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Original research article

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

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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.

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

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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.

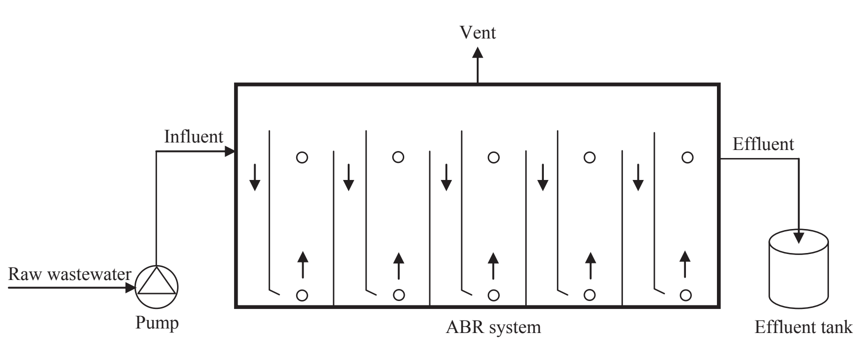

Fig. 1. The schematic of the ABR setup.