



A survey on the performance of moving bed biofilm reactor and rapid sand filter in wastewater treatment

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Original Article

Abstract

Moving bed biofilm reactor (MBBR) is a process in which attached growth is utilized for wastewater treatment. This process does not require sludge recycling or backwash. Activated sludge processes can be promoted to an MBBR by adding media to an aeration tank. Rapid sand filter is a physical method for the removal of total suspended solids (TSS) in advanced wastewater treatment. The purpose of this study was the evaluation of effluent reuse feasibility of MBBR and rapid sand filter in agricultural irrigation. Results showed TSS, biochemical oxygen demand (BOD₅), and chemical oxygen demand (COD) concentrations in effluent were 10, 7.7, and 85.75 mg/l, respectively. Removal efficiency of TSS, BOD₅, and COD was 98%, 98.8%, and 94.6%, respectively. Furthermore, the value of chemical parameters was less than the standard limitations. Average removal efficiency of total coliform, fecal coliform, and nematode was 100%. Total dissolved solids (TDS) and electrical conductivity (EC) in effluent were 960.5 mg/l and 1200.63 $\mu\text{S}/\text{cm}$, respectively. The Wilcox diagram showed that effluent was in the C3-S1 class, which means effluent quality was appropriate for irrigation. The results showed that effluent quality was completely compatible with the national standards in agricultural irrigation.

KEYWORDS: Wastewater, Rapid Sand Filter, Moving Bed Biofilm Reactor (MBBR)

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Introduction

Activated sludge process is widely used for wastewater treatment. However, it has some disadvantages that affect its efficiency and can decrease the quality of effluent, such as sensitivity to hydraulic and organic shock,

sludge bulking, and sludge rising. Due to these disadvantages, in recent years, the use of processes such as membrane bioreactor (MBR) and moving bed biofilm reactor (MBBR) has increased.^{1,2}

MBBR is a process in which attached growth is utilized for conducting wastewater treatment. Media may fill 25-50% of the volume of the aeration tank. Specific area of media is about 500 m^2/m^3 . The process does

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not require sludge recycling or backwash. Activated sludge processes can be promoted to an MBBR by adding media to an aeration tank. Other advantages of MBBR include the capability to handle organic and hydraulic shock. Furthermore, through attached growth, sludge bulking cannot occur in the process.²

In the case of MBBR, in the study by Qdegaard, the removal efficiency of organic matters was reported as higher than 99%, but in most studies it was 94%.³ However, in an experimental comparison between MBBR and activated sludge system in the treatment of municipal wastewater, the efficiency of activated sludge in chemical oxygen demand (COD) removal was higher than MBBR. The average efficiencies for total COD removal were 76% for MBBR and 84% for activated sludge. The difference between the efficiency of the two systems is related to the difference in biomass concentration. Biomass concentration in activated sludge system was higher than MBBR. The average efficiencies for soluble COD were 71% for both systems.⁴

Another study was conducted on the performance of MBBR in the treatment of anaerobic reactor biowaste effluent.⁵ The total COD removal achieved was 53%. The limited COD removal achieved was in agreement with the high COD to biochemical oxygen demand (BOD₅) ratio (1:3) of the influent wastewater. Furthermore, in comparison to a sequencing batch reactor (SBR) system (30%), MBBR offered a higher dissolved COD removal (40%).⁵

Deep filtration is a physical method for removing total suspended solids (TSS) in water treatment plants and advanced wastewater treatment. Rapid sand filters, in comparison to slow sand filters, are more stable during quality variations in wastewater. Moreover, these filters have a longer lifespan.^{6,7} The application of these filters in wastewater treatment is for the removal of TSS and suspended BOD (by straining mechanism). Furthermore, considering future upgrading of plants by membrane processes, the

application of multi-bed filters before those units are proposed.^{2,6}

The quality of water used in agricultural irrigation has short-term and long-term effects on the soil. Continuous irrigation with low quality water places the land at risk of becoming non-arable.⁸ High TSS levels also cause blockage of soil pores and reduce its permeability.⁹ Moreover, high TSS reduces the efficiency of the disinfection process and can increase the possibility of nozzle clogging in drip irrigation.² The presence of large amounts of organic matters (BOD and COD) in the soil has adverse effects on soil quality, including an increase in partial pressure of carbon dioxide and temperature, and formation of organic acids during decomposition that can stabilize nutrients.^{10,11} In a study on effluent from treatment plants in Tehran, Iran, during 2005 to 2007, only in 68% of samples, TSS amount in the effluent was compatible to Iranian national standard levels.¹²

In another study on conventional activated sludge process of Tabriz treatment plant, values of BOD, COD, and TSS were 22.5 mg/l, 34 mg/l, and 16.5 mg/l, respectively.¹³ Another study on Owlang treatment plant effluent showed that average BOD₅, COD, and TSS levels were 69 mg/l, 139 mg/l, and 89 mg/l, respectively.¹⁴ The process used in Owlang treatment plant was stabilization ponds. Moreover, a research was conducted on the upgrading of a full-scale overloaded activated sludge treatment plant by MBBR technology.¹⁵ The results showed a relevant increase of up to 60% in the treated flow rate, acceptable efficiency in organic carbon removal and nitrification (equal to 88% and 90%, respectively), and the prevention of the hydraulic overload of the secondary settler.¹⁵

The purpose of this study was the evaluation of reuse feasibility of MBBR and rapid sand filter effluent in agricultural irrigation. These two processes can easily be included in existing plants to improve

performance. We expected that parameters related to organic compounds and suspended solids would be reduced by these units.

Materials and Methods

The present study was conducted on the City Center treatment plant, a commercial-recreational complex in Isfahan, Iran. The plant uses a MBBR unit for secondary treatment of wastewater. Its tertiary treatment units consist of a rapid sand filter and a granular activated carbon filter.

Wastewater retention time in MBBR is 5 hours at peak flow. Specific area of media is 494 m²/m³. Filling percentage of first aeration stage and second aeration stage by media are 50% and 25%, respectively. The diameter of the rapid sand filter vessel is 1.2 m and the height is 2.2 m. Filtration rate of the rapid sand filter is 10 m³/m²/hour. In addition, 60 cm of filter height includes two types of sand with grain size of 0.7-1.18 mm and 1.18-2 mm. The effluent did not pass through the activated carbon filter (bypass mode) and final disinfection was performed using sodium hypochlorite. The flow diagram of the treatment plant process is shown in figure 1.

Figure 1. Flow diagram of treatment plant

Sampling was performed 4 times during 6 months in the year 2013. BOD₅, COD, TSS, EC, pH, and sodium, calcium, magnesium, potassium, chloride, sulfate, total coliform, fecal coliform, and nematode content of samples were analyzed according to standard methods.¹⁶ Method ID for BOD, COD, and TSS analyses was 5210 B, 5220 C, and 2540 D, respectively. Other

method IDs are presented in table 1. In this study, mixed samples were used to analyze the process. The samples were collected during 8 hours. Although in order to undertake a more accurate investigation of process efficiency, effluent sampling was started about 6-8 hours after the beginning of influent sampling. This time is almost equal to wastewater retention time within the system.¹⁷ It is noteworthy that the data used in this study was obtained from operational records of the City Center wastewater treatment plant. The sampling and analyses were a part of routine monitoring of the plant. Thus, no study was designed for this manuscript.

Sodium adsorption ratio (SAR) was calculated according to the following equation:

$$(1) SAR = \frac{Na^+}{\sqrt{\frac{Ca^{++}+Mg^{++}}{2}}}$$

This equation is based on the integrated effect of EC (salinity hazard) and SAR (alkalinity hazard), and has been used to assess water suitability for irrigation.¹⁸ When analytical data of EC and SAR are plotted on the US salinity diagram, it is illustrated that most treated wastewater samples fall into the class of C3-S1 indicating high salinity with low sodium water, which can be used for irrigation on almost all types of soil, with only a minimum risk of exchangeable sodium. This type of water can be suitable for plants with acceptable salt tolerance, but its suitability for irrigation is restricted, especially in soils with restricted drainage.

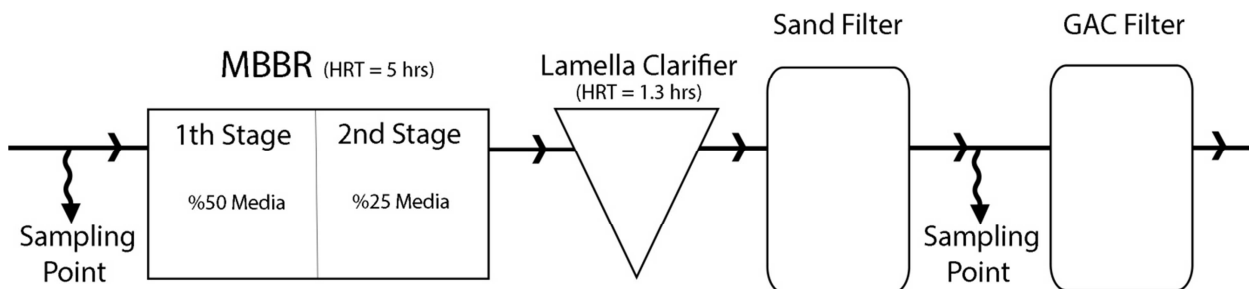


Figure 1. Flow diagram of the treatment plant
 MBBR: Moving bed biofilm reactor

Table 1. Results of analyses and standards of the Iranian Environmental Protection Agency

	Unit	Raw wastewater	Effluent	Standard	Method No.
pH	-	7.65	7.55	6.5-8.5	pH Meter-Metrohm 827
TDS	mg/l	940.00	960.50	-	2540 C
EC	µs/cm	1120.00	1200.63	-	D1125A
Sodium	mg/l	108.00	104.00	-	3500-Na B
Calcium	mg/l	80.00	78.00	-	3500-Ca B
Magnesium	mg/l	10.78	10.52	100	3500-Mg B
Potassium	mg/l	12.10	12.00	-	3500-K B
Chloride	mg/l	-	203.00	600	4500-Cl ⁻ B
Sulphate	mg/l	-	13.00	500	4500-SO ₄ ²⁻ A
Total coliform	MPN/100ml	-	0	1000	9221C
Fecal coliform	MPN/100ml	-	0	400	9221E
Nematode	-	-	0	1	10750

TDS: Total dissolved solids; EC: Electrical conductivity; MPN: Most probable number

The Wilcox diagram or US salinity diagram was used to evaluate the chemical quality of effluent. The Wilcox diagram, which is based on the integrated effect of EC (salinity hazard) and SAR (alkalinity hazard), was used to assess the suitability of water for irrigation. The diagram is not presented in this manuscript, but it is available in various references.^{18,19}

The results were analyzed in SPSS software (version 16, SPSS Inc., Chicago, IL, USA) using one-sample t-test, with P-value of 0.05 and confidence level of 0.95.

Results and Discussion

One of the parameters for assessing the quality of effluent is hydrogen ion concentration that is presented as pH. In this study, average pH of raw wastewater and effluent was 7.65 and 7.55, respectively, that is within the permitted range for discharge into the environment (pH = 6.5-8.5). This finding is compatible with the results of the study by Altin et al.²⁰

TSS, BOD₅, and COD are among the main parameters for evaluation of the performance a treatment plant. According to figure 2, average values for BOD₅ and COD in the effluent were 7.7 mg/l and 85.75 mg/l, respectively. These values are much lower than the standard limitations for wastewater reuse. In addition, as seen in figure 2, TSS removal efficiency with respect to the inlet value (495 mg/l) was very high. TSS concentration of effluent was 10

mg/l. The results indicate that MBBR and rapid sand filter are efficient in the removal of high levels of suspended solids and organic matters.²¹ Delnavaz et al. used MBBR for treating wastewater containing different COD levels (1000-3500 mg/l).²² The results showed 75-90% efficiency for a COD of 750-1000 mg/l.²² In a study on municipal wastewater reuse in Jubail treatment plant, Saudi Arabia, the biological process and filtration could achieve the values of 4.4 and 2.7 mg/l for TSS and BOD, respectively.²³

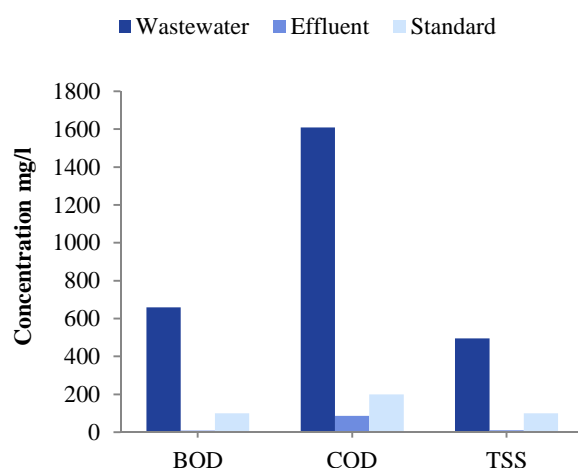


Figure 2. Comparison of total suspended solids, biochemical oxygen demand, and chemical oxygen demand levels of the effluent and standard levels

BOD: biochemical oxygen demand; COD: Chemical oxygen demand; TSS: Total suspended solids

Microorganisms and pathogens are another important issue related to wastewater effluent discharged into the environment and surface water. The presence of microorganisms in water can cause various diseases in animals and humans. Hence, the analysis of the microbial quality of raw wastewater and effluent is essential. Average removal efficiency of total coliform, fecal coliform, and nematode was 100% (Table 1). This result is not in agreement with the results of other studies on processes such as conventional activated sludge and extended activated sludge.^{24,25} This may be due to attached growth in MBBR that is supplemented for the application of rapid sand filter and chlorine disinfection. Wilen et al. in a study of sludge particle removal from wastewater through disc filtration concluded that the removal efficiency of COD and indicator microorganisms increased.²⁶ In a study by Lubello et al., through the application of filtration, peracetic acid, and UV disinfection for tertiary treatment, the most probable number (MPN) value of total coliform was 2 in 100 ml.²⁷ These results indicate the important role of sand filter and appropriate disinfection in achieving a high microbial quality.²⁷

Table 1 shows that average levels of sulphate, chloride, and magnesium are much lower than the related standards for reuse. In addition, a SAR value of 2.39 was obtained. Binavapour et al. reported the average concentration of chloride, sulphate, SAR, and magnesium as lower than the standard values.²⁸ In a study on Owlang city treatment plant, Mashhad, Iran, Pirsahab et al. concluded that the effluent was suitable for irrigation, because SAR and (residual sodium carbonate) RSC were low.¹⁴ Hashemi et al. studied the possibility of the reuse of effluent from treatment plants in Isfahan, Iran, and concluded that boron concentration and SAR in the northern treatment plant were within the permitted range for irrigation.²⁹ The northern treatment plant of Isfahan uses a two-stage

activated sludge process. In the study by Al-A'ama and Nakhla, using a biological process and filtration, the obtained total dissolved solids (TDS) and SAR values of effluent were 936 mg/l and 7.4, respectively.²³

The Willcox diagram illustrated that the studied effluent was in the C3-S1 class, which means the effluent quality is appropriate for irrigation. Considering the results of previous studies, it is evident that most treated wastewater samples fall within the C3-S1 class, indicating high salinity with low sodium water. Thus, they can be used for irrigation on almost all types of soil with only a minimum risk of exchangeable sodium. This type of water is suitable for plants with acceptable salt tolerance, but its suitability for irrigation is restricted, especially in soils with restricted drainage.¹⁹

The comparison of TDS and EC of wastewater and effluent showed that the value of the effluent had increased, which was due to the use of sodium hypochlorite for the disinfection of effluent. A way to control EC and TDS is the application of chlorine gas instead of sodium hypochlorite. Chlorine gas does not cause an increase in dissolved solids and EC. Finally, through the comparison of the results with the Iran national standards, it became clear that the effluent characteristics had complete compliance with standard values and it was suitable for reuse.

Conclusion

Results of analyses indicate that MBBR and rapid sand filter have acceptable efficiency in parameters such as BOD, COD, and TSS (98.8%, 94.6%, and 98%, respectively). Furthermore, the results showed that effluent quality in term of EC, TDS, total and fecal coliform, and nematode was completely compatible with the national standards for discharge into surface and groundwater resources and agricultural irrigation. By using the Willcox diagram, it was found that effluent

was in the C3-S1 class, indicating high salinity with low sodium water. Therefore, it can be used for irrigation on almost all types of soil with only a minimum risk of exchangeable sodium. Thus, it can be concluded that MBBR and rapid sand filter have a significant impact on treatment performance and existing plants can be upgraded using these units.

Conflict of Interests

Authors have no conflict of interests.

Acknowledgements

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