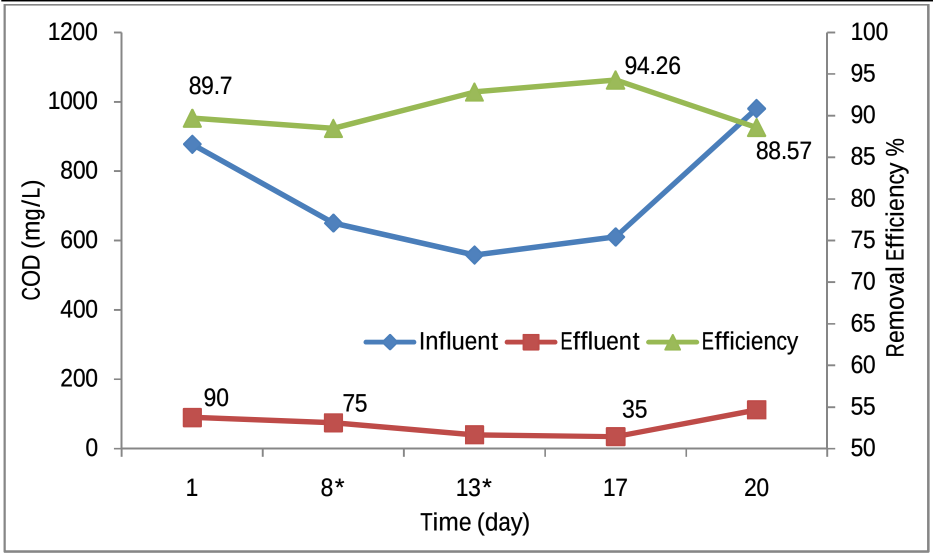

Figure (4) The influent, effluent and removal efficiency of COD for MLE- type MBR system. (*) means rainy day.

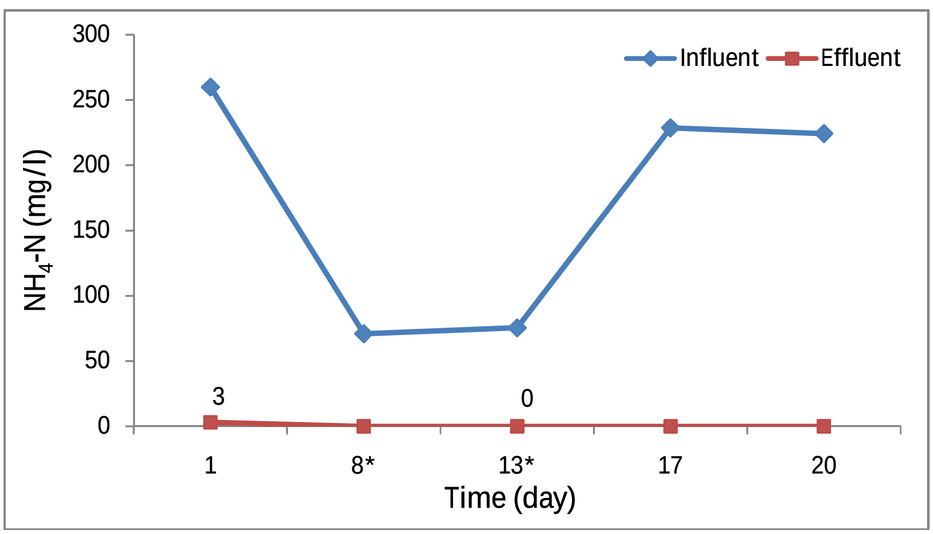

Figure (5) The influent and effluent and NH_4-N for MLE-type MBR system. (*) means rainy day.

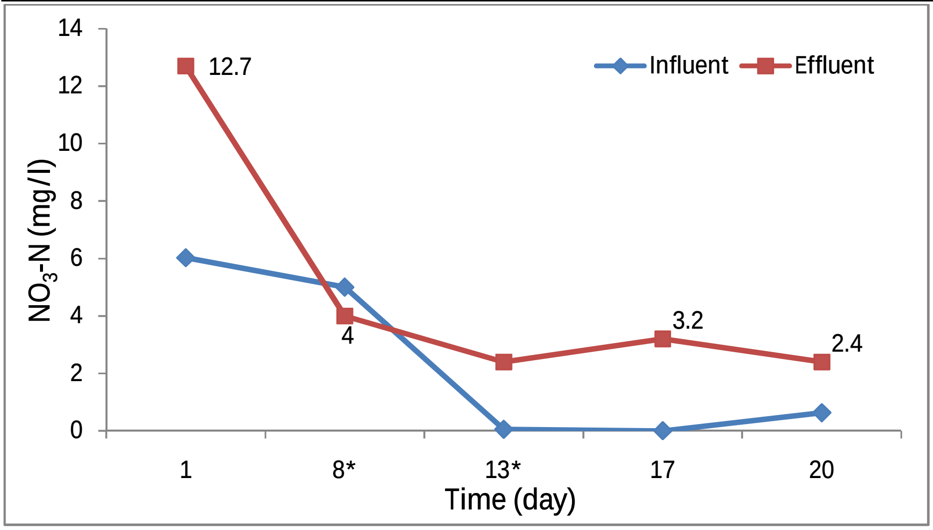

Figure (6) The influent and effluent and NO_3-N for MLE- type MBR system. (*) means rainy day.

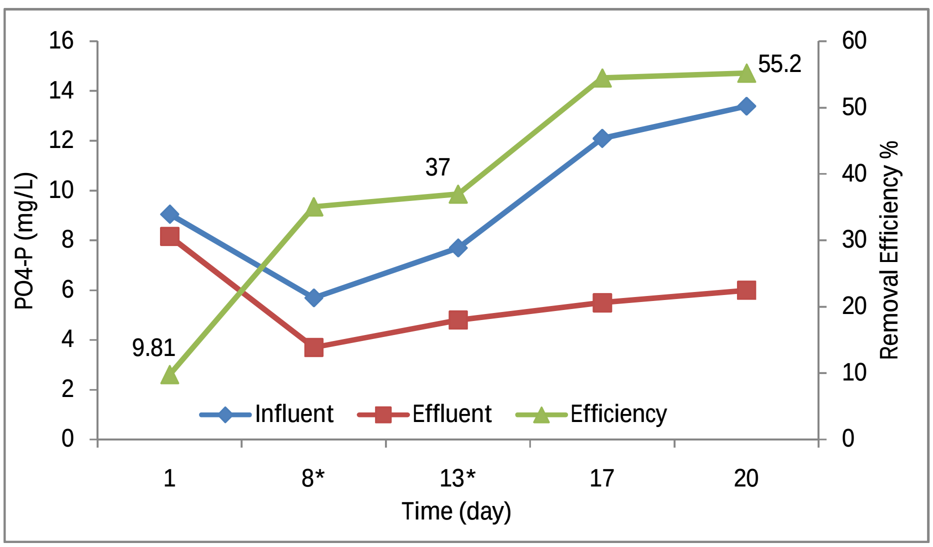

Figure (7) The influent, effluent and removal efficiency of PO_4-P for MLE-type MBR system. (*) means rainy day.

Table (4) Water quality of the influent and effluent during the experiment.

Parameters	Unit	Average value		
		Influent	Effluent	Removal Efficiency %
BOD_5	mg/L	612	10.4	98.41
COD	mg/L	735	60	90.76
NH_4-N	mg/L	170.93	0.6	99.6
NO_3-N	mg/L	2.34	4.94	
NO_2-N	mg/L	0.38	1.21	
PO_4-P	mg/L	9.6	5.6	38.3
TSS	mg/L	175	<1.0	99.5
Fecal coliforms	MPN/100ml	780	13	98.33

Table 5 Comparison of effluent MLE- type MBR system with the Iraqi limits.

parameters	TSS	BOD_5	COD	NO_3	PO_4	NH_4	Fecal coliforms
Unit	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	MPN/100ml
ILWRA no. 3, 2012	40	40	100	221	25	10	1000
Anoxic MBR system	<1.0	10.4	60.4	21.8	17.16	0.6	13

CONCLUSIONS

The performance of MLE- type MBR system shows excellent removal of pollutants from hospital wastewater for all measured parameters compared to CAS system, especially for nitrogen, BOD5, TSS and pathogens with removal efficiency of 96, 98.4, 99.5 and 98.33%, corresponding to average effluent of 6.75,10.4,<1.0mg/l and 13 MBN/100mL, respectively. The effluent water quality of MLE-MBR system is stable and does not affected by the fluctuation in the influent quality compared to CAS system.

The MLE- type MBR system provides appropriate treatment technology that is available to produce high quality effluent to be reused for irrigation purpose (restricted agriculture) which can significantly reduce the demand for fresh water.

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