Sustainable Environment Research 26 (2016) 203–208

Contents lists available at ScienceDirect

Sustainable Environment Research

journal homepage: www.journals.elsevier.com/sustainable-environment-research/

Original research article

Electrochemically enhancement of the anaerobic baffled reactor performance as an appropriate technology for treatment of municipal wastewater in developing countries

Mohammad Aqaneghad, Gholamreza Moussavi*

Department of Environmental Health Engineering, Faculty of Medical Sciences, Tarbiat Modares University, Tehran 14115-331, Iran

A R T I C L E I N F O

Article history:
Received 5 January 2016
Received in revised form
22 February 2016
Accepted 18 April 2016
Available online 16 June 2016

Keywords:
Anaerobic baffled reactor
Municipal wastewater treatment
Electrochemical process
Electrocoagulation
Performance

A B S T R A C T

This work was aimed at investigating the performance of the anaerobic baffled reactor (ABR) for treatment of municipal wastewater at various hydraulic retention time (HRT). An effort was also made to improve the performance of ABR opting two strategies of effluent recirculation and electrochemical process integration. The mean steady-state removal of TSS, tCOD (total chemical oxygen demand), sCOD (soluble COD) and BOD (biochemical oxygen demand) at HRT of 48 h was 93 ± 1, 89 ± 1, 82 ± 1 and 92 ± 1%, respectively. The performance of ABR decreased when the HRT was decreased from 48 to 24 h. The effluent recirculation did not improve the performance of ABR. The integration of electrochemical process with the ABR (EABR) using a pair of electrodes (steel or aluminum) could enhance the removal of contaminants in the ABR. The EABR with steel electrodes at the current density of 0.1 mA cm^{-2} at the HRT of 24 h could decrease the concentrations of TSS, tCOD, BOD, sulfate and phosphate in the wastewater to the standard limits for discharge into surface water bodies. Therefore, EABR is a promising and efficient technology appropriate for domestic wastewater treatment mainly in the developing countries.
© 2016 Chinese Institute of Environmental Engineering, Taiwan. Production and hosting by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

1. Introduction

Anaerobic treatment of wastewater gained wide attention among researches and sanitary engineers, mainly due to its economical merits over the conventional aerobic methods. The major advantages of anaerobic treatment are: (1) no need to aeration and thus less energy requirement, (2) very low excess sludge production which reduces the cost of sludge management and disposal, (3) biogas production with high energy content that can be used as a fuel, (4) low nutrients requirement, and (5) application of high organic loading and thus space saving [1]. These feature posse the anaerobic process as a viable option for treatment of municipal wastewater particularly in developing countries.

A large number of full-scale anaerobic treatment plants using different anaerobic reactors including upflow anaerobic sludge blanket (UASB) and expanded granular sludge bed [2] with the satisfactory removal efficiencies have been built throughout the world [3]. However, these technologies have not been well-adopted for the decentralized treatment of rural and urban sewage in the most of developing countries because they need complex maintenance and control, and skilled manufacturers and operators. Among the high rate anaerobic reactors, anaerobic baffled reactor (ABR) are promising for municipal wastewater treatment in such a case. ABR is described as a series of UASB reactors in which the wastewater is forced to flow under and over of a series of the vertical baffles as it passes from the inlet to the outlet.

The compartmentalization of the reactor prevents horizontally movement of the biomass and thus a high amount of active biomass retains in each compartment. Indeed the bacteria within the reactor tend to rise and settle with gas production in each compartment [4]. This feature provides the excellent contact between the contaminants and the microorganisms, longer biomass retention times and better resilience to organic and hydraulic shock loadings [5]. The main feature of ABR as compared to other high-rate anaerobic reactors is its simplicity to design, construct and operate. Few studies have been performed on the treatment of municipal wastewater by ABR. The recent publications have revealed the potential of ABR for treatment of wastewater from

* Corresponding author.
E-mail address: moussavi@modares.ac.ir (G. Moussavi).
Peer review under responsibility of Chinese Institute of Environmental Engineering.

http://dx.doi.org/10.1016/j.serj.2016.04.013
2468-2039/© 2016 Chinese Institute of Environmental Engineering, Taiwan. Production and hosting by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

different sources. Nonetheless, the ABR still suffers from the defect of the low-quality effluents when treating the domestic and municipal wastewaters which may not satisfy the discharge standards. The removal of nitrogenous pollutants in these bioreactors is also an environmental challenge [6].

Therefore intensive research works have been conducted on the enhancement of the ABR's performance to take its unique features in treatment of municipal wastewater. One of the main modifications proposed for improvement of the ABR performance is its integration with the fixed-bed process [7–9]. Another interesting alternative to improve with performance of ABR might be its integration with the electrochemical process. The electrochemical process produces in-situ coagulants which result in the occurrence of the electrocoagulation process and thus increasing the removal of the contaminants [10,11].

Accordingly, this study was aimed at integrating the electrochemical process with the ABR for improving its performance in treating municipal wastewater. At first, upon the start up of the ABR, its performance in treating the municipal wastewater was evaluated at different hydraulic retention times (HRT). Then an electrochemical process was integrated with the ABR and the effect of various electrical densities was investigated on the enhancement of the ABR effluent quality.

2. Materials and methods

2.1. Setup of the reactors

A bench-scale ABR setup was fabricated from Plexiglas sheet and installed in Khoy city wastewater treatment plant, western Azerbaijan, Iran. The schematic of the setup is shown in Fig. 1. The ABR had L × W × H dimension of 60 × 27 × 30 cm consisting of 6 equal size chambers with the total working volume of 37 L. Each chamber had a working volume of 6.17 L. The ratio of up-comer to down-comer section of each compartment was 3:1. Top of the reactor was covered and a valve was installed to vent the biogas. The reactor was fed with the real municipal screened wastewater using a peristaltic pump. The effluent was collected in a tank and discharged daily.

In order to improve the performance of the ABR, it was integrated with an electrochemical system providing the EABR (electrochemical system with ABR). The electrochemical system was composed of a pair of similar material (steel or aluminum) plate-type electrode with the width and length of 2 and 25 cm, respectively, powered by a DC power supply. The thickness of the electrodes was 2 mm. In the EABR, the electrodes were inserted at the distance of 1 cm from each other in the 4th down-comer chamber of the reactor. The submerged length of each electrode was 15 cm. The DC electrical current at the given density was applied between the electrodes through the weirs connected to the power supply instrument.

2.2. Reactor start up and experimental procedure

At the beginning of the study the set up was examined for its water-tightness and troubleshot. Then the ABR was inoculated with the sludge, having a total suspended solids (TSS) concentration of 8.6 g L^{-1} and pH of 7.5, taken from a local anaerobic treatment plant as the initial seed. The raw municipal wastewater taken from the downsteam channel of the screening unit of the target treatment plant (Khoy city, Western Azerbaijan, Iran) was used to feed the ABR. The average characteristics of the screened raw wastewater used over the course of the study are shown in Table 1. Upon seeding, the ABR was started up with the continuously feeding the screened raw wastewater using a calibrated variable speed peristaltic pump at an HRT of 48 h. When the change in removal of soluble chemical oxygen demand (sCOD) and TSS remained below 2% during 10 consecutive days, the startup was considered to be completed.

Upon startup, the steady-state performance of the ABR was evaluated at different HRTs of 48, 36 and 24 h. The effect of effluent recirculation ratio (ratio of recycle effluent flow rate to the influent flow rate) ranging from 0.25 to 1.0 at the constant HRT of 24 h was also investigated on the performance of ABR. The steady-state performance was defined when the change in total COD (tCOD) and TSS removal percentages remained below 5% during 10-d consecutive operation. At day 352 of the operation, the ABR integrated with the electrochemical process. The electrochemical process was operated with two different electrodes (steel and aluminum). The electrical current densities was between 0.05 and 0.2 mA cm^{-2} for Al electrodes and between 0.1 and 0.4 mA cm^{-2} for steel electrode. The reactor was operated for 1 wk for each

Table 1
The average main characteristics of the raw municipal wastewater used in this study.

Parameter[a]	Value (mean ± SD)[b]
TSS	267 ± 14
BOD	352 ± 24
Total COD	564 ± 37
Soluble COD	277 ± 17
pH	7.4–7.6
Phosphate	23 ± 2
Total Kjeldhal nitrogen (TKN)	66 ± 8
Ammonia nitrogen	57 ± 11
Nitrate	2.4 ± 0.3
Sulfate	76 ± 9
Total alkalinity, as $CaCO_3$	513 ± 20

[a] All unit expressed as mg L^{-1} except for pH.
[b] Total number of samples = 273.

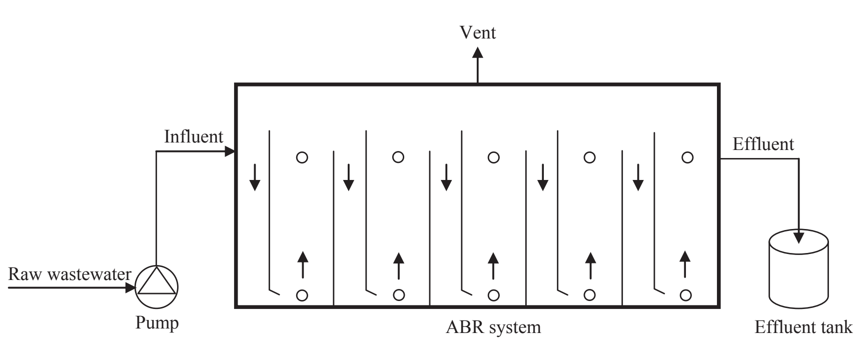

Fig. 1. The schematic of the ABR setup.

electrochemical experimental condition and the target parameters were analyzed in the effluent.

2.3. Sampling and analysis

The influent and effluent streams of the experimental system were sampled three times a week. Moreover, to determine the performance of the each chamber, all compartments were sampled through the sampling port installed at top of the compartment when the ABR performed at steady-state under each set of experimental conditions. The target parameters including TSS, volatile suspended solids (VSS), tCOD, sCOD, BOD, PO_4^{3-}, NO_3^-, NH_4^+, TKN, SO_4^{2-} and total alkalinity were analyzed as described in the Standard Methods [12]. The samples were filtered using a 0.45 μm Whatman filter before measurement of the sCOD. pH and temperature of wastewater were measured using the specific electrodes.

3. Results and discussion

3.1. Startup of the ABR

The ABR was started up with feeding the screened raw municipal wastewater at an HRT of 48 h. Fig. 2 shows the performance profile of the ABR during the startup phase. As observed in Fig. 2, after some initial fluctuations, the ABR approached to the steady-state performance on day 105 of the operation. At this point the startup was considered to be successfully completed. The average (± SD) steady-state removals of TSS, sCOD and tCOD after completion of the startup under the selected conditions was determined to be 93 ± 1, 81 ± 1 and 89 ± 1%, respectively. The median effluent pH was 7.8 during the startup period which is at the optimum level for methanogenesis bacteria. Indeed, considering the relatively high sCOD removal and the effluent pH, the system shows clear symptoms of the accomplishment of the anaerobic biodegradation of the organic compounds.

3.2. Effect of HRT on performance of the ABR

After achieving the steady-state performance in the ABR operated at HRT of 48 h and startup completion, the HRT was changed to 36 h and then to 24 h. At each HRT, the ABR was operated to attain the steady-state performance. Fig. 3 shows the profile of ABR's performance in treating the municipal wastewater treatment at various HRTs. After each decrease in HRT, the performance of ABR in removal of the target parameters was reduced but it improved over time to a steady-state level. Based on Fig. 3, the performance of the ABR dropped first when the HRT was switched from 48 h to 36 h but it recovered to approximately the previous steady-state condition by continuing the operation under HRT of 36 h. Further decreasing the HRT to 24 h resulted in a significant reduction in the performance of ABR particularly in the COD removal. Continuing the ABR operation for 19 d resulted in another steady-state performance although unable to achieve the previous level. The mean of steady-state removals of TSS, sCOD, tCOD and BOD_5 at different HRTs are shown in Fig. 4.

As seen in Fig. 4, the mean steady-state removal of TSS, tCOD, sCOD and BOD at HRT of 48 h was 93 ± 1, 89 ± 1, 82 ± 1 and 92 ± 1%, respectively. The performance of ABR in removing TSS, tCOD, sCOD and BOD was not significantly (< 1%) affected by the reduction of HRTs from 48 h to 36 h. However, the performance of ABR decreased when the HRT was further reduced to 24 h; the mean steady-state removal of TSS, tCOD, sCOD and BOD at HRT of 24 h was 91, 83, 70, and 87%, respectively. It is seen that the ABR performed well at HRTs ≥ 36 h while the lower HRTs resulted in the reduction of the performance particularly in removing the organic compounds. The reduction of ABR performance at the lower HRT can be related to the increase of organic loading rate applied on the bioreactor and thus affecting the microbial metabolism [13–15].

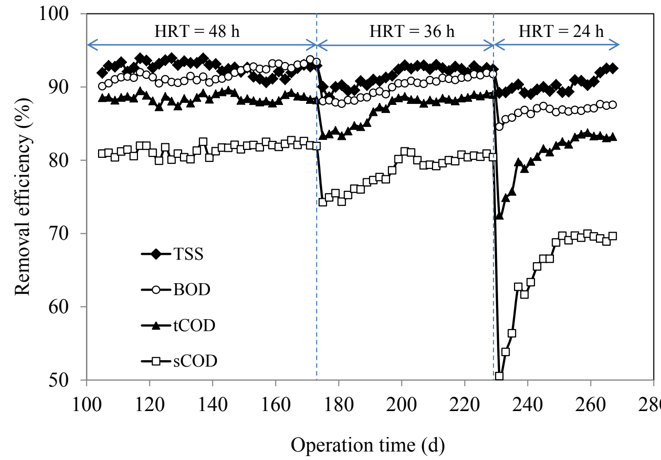

Fig. 3. The profile of TSS, BOD, tCOD and sCOD removals in the ABR at various HRTs of 48, 36 and 24 h.

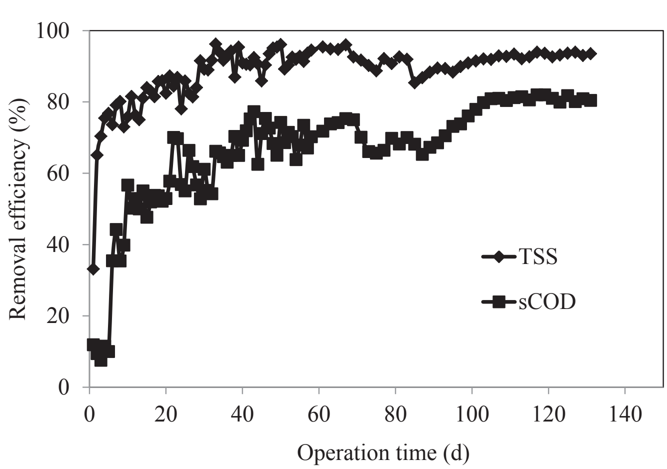

Fig. 2. The TSS and sCOD removals during the start up period (HRT = 48 h).

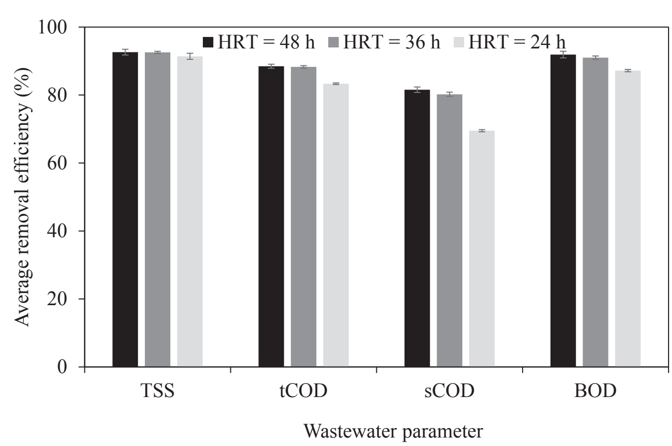

Fig. 4. The average steady-state performance of ABR at various HRTs of 48, 36 and 24 h.

Table 2
Literature on the performance of ABR and its modifications for treatment of domestic and municipal wastewater.

Process	Inlet tCOD (mg L^{-1})	HRT (h)	Organic loading rate (kg COD m^{-3} d^{-1})	COD removal (%)	Reference
Combined ABR	386	10	0.93	83.4	[7]
Modified ABR	400	6	1.6	84	[8]
Combined ABR	305	48	0.15	79	[9]
ABR	760	12	1.52	43	[17]
Modified ABR	300	15	0.48	62–72	[18]
ABR	716	22	0.78	73	[19]
ABR	682	24	0.68	82	[20]
ABR	2914	28.8	2.43	47	[21]
ABR	564	48	0.28	88	This research
EABR[a]	564	24	0.56	91	This research

[a] Electrochemically-enhanced ABR.

Indeed, the reduction of HRT caused the less time for methanogens bacteria to metabolize the soluble products produced by the acidogenesis resulting in their accumulation in the effluent [13–16]. Another reason might be the reduction of effective volume in each chamber due to the accumulation of the solids over the operation course. The main mechanism of TSS removal might be the settlement and flotation of solid particles in the compartments as well as the enmeshment of the particles in the sludge blanket in the compartments [17]. Also, the main mechanism deduced to be contributed in the removal of the organic compounds (BOD and COD) was likely to be methanogenesis, sulfate reduction and physical capture of particulate organics [17]. Table 2 compares the performance of ABR for the treatment of municipal wastewater in this study with the literature. As seen in Table 2, the ABR investigated in this work is comparable with the related literature.

Table 3 compares the effluent quality of the ABR at different HRTs under steady-state conditions with the Iran's standards for effluent discharge into the surface water bodies [22]. Based on data given in Table 3, the ABR could only meet the effluent standard of TSS in all HRTs. The other measured parameters were above the standard limits for effluent discharge into surface water bodies even at the highest tested HRT of 48 h. Therefore, the ABR operated at the above-mentioned conditions could not be considered as a technically viable option for municipal wastewater treatment. However, several options are available for improving the effluent quality of the ABR to meet the discharge standards. We tried two options: effluent recirculation and electrochemical process. Another point observed in Table 3 is the increase of the ammonia concentration in the effluent due to anaerobic decay and hydrolysis of the organic nitrogen in the reactor [18].

3.3. TSS and tCOD removals at different ABR's compartments

The removal of TSS and tCOD at various compartments of ABR operated at HRT of 24 h was evaluated and the results are shown in Fig. 5. As seen in Fig. 5, the removal of TSS improved from 41 to 91% and that of tCOD increased from 58 to 83% as the wastewater passed from the first compartment along the length of the ABR. It is also observed in Fig. 5 that around 75% of the TSS and tCOD removals achieved in the three first compartments. It suggests that the forth compartment might be an appropriate place to incorporate the electrochemical process in order to enhance the performance of ABR.

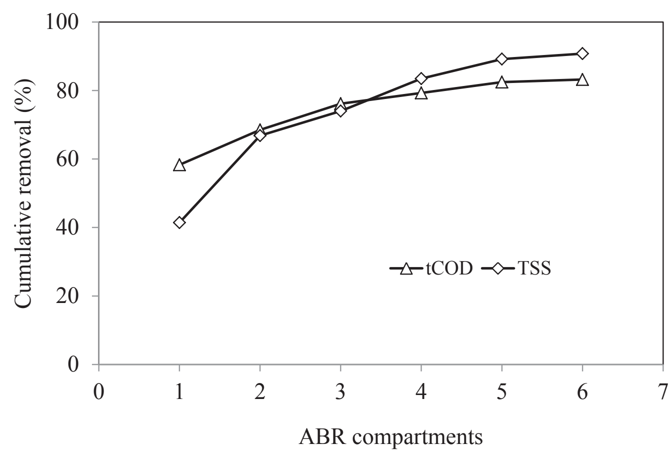

Fig. 5. The profile of TSS and tCOD removal at different compartments of the ABR (HRT = 24 h).

3.4. Effect of effluent recirculation on performance of the ABR

The effect of effluent recirculation ratio at values between 0.25 and 1.0 was evaluated on the effluent quality of the ABR. Fig. 6 depicts the profile of ABR's performance at various effluent recirculation ratio. Unfortunately, the effluent recirculation did not improve the effluent quality but in fact slightly adversely affected the effluent quality. The effluent recycle may affect the performance of ABR through different mechanisms including diluting the influent in terms of organic compounds and the toxicity as well as the addition alkalinity for better pH control [23]. Nonetheless, as the influent was a low strength municipal wastewater with no toxic

Table 3
The effluent quality of the ABR operated at different HRTs under steady-state conditions.

HRT	TSS (± SD), mg L^{-1}		tCOD (± SD), mg L^{-1}		BOD (± SD), mg L^{-1}		pH		NH_4^+ (± SD), mg-N/L		PO_4^{3-} (± SD), mg L^{-1}	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
48 h	258 ± 11	20 ± 2	588 ± 28	70 ± 4	376 ± 10	31 ± 10	7.5	7.5	72 ± 3	93 ± 2	23 ± 2	20 ± 1
36 h	276 ± 10	21 ± 1	595 ± 12	68 ± 2	370 ± 7	33 ± 7	7.6	7.5	66 ± 2	81 ± 1	23 ± 1	19 ± 1
24 h	270 ± 18	23 ± 3	582 ± 17	95 ± 2	375 ± 11	47 ± 11	7.6	7.5	60 ± 6	73 ± 1	23 ± 1	19 ± 1
Standard[a]	–	30	–	60	–	30	–	6.5–8.5	–	2.5	–	6

[a] Effluent discharge standards (average monthly) to the surface water bodies based on the Iran Environment Protection Organization.

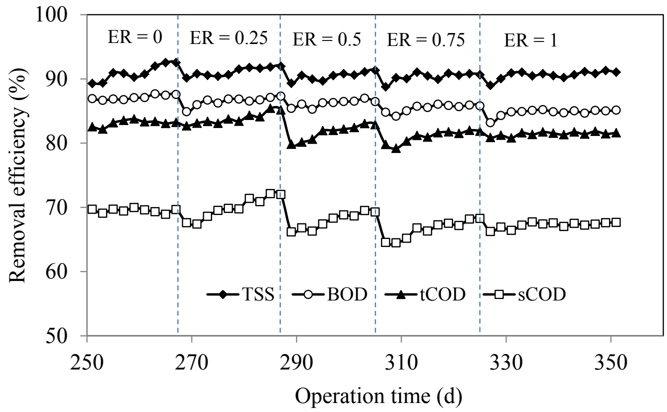

Fig. 6. Effect of effluent recirculation (ER) on the performance of ABR in treating municipal wastewater (HRT = 24 h).

materials, the effluent recycle had no significant influence on the ABR performance. The slight reduction of ABR's performance with the increase of effluent recycle rate can be related to the dilution of the influent and thus slowing the rate of microbial metabolism.

3.5. *Effect of electrochemical process integrated with the ABR*

Another option designated to improve the effluent quality of the ABR for treating the municipal wastewater was its integration with an electrochemical process. Therefore, the 4th down-flow compartment was converted to the electrochemical cell by inserting a pair of electrodes from steel or aluminum materials and applying various densities of the DC electrical current. Table 4 compares the effluent quality of the ABR with that of the electrochemically-enhanced ABR (EABR) using steel and aluminum electrodes. As shown in Table 4, the integration of electrochemical process with both steel and aluminum electrodes could improve the effluent quality of the ABR for parameters of TSS, tCOD, BOD_5, SO_4^{4-} and PO_4^{3-} to the standard levels set for discharge into the surface water [22]. As observed in Table 4, the EABR with Al electrode using a current density as low as 0.1 mA cm^{-2} decreased the concentration of TSS, tCOD, BOD, SO_4^{4-} and PO_4^{3-} to the discharge standard levels where as a minimum current density of 0.3 mA cm^{-2} was needed in the EABR with steel electrodes to attain the discharge standards. It is observed that the EABR with Al electrodes performed much better than that with steel electrodes at considerably lower current densities. Therefore, the EABR is a promising and simple-to-operate process for efficient treatment of municipal wastewater to the regulatory levels. The removal of TSS, tCOD, BOD and phosphate obtained in the EABR with a relatively small current density is well comparable with those attained in the chemically enhanced sedimentation as well as in the UASB [17]. The main features of EABR as compared with the enhanced sedimentation are no need to any external chemical addition and the daily solids wasting [17]. Therefore, the EABR can be an efficient and promising technique for protection of the quality of water sources [24].

The improvement of ABR effluent quality upon integration with the electrochemical process can be attributed to the formation of hydroxyl-metal precipitates due to anode scarification and thus co-precipitation of contaminants with the generated flocs [10,11]. The higher the current density applied between the electrodes, the better quality of the ABR effluent. The increase of the EABR performance with the increase of applied current density can be explained by the fact that increasing electrical current density accelerates anodic sacrification and the generation of Fe^{2+} ions which enhances the electrocoagulation reaction [25,26]. Considering the small scarification of Al electrode (< 1 wt%) and very low current density applied to the system (0.1 mA cm^{-2}), the EABR with Al electrodes is a cost-effective system for efficiently treating the municipal wastewater to the discharge standards.

Conclusions

The present work presents the investigation of ABR and electrochemically-enhanced ABR for municipal wastewater treatment. The effect of HRT and effluent recirculation was evaluated on the performance of ABR in treating the municipal wastewater. The ABR could only meet the TSS effluent standard for discharge into the surface water. In the other word, the concentration of tCOD, BOD and nutrients in the effluent of ABR operated at HRT of 48 h was above the standard limits. The effluent recirculation rate ranging from 0.25 to 1.0 at the constant HRT of 24 h slightly deteriorated the effluent quality of ABR. Integration of an electrochemical process with the ABR (EABR) could considerably enhance the performance of the treatment. The electrochemical process with aluminum electrodes was more efficient than that with the steel electrodes. The EABR with aluminum electrodes using a relatively low current density of 0.1 mA cm^{-2} operated at the HRT of 24 h could treat the municipal wastewater to the discharge limits for TSS, tCOD, BOD, SO_4^{4-} and PO_4^{3-} parameters. In conclusion, integration of the electrochemical process with low current density with the ABR is a feasible technique for improving the performance of ABR in treating wastewater to the standard level.

Table 4
The comparison of the effluent quality of ABR with EABR in treatment of municipal wastewater.

Parameter	pH	TSS, mg L^{-1}	tCOD, mg L^{-1}	BOD_5, mg L^{-1}	SO_4^{4-}, mg L^{-1}	NH_4^+, mg-N/L	PO_4^{3-}, mg L^{-1}
Inlet	7.6	267	564	352	76	57	23
ABR outlet	7.5	23	95	47	26	73	19
EABR outlet (Al electrodes)							
0.05 mA cm^{-2}	8.0	17	68	32	23	44	1.0
0.075 mA cm^{-2}	7.9	19	61	29	14	46	0.7
0.1 mA cm^{-2}	7.9	18	53	25	18	49	0.4
0.2 mA cm^{-2}	7.9	17	41	19	12	46	0.5
EABR outlet (St electrodes)							
0.2 mA cm^{-2}	7.8	18	61	29	8.0	51	1.6
0.3 mA cm^{-2}	8.5	20	53	25	4.7	53	1.5
0.4 mA cm^{-2}	8.1	20	46	22	7.6	50	1.9
0.5 mA cm^{-2}	7.8	23	35	20	9.3	54	1.8
Standard[a]	6.5–8.5	30	60	30	400	2.5	6

[a] Effluent discharge standards (monthly average) to the surface water bodies based on the Iran Environment Protection Organization.

Acknowledgements

The authors gratefully acknowledge the financial and technical support provided by Tarbiat Modares University, Tehran, Iran. We also appreciate the Water and Wastewater Company, Western Azerbaijan, Iran, for the technical support.

References

[1] Haydar MM, Khire MV. Geotechnical sensor system to monitor injected liquids in landfills. Geotech Test J 2006;29:37–44.
[2] Barber WP, Stuckey DC. The use of the anaerobic baffled reactor (ABR) for wastewater treatment: a review. Water Res 1999;33:1559–78.
[3] Mergaert K, Vanderhaegen B, Verstraete W. Applicability and trends of anaerobic pretreatment of municipal wastewater. Water Res 1992;26:1025–33.
[4] Grobicki A, Stuckey DC. Performance of the anaerobic baffled reactor under steady-state and shock loading conditions. Biotechnol Bioeng 1991;37:344–55.
[5] Polprasert C, Kemmadamrong P, Tran FT. Anaerobic baffle reactor (ABR) process for treating a slaughterhouse wastewater. Environ Technol 1992;13:857–65.
[6] Grobicki A, Stuckey DC. Hydrodynamic characteristics of the anaerobic baffled reactor. Water Res 1992;26:371–8.
[7] Yu H, Anderson GK. Performance of a combined anaerobic reactor for municipal wastewater treatment at ambient temperature. Resour Conserv Recycl 1996;17:259–71.
[8] Bodkhe SY. A modified anaerobic baffled reactor for municipal wastewater treatment. J Environ Manag 2009;90:2488–93.
[9] Feng HJ, Hu LF, Mahmood Q, Qiu CD, Fang CR, Shen DS. Anaerobic domestic wastewater treatment with bamboo carrier anaerobic baffled reactor. Int Biodeterior Biodegrad 2008;62:232–8.
[10] Moussavi G, Khosravi R, Farzadkia M. Removal of petroleum hydrocarbons from contaminated groundwater using an electrocoagulation process: batch and continuous experiments. Desalination 2011;278:288–94.
[11] Moussavi G, Majidi F, Farzadkia M. The influence of operational parameters on elimination of cyanide from wastewater using the electrocoagulation process. Desalination 2011;280:127–33.
[12] APHA. Standard Methods for the Examination of Water and Wastewater. Washington, DC: American Public Health Association; 2005.
[13] Langenhoff AAM, Intrachandra N, Stuckey DC. Treatment of dilute soluble and colloidal wastewater using an anaerobic baffled reactor: influence of hydraulic retention time. Water Res 2000;34:1307–17.
[14] Thanwised P, Wirojanagud W, Reungsang A. Effect of hydraulic retention time on hydrogen production and chemical oxygen demand removal from tapioca wastewater using anaerobic mixed cultures in anaerobic baffled reactor (ABR). Int J Hydrogen Energ 2012;37:15503–10.
[15] Elreedy A, Tawfik A. Effect of hydraulic retention time on hydrogen production from the dark fermentation of petrochemical effluents contaminated with Ethylene Glycol. Energ Proced 2015;74:1071–8.
[16] Kuscu ÖS, Sponza DT. Effects of nitrobenzene concentration and hydraulic retention time on the treatment of nitrobenzene in sequential anaerobic baffled reactor (ABR)/continuously stirred tank reactor (CSTR) system. Bioresour Technol 2009;100:2162–70.
[17] Hahn MJ, Figueroa LA. Pilot scale application of anaerobic baffled reactor for biologically enhanced primary treatment of raw municipal wastewater. Water Res 2015;87:494–502.
[18] Bodík I, Kratochvíl K, Gašpariková E, Hutňan M. Nitrogen removal in an anaerobic baffled filter reactor with aerobic post-treatment. Bioresour Technol 2003;86:79–84.
[19] Foxon KM, Pillay S, Lalbahadur T, Rodda N, Holder F, Buckley CA. The anaerobic baffled reactor (ABR): an appropriate technology for on-site sanitation. Water SA 2004;30:592–8.
[20] Nasr FA, Doma HS, Nassar HF. Treatment of domestic wastewater using an anaerobic baffled reactor followed by a duckweed pond for agricultural purposes. Environmentalist 2009;29:270–9.
[21] Singh S, Haberl R, Moog O, Shrestha RR, Shresthad P, Shrestha R. Performance of an anaerobic baffled reactor and hybrid constructed wetland treating high-strength wastewater in Nepal – a model for DEWATS. Ecol Eng 2009;35:654–60.
[22] DoE. Standards for Wastewater Discharge. Tehran, Iran: Department of Environment; 1999.
[23] Liu RR, Tian Q, Chen JH. The developments of anaerobic baffled reactor for wastewater treatment: a review. Afr J Biotechnol 2010;9:1535–42.
[24] Huang C, Ishikawa S, Kabasawa K, Morimoto M, Motoshima N, Ogata S, et al. Effluent water and river water purification by the installation of decentralized water treatment facilities in Surabaya City, Indonesia. Sustain Environ Res 2015;25:185–93.
[25] Moussavi G, Aqanaghad M. Performance evaluation of electro-Fenton process for pretreatment and biodegradability improvement of a pesticide manufacturing plant effluent. Sustain Environ Res 2015;25:249–54.
[26] Zuluaga Rojas MV, Taborda Ocampo G, Palomá Parra LL, Penagos Gonzalez JP. Electrocoagulation as an alternative to separate metabolites in *Furcraea cabuya* and environmental impact mitigation. Sustain Environ Res 2013;23:267–72.