Research Article

Fatimah K. Mahdi*, Saad Abu-Alhail and Ammar Salman Dawood

Performance of the anaerobic baffled reactor for primary treatment of rural domestic wastewater in Iraq

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Abstract: The purpose of this work is to evaluate the performance of the anaerobic baffled reactor (ABR) for on-site primary treatment of domestic wastewater in rural areas of Iraq. The performance of the three-chamber ABR has been investigated at four different hydraulic retention times (HRTs) ranging from 6 to 36 h. The results showed that the chemical oxygen demand (COD) removal efficiency is enhanced with increasing HRT, where it was recorded at 75, 71, 63, and 56% removals rate of COD at HRTs of 36, 24, 12, and 6 h, respectively. The mean steady-state removals of total suspended solids are 91, 78, 72, and 67% at HRTs of 36, 24, 12, and 6 h, respectively. Also, it was shown that there was low-nutrients removal within the ABR. Consequently, the effluent ABR wastewater needs to be post-treated before being discharged to the receiving water bodies. In general, it is concluded that the ABR could introduce a solution for on-site primary treatment of domestic wastewater in rural communities in Iraq.

Keywords: anaerobic baffled reactor, hydraulic retention time, chemical oxygen demand, total suspended solids

1 Introduction

Water is the world's most valuable source and the most important for ecological and human survival [1]. This valuable resource has continuously been considered an indicator of countries' political, social, environmental, and economic status, where the availability and quality of water represent an indicator for the life quality of people [2]. In recent years, the crisis of water scarcity has become a very serious issue, especially in the third world, including Iraq, where water resources are facing a real threat, and it has become one of the biggest challenges that severely affect people's health and environment. Water pollution is the main reason that led to this crisis [3].

Anaerobic wastewater treatment is characterized by good removal efficiency, simple construction, simple operation, and reduced solids generation [4,5]. It is widely used in South America, Asia, Africa, and the Middle East [6–11]. Anaerobic digestion can be implemented as a primary treatment facility to minimize the requirement of aeration, minimize the production of biomass, and minimize organic loading to downstream processes [12]. There are many types of anaerobic digesters, and the anaerobic baffled reactor (ABR) is one of the high-rate anaerobic reactors that has been widely used in wastewater treatment. In this study, the focus is on its application for the primary treatment of domestic wastewater.

The ABR is extensively used in treating wastewater as one of the high-rate anaerobic reactors. It can be considered an upgraded septic tank as it includes vertical baffles. ABRs have been applied for various types of wastewater, such as vegetable/food wastewater [14,15], raw municipal wastewater [16], baker's yeast manufacturing wastewater [17], thin stillage [18], and blackwater [19].

The aim of this study is to evaluate the overall performance of ABR for on-site primary treatment of domestic wastewater in rural areas in Iraq. The tests conducted to investigate the overall performance of the ABR at steady state conditions of different hydraulic retention times (HRTs) ranged from 6 to 36 h. Also, the effect of the chambers in terms of chemical oxygen demand (COD) on ABR feasibility had been investigated.

* **Corresponding author: Fatimah K. Mahdi,** Civil Engineering Department, College of Engineering, University of Basrah, Basrah, Iraq, e-mail: fatimakm4@gmail.com
Saad Abu-Alhail: Department of Civil Engineering, College of Engineering, University of Basrah, P.O. Box 49, Basra City, 61004, Iraq
Ammar Salman Dawood: Civil Engineering Department, College of Engineering, University of Basrah, Basrah, Iraq

2 Material and methods

2.1 Reactor setup

The dimensions of ABR (Photograph 1) were chosen based on the guidelines developed by [20]. Figure 1 presents a schematic diagram of the ABR setup. The ABR consisted of three sequentially identical compartments with the following dimensions: length, 0.33 m; width, 1 m; and height, 1 m. The reactor was fed with raw wastewater through a 5-inch polyvinyl chloride pipe placed on top of the 1,000 L feed tank, which flowed downward to the bottom of the first compartment inside the reactor. Then, the wastewater flows to the top of the next compartment, passing through the accumulated sludge layer. This flow pattern is repeated throughout each of the compartments. The ABR had provided sampling ports located at the top center of each compartment along one side of the reactor. The ABR was constructed from mild iron and coated with a sealant material (webrep501ZRP) to prevent watertightness. The reactor had been provided with an exhaust valve for the release of the formed biogas through anaerobic digestion.

Photograph 1: The ABR.

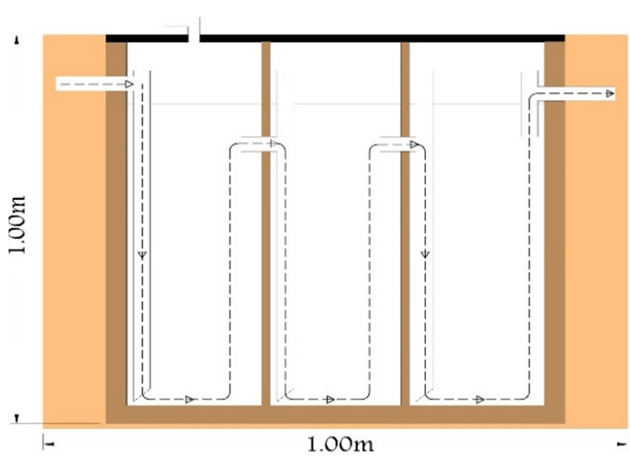


Figure 1: The schematic diagram of the ABR setup.

2.2 Seeding

The ABR was initially seeded with anaerobically digested sludge, as the start-up of the ABR without the seeding of sludge is rather difficult and time-consuming. The seeding sludge was taken from the anaerobic digester of the old treatment plant of wastewater in Kufa city, Iraq (Al-Barrakiah traditional treatment plant), in order to reduce the period required for the microorganisms' acclimatization and to be familiar with the characteristics of the target wastewater [13]. Before seeding the sludge, it was passed through a <5-mm sieve to remove the debris and large particles. Then, it was introduced uniformly into the reactor at a percentage of about 30% of the volume of each ABR compartment [21]. After seeding the reactor with anaerobic sludge, it was filled with the raw domestic wastewater from the feed tank, and its lids were sealed. Then the reactor was left standing for 2 days to allow the biomass to settle [22]. After that, the domestic wastewater was fed continuously to the ABR throughout the study period.

2.3 Characteristics of influent wastewater

The ABR reactor was established in the southeast of Kufa city, located at 32° 03′ 4.10″ N latitude and 44° 26′ 24.61″ E longitude. It was located close to the old sewage water treatment plant (a traditional treatment plant in Al-Barrakiah). The raw domestic wastewater was obtained from a nearby sewage source. It was transferred using a submersible pump to the feed tank. The cylindrical-shaped plastic tank with a capacity of 1,000 L was the source of the influent raw sewage, and the tank contains a branch pipe ending with a valve to control the sewage flow rate. Table 1 shows the wastewater characteristics in terms of the maximum, minimum, and average values for the concentrations of the major wastewater parameters.

Table 1: The average concentrations of the main characteristics of the influent wastewater

Parameter	pH	BOD_5 (mg/L)	COD (mg/L)	TSS (mg/L)	TP (mg/L)	TN (mg/L)	NH_4–N (mg/L)
Average	7.27	245.69	431.06	206.85	4.57	34.36	26.17
Maximum	7.5	356.6	570	259.5	5.5	41.6	32.7
Minimum	6.9	161.8	3019	154.6	3.2	23.4	16.5

BOD, biochemical oxygen demand.

2.4 Water sample collection and quality analysis

To evaluate the treatment performance of the ABR, analytical measurements had been made. In that order, liquid samples were taken from the influent, effluent, and three compartments of the reactor. Using 0.5 L clean polyethylene bottles, the samples were taken from the last compartment toward the first one. This order was followed in order to maintain the anaerobic conditions of the ABR. Then, the samples were directly carried to the lab for analysis of selected water quality parameters, which include COD, total nitrogen (TN), total phosphorus (TP), and NH_4–N. The target wastewater parameters were analyzed according to the standard methods [23]. The total suspended solid (TSS) was measured according to the method described in [24]. Meanwhile, the potential of hydrogen ions (pH) was measured by the WTW pH 3110 is the name of a simple meter for portable pH measurements set 2 at the field.

2.5 Statistical analysis

All experimental data were statistically analyzed using MS-Excel programs. All the analyses were performed in duplicate to substitute for experimental errors.

3 Results and discussion

3.1 Chemical oxygen demand (COD) removal

Several studies have shown that the treatment performance of the ABR depends strongly on the HRT [25]. Therefore, the performance of the ABR in removing COD has been investigated at different HRTs (Figure 2). In general, it can be concluded that the increment of HRT has a significant effect on the ABR performance of COD removal. Also, it was shown that the effectiveness of the ABR in removing organic matter increases with the increase in the HRT. The mean steady-state removal of COD at HRTs of 36, 24, 12, and 6 h was 75, 71.49, 63.35, and 56.36%, respectively. The higher COD removal associated with the long HRT can be related to the long contact time [26]. While the reduction of HRT led to less contact time due to an increase in organic compounds in the ABR effluent [27], another possible reason could be an increase in organic load on the ABR, which affected the microbial metabolism [28].

On the other hand, the influent and effluent COD concentrations for each ABR compartment were measured at the steady-state conditions to study the effect of the compartmentalized configuration on the removal performance of ABR. The results indicated that the first ABR compartment achieved the highest COD removal rate. These results were similar to those obtained by [29,30], who reported that the highest COD removal happened at the first ABR compartment. Also, it was noticed that the last two ABR compartments gradually had a larger role in the COD removal with continued reduction of HRT, and the removal rate had been distributed across all three compartments. These results were also concluded by ref. [29]. Theoretically, the sufficient contact time between sewage and the active microbial population in the wastewater, the higher removal rate of the pollutants matter. The microorganisms need adequate time to complete the degradation of the pollutants in the wastewater [29].

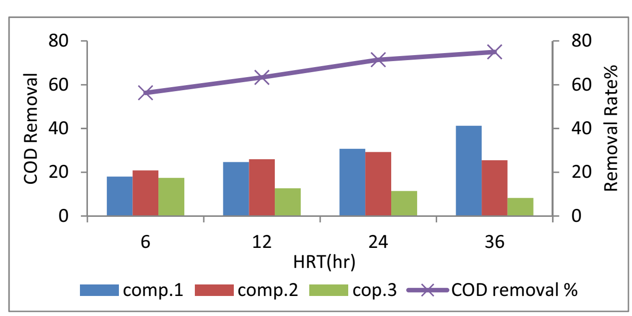


Figure 2: The average steady-state COD removal rate at the three compartments of the ABR for HRTs of 6, 12, 24, and 36 h.

3.2 Reactor pH

Anaerobic microorganisms have a defined proper pH range for their growth. pH values higher or lower than this range have a negative effect on the microbiological conditions in the ABR [31]. Therefore, pH values must be stable and within the most proper range [32]. Figure 3 shows the daily variation in pH of the influent and effluent of ABR.

As shown in Figure 3, the measured pH values of influent and effluent wastewater were ranging from 6.9 to 7.5, which were within the appropriate range for the anaerobic process. In general, the effluent pH values were higher than the influent pH values, which was expected because anaerobic processes increase the pH by producing alkalinity [32].

pH measurements in the ABR showed that its value decreased significantly in the first compartment, as shown in Figure 3. This noticeable decrease attributed to an increase in the acid concentration resulting from the acidogenesis and acetogenesis processes that dominate in the first compartment. The same noticeable was recorded by refs. [29,33]. Then, the pH measurements showed that its values increased gradually with the transfer of wastewater through the following ABR compartments, which could be attributed to the compartmentalized design of the ABR, which results in a buffering zone between the primary acidification zone and the active methanogenesis in the latter zones on the ABR [29]. The dominant methanogenesis process in the last compartment removes accumulated acid in later compartments [32]. Similar results were also established by refs. [33,34].

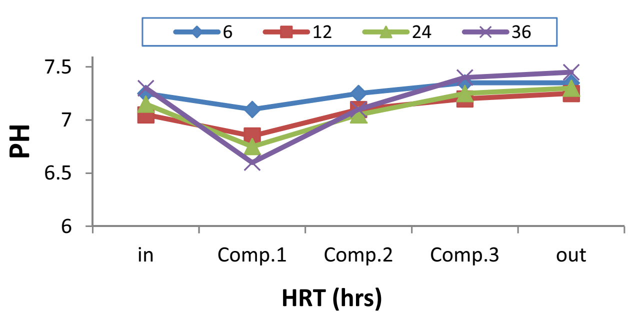


Figure 3: The influent and effluent variations in the pH.

3.3 TSS removal efficiency

The performance of ABR in removing TSS at the studied HRTs of 6, 12, 24, and 36 h is shown in Figure 4. The highest HRT associated with the lower up-flow velocity has the highest TSS removal rates.

In general, in the ABR, retention of solids depends mainly on the up-flow velocity and the solids settling [35]. Regarding the results of the TSS removal efficiency, it can be deduced that the ABR has the capacity to retain a large amount of solids. Also, the results showed that the reactor works efficiently as a pretreatment for reducing the high loads of TSS in the influent wastewater. Photograph 2 showed a visual illustration of the clarity of effluent wastewater compared to influent wastewater. The reactor is similar to a septic tank where it pretreats the influent wastewater by retaining the solids and scum to be digested anaerobically by the developing population of anaerobic microorganisms. The baffled configuration of ABR ensures good contact between wastewater flow and active biomass where the down-flow zone is narrower than the up-flow zone. This made the up-flow velocity to be lower than the average velocity through the reactor, which forced the wastewater to pass through the sludge blanket that accumulates at the bottom of each compartment of the ABR [35].

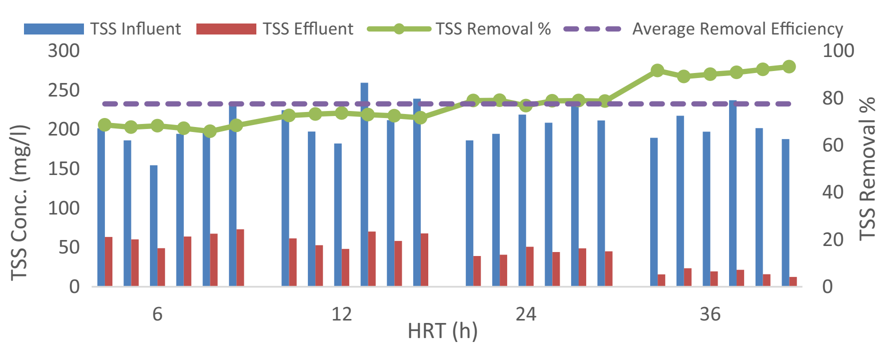
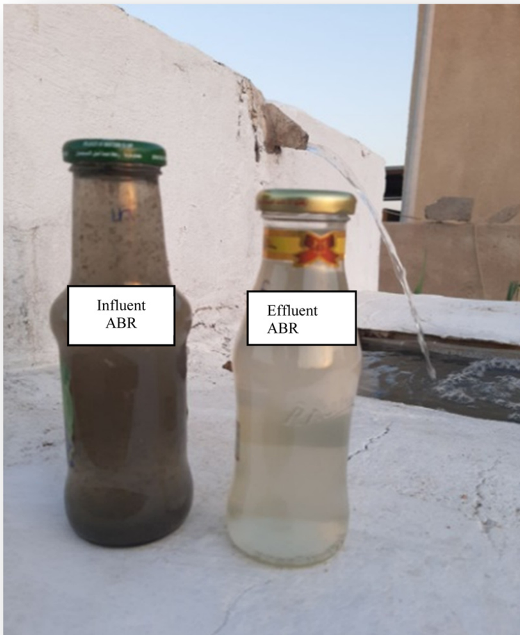


Figure 4: Average TSS removal during steady-state conditions at various HRTs of 36, 24, 12, and 6 h.



Photograph 2: A visual illustration of the effluent clarity.

3.4 Nutrients removal

Discharges of high-nutrient-load wastewater increase the potential of eutrophication and lead to the deterioration of the receiving aquatic ecosystems [36]. Therefore, the removal of nutrient concentration from wastewater in terms of NH_4^+–N, TN, and TP in ABR was observed during the experiments. Table 2 presents the influent, effluent, and removal rates of TP, TN, and NH_4^+–N of the ABR.

The results showed that there was no removal of TP within ABR. Otherwise, there was a small increase in the TP concentration in the effluent of ABR. This increase in TP was due to the release of orthophosphates, which were obtained mainly during the degradation of polyphosphate by polyphosphate-accumulating organisms in anaerobic conditions [37].

The results of the influent and effluent concentrations of TN showed that the ABR had a relatively low average removal efficiency of TN. Also, the results of ABR showed an increment in NH_4–N concentration. The same results were achieved by [27]. This increase in NH_4–N concentration in the effluent is due to the anaerobic decay and hydrolysis of the organic nitrogen in the reactor. While the entrapped of the non-biodegradable compounds of nitrogen within the accumulated sludge at the bottom of the reactor explained the decrease of its concentrations in the ABR effluent [29].

In general, the anaerobic treatment process is not effective in the reduction of phosphorus and nitrogen. This low nutrient removal was expected since the anaerobic processes are characterized by low-growth yields; therefore, the nutrient requirements are relatively low, and the fecal material supplies these requirements in sufficient quantities [32].

4 Conclusion

The main conclusions of this study are the following:

- The ABR has a greater efficiency for COD and TSS removal at different HRTs. In general, the results showed that the removal rate of COD and TSS enhanced with the increment of HRT.
- The results showed that the first compartment achieved the highest COD removal rate. Also, it was noticed that the last two ABR compartments gradually had a larger role in the COD removal with continued reduction of HRT, and the removal rate had been distributed across all three compartments.
- The results showed that there was low-nutrients removal within the ABR. Consequently, the effluent ABR wastewater needs to be post-treated to reduce the nutrient load on the receiving water bodies.
- Based on the study results, the ABR could introduce innovative solutions for on-site primary domestic

Table 2: The influent, effluent, and removal rates of TP, TN, and NH_4–N of the ABR

HRT (h)	TN (mg/L)			NH_4–N (mg/L)			TP (mg/L)		
	Infl.	Eff.	Rem.%	Infl.	Eff.	Rem.%	Infl.	Eff.	Rem.%
6	33.0	31.4	5.0	25.4	27.5	−8.4	4.4	5.5	−24.5
12	34.6	32.45	6.4	26	28.7	−10.6	4.9	6.2	−27.16
24	36.4	33.1	9.1	28.3	31.8	−12.5	4.76	6.1	−29.03
36	33.2	30.1	9.48	25	29.0	−16.5	4.13	5.5	−34.97

wastewater treatment for rural communities in Iraq. However, posttreatment is necessary to protect the receiving water bodies from deterioration due to high-nutrient load.

5 Recommendations

In light of the above conclusions drawn from this study, the recommendations for future work can be written as follows:

- Investigation of the other factors that affect the performance efficiency of the ABR to treat organic matter, such as feeding types.
- Further study the sludge characteristics and microorganism experiment, odor and biogas and volatile fatty acids analysis to evaluate all aspects of efficiency.

Nomenclature

ABR	anaerobic baffled reactor
HRT	hydraulic retention time
COD	chemical oxygen demand
TSS	total suspended solids
BOD	biochemical oxygen demand
TP	total phosphorus
pH	potential of hydrogen ions
TN	total nitrogen
NH_4–N	ammonium

Conflict of interest: Authors state no conflict of interest.

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