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Research Paper

Performance Upgrading Evaluation of the Anaerobic Baffled Reactor by Integrating Aerobic Media Filter for Municipal Wastewater Treatment

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ABSTRACT

Background & Aims of the Study: Anaerobic baffled reactor (ABR) is one of the low-cost wastewater treatment systems; however, it has some limitations, such as insufficient standard nutrient outflow. Accordingly, it should be studied and developed. This research aims to determine the efficiency of a five-sectional reactor pilot and to upgrade it with an integrated aerated media filter in the reactor (integrated reactor) for municipal wastewater treatment.

Materials and Methods: This study was performed on a laboratory scale with field conditions in the Khoy City wastewater treatment plant. The ABR reactor operated for 270 days with a hydraulic retention time (HRT) of 48, 36, 24, and 18 hours, respectively. The Integrated anaerobic baffled reactor (IABR) was operated for 35 days with 24 hours of HRT, i.e., aeration time of 5 hours. The reactors were fed in line from the inflowing wastewater to the treatment plant. A 24-hour combined sampling was performed 224 times from the inflow and outflow of the system, and volatile suspended solids, total kjeldahl nitrogen (TKN), total phosphorus (TP), biochemical oxygen demand (BOD), chemical oxygen demand (COD), and Total Suspended Solids (TSS) parameters were measured and compared with the effluent disposal standard.

Results: The launch of ABR lasted 105 days, and its helpful operation lasted 200 days. In 18 to 48 hours, the reactor removed 79% to 91% of COD, 9% to 20% of TKN, 19% to 30% of phosphorus, and 89% to 94% of TSS. The IABR reached the effluent disposal standard in terms of TSS, BOD, COD, and phosphorus under 24 hours HRT, i.e., aeration time of 5 hours, and increased the COD removal efficiency by 6% compared to ABR under 24 hours HRT and the same conditions.

Conclusion: By integrating the final aerobic media filter in ABR while reducing the required HRT by 50%, its efficiency in achieving the effluent disposal standards increased compared to ABR. Therefore, this system can be used to treat municipal wastewater.

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1. Introduction

Aerobic wastewater treatment methods such as activated sludge have some limitations, including high construction and management costs, high sludge production, and subsequent costs. Therefore, their use is not appropriate and economical, at least in small and scattered communities. Methods such as lagoon types are not efficient enough, especially in cold and hot climates. They have various problems, for instance, algae growth and odor and unfitting wastewater disposal standards. Because of these limitations, using anaerobic or integrated methods (anaerobic-aerobic) can have the necessary efficiency as a new and appropriate solution, while they are cheap and easy to build and operate [1]. One such method is an anaerobic baffled reactor (ABR). Given the many advantages and capabilities of the reactor, including the improvement of process kinetics because of the separation of anaerobic decomposition phases, methane gas recovery, and its upgrading possibility for increasing its treatment capacity and removing its limitations, its application has been considered [2]. Accordingly, its use for wastewater treatment is completely justified and cost-effective in most industries, treatment, and pre-treatment of municipal wastewater, especially in the existence of a source of effluent such as rivers. Also, the reactor can quickly meet the effluent standard for agricultural irrigation [3]. However, to replace it with aerobic methods, it is necessary to make corrections and study its upgrading. One of the reactor's modifications is its integration with the final aerobic phase. This integration can improve its effluent quality and meet the standard of effluent disposal.

In 2018, ABR was used for the linear treatment of sanitary wastewater on a pilot scale with a hydraulic retention time (retention time) of 22 hours. Removal of chemical oxygen demand (COD) was 58%-72%, and Coliform bacteria removal was about 90%. The results showed that the longer the Hydraulic Retention Time (HRT), the better the quality of the effluent. Also, the result demonstrated that ABR is a suitable method for wastewater treatment in low-income communities and can meet the sanitary standard of effluent with final disinfection [4]. In 2016, four sectional ABR with a volume of one cubic meter on a pilot scale with a wastewater temperature of 12-23°C were operated for 2 years for municipal wastewater treatment with COD 760±190 mg/L under 12 hours HRT. The removal efficiency of COD was 49%, and total suspended solids (TSS) 83% and 70% of their removal occurred in the first section. The result was that ABR is a suitable method for the primary treatment of municipal wastewater, and the efficiency of the reactor mainly depends on the number of sections and the HRT [5]. In 2019, ABR integrated with submerged membranes was used to treat municipal wastewater as a 105-L pilot under 12 hours HRT, which showed complete removal of suspended particles and 94% and 54% of organic matter and nitrogen [6].

Previous research has shown that integrating anaerobic wastewater treatment processes with the aerobic process increases the overall efficiency and reduces the operating costs by reducing the anaerobic load in the anaerobic sector and excess sludge compared to purely aerobic methods [7]. On the other hand, ABR alone does not meet all the standards of effluent disposal with normal HRT; therefore, it is necessary to study its upgrading and development, especially as an aerobic integration with suitable microbial media. According to the literature, a similar study had not been conducted to upgrade ABR, and the present study was necessary to develop and implement this system, which has high technical and economic capabilities for wastewater treatment. Thus, this study aims to determine the efficiency of ABR in municipal wastewater treatment and then convert the fourth section into a microbial media filter with floor aeration to upgrade its performance and compare the two in achieving national standards for wastewater disposal.

2. Materials and Methods

Launching and operating reactors

The reactor was designed and built according to the specifications in Table 1 and Figure 1 of the Plexiglas sheet. The reactor was installed in a room built for this purpose after testing the sealing and measuring the effective volume by moving the water in Khoy City wastewater treatment plant. The five-section reactor consisted of four equal sections and a larger first section, 1.5 times larger than the others, which served as the initial precipitation. The reactor had three equal inflows and three outflows to distribute the current evenly across the reactor. The reactor was launched under 48 hours of HRT for better growth and multiplication of methane-forming bacteria and the formation of leach-resistant microbial flakes. The basis for selecting the HRT range was to provide COD and biochemical oxygen demand (BOD) effluent outflow standards; therefore, the reactor could continuously operate for 480, 36, 24, and 18 hours for 270 days, respectively, and its efficiency in achieving the effluent disposal standard with optimal HRT was determined. After finishing the reactor, the HA1LEA model aerator (ACO-9630) with a ceramic diffuser of 25 cm

Table 1. Anaerobic baffled reactor specifications

Dimensions	Values
Length	60 cm
Wide	24 cm
Height	30 cm
Volume	48.6 L
Net volume	37 L

Archives of Hygiene Sciences
Qom University of Medical Sciences

long rods was placed in the upper part of the reactor in section 4, and rigid polyethylene microbial media (2H) with a specific surface area of 535 m^2/m^3, with a volume of approximately 30% of this section, was poured into this section and mixed with the sludge in that section. This media was floating. Thus, the system became an Integrated Anaerobic-aerobic Baffled Reactor (IABR). This system was operated under 24 hours of HRT for 35 days in the same conditions as before to evaluate the final aerated section's effect and the microbial media filter in increasing its efficiency. A reactor was used under the same conditions, and the comparison between the two reactor modes was logically made to determine the effect of ABR upgrading with an aerated media filter. The criterion for the system to reach a steady state at each stage was the approximate stability of the COD removal efficiency of less than 3% in one week. Subsequently, the shift to the next step was performed.

Specifications of sludge seeds and inflow sewage

As for sludge seeds, a quantity of 10 L of fresh and condensed sewage sludge was prepared from the Salmas City wastewater treatment plant, a sequencing batch reactor (SBR). Thirty percent of the effective reactor volume of this sludge was filled and mixed with filtered cow excrement in 1.5 L. Because of the lack of anaerobic sludge, these excrements were used to enrich the sludge with methane-forming bacteria. TSS and VSS concentrations of mixed sludge were 8.6 and 4.4 g/L, respectively. The reactor was fed with screening and grit chamber sewage and fed from a depth of 30 cm into the sewer line. According to the WTW oxygen meter, the O_2 solution at the system inflow was almost zero and also zero inside the reactor, meaning that anaerobic conditions were maintained throughout the reactor. According to the selected HRT, the inflow was adjusted by an Etatron model Peristaltic pump (made in Italy) and calibrated with accurate volumetric measurement. The specifications of the wastewater fed by the system are provided in Table 2 as the mean of the whole period. In addition, the pH and alkalinity of this wastewater on the overall mean were 7.5 and 512 mg/L, respectively. At the end of the study, after removal from the reactor and complete disposal of the supernatant, the sludge of all sections was shaken separately, and each section was sampled and concentrated. The highest concentration of VSS was 33.9 g/L in the first section, and the other sections had almost the same concentration of 26.6 g/L.

During 105 days of commissioning and 200 days of the operation period, 224 samples were taken from the pilot inflow and outflow one day between and three consecutive days at the end of each period of HRT changes from the outflow of all reactor sections. Because of the qualitative fluctuation of the inflow and outflow sewage of the system, sampling of inflow and outflow was performed a 24-hour and every 8 hours. Analysis of outflow samples was to determine the system's overall efficiency and analysis of outflow samples of each section to determine the performance of each reactor section. The parameters were measured using the given methods: TP (PO_4), pH, SCOD (Soluble COD), COD, BOD_5, TSS, TKN, SO_4, NO_3, and alkalinity by standard methods [8], respectively; by methods of BOD metraxitap, closed reflex, pH meter WTW, perSulfate digestion, and tin chloride colorimetry, HACH Macro Kjeldahl digestion and distillation apparatus to convert organic nitrogen to ammonium and then Nessler colorimetric method for ammonium measurement, gravimetry, NTU-Turbidity, Brucine method, and titration. HACH DR5000 spectrophotometer was used to read the concentration parameters of COD, PO_4, NH4, SO_4, and NO_3. Because of the variable concentration of output parameters, graphs and results are plotted based on the mean of the stable conditions data (the mean of the final week's data at the end of each HRT). Data were statistically analyzed with Excel 2018 software.

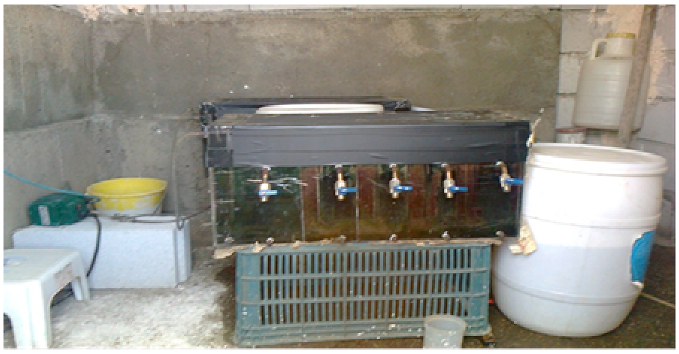

Figure 1. Picture of a five-sectional anaerobic baffled reactor in operation

3. Results

Launching the system and achieving stable conditions

Launching performance was monitored by measuring the parameters SCOD, TSS, pH, and alkalinity at the inflow and outflow of the reactor. At the beginning of this period, because of the leaching of fine sludge particles, TSS and SCOD outflow concentrations fluctuated significantly. The pH changes of the reactor inflow and outflow were in the range of 2.7 to 7.7, and 7.3 to 8, respectively. Because of the high alkalinity of the inflowing wastewater and its 11% increase in the outflow, the pH of the outflow was equal to or higher than the inflow. After 105 days, the outflow SCOD concentration reached an almost constant value of 68 mg/L, the removal efficiency of 88%. The TSS removal efficiency reached a constant value of 93%. The SCOD removal efficiency stabilized during the final week when the launching period ended.

Systems efficiency in removing TSS

Table 2 presents the mean TSS outflow concentration at the end of the stable condition of each period. In ABR under 18, 24, 36, and 48 hours of HRT, TSS removal efficiencies were 89%, 92%, 93%, and 94%, respectively, with a standard deviation of 2.1%. This value was 93.9% for the integrated reactor (IABR). The reduction in HRT reduced the TSS removal efficiency almost linearly but did not change significantly during the study and remained almost constant in each period of HRT changes as the system reached stable performance. Therefore, this system met the standard of particulate matter outflow under 18 hours of HRT.

The efficiency of reactors in removing COD and BOD_5

In all 5 stages of the research, the reactor operated until a constant and maximum COD removal efficiency was achieved. The reactor lasted 63 days under 48 hours, 55 days under 36 hours, 40 days under 24 hours, 20 days under 18 hours of HRT, and then 35 days in integration. Then, it gradually reached an optimal and almost constant performance in each period. Table 2 and Figure 1 demonstrate the outflow concentration and removal of COD and BOD relative to the HRT. The COD removal efficiencies were 91%, 89%, 83%, and 79% for 18 to 48 hours (Figures 2, 3). The removal efficiency of COD, compared to the reduction of HRT, had a linear downward trend with 0.97 R^2. ABR reached the COD and BOD_5 outflow standard in just 48 hours. According to Figure 2, an integrated reactor (IABR), by removing 89.7% of COD, increased the concentration of this parameter to 58 mg/L under 24 hours of HRT, which was half the optimal HRT of ABR. As the HRT decreased, the SCOD/COD ratio increased from 0.74 in 48 hours to 0.88 in 18 hours. These numbers indicate that the opportunity and the possibility of eliminating anaerobic decomposition products in the last sections of the reactor have been reduced by lowering the HRT. Similar research shows a direct relationship between the percentage of pollutant removal and the HRT, and the most important factor in the efficiency of this type of reactor is HRT [9]. Figure 2 shows the COD removal process in the IABR. Despite the large fluctuations related to the stabilization of the aerobic phase and the adaptation of the optional anaerobic microbes to the aerobic conditions in the fourth section, the reactor reached a maximum and almost constant removal efficiency of 89% COD after 30 days.

Longitudinal or sectional operation of reactors

At the end of each period of changes in HRT for 3 consecutive days, the performance of all reactor sections was evaluated by sampling their tap and performing the required tests to determine the role of each section in the overall efficiency of the reactor. Table 3 shows the performance of the reactor sections. For the first section, the TSS removal efficiency was 51% under the

Table 2. Mean±SD of reactors outflow concentration in stable conditions of each period in mg/L

Reactors	HRT-h	Mean±SD				
		TSS	COD	BOD	TKN	TP
Influent		267±14	564±37	352±24	66±8.2	23±2
ABR	48	16.2±2.2	56±4.2	26±3	55.6±1.5	15.9±1.3
ABR	36	19.2±2.7	67±6	31±4	58.9±2.1	16.5±1
ABR	24	22.2±3.5	97±9.2	46±5.1	60.7±2.7	17.2±1.1
ABR	18	28.6±4.2	123±14	58±6.2	63±3.2	18.3±1.3
ABR	24	21±2.4	58±7	28±5.4	59.4±2.8	14.7±1.2

Archives of Hygiene Sciences
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ABR: Anaerobic Baffled Reactor; IABR: Integrated ABR; HRT-h: Hydraulic Retention Time-hour; COD: Chemical Oxygen Demand; BOD: Biochemical Oxygen Demand: TSS: Total Suspended Solids; TKN: Total Kjeldahl Nitrogen; TP: Total Phosphorus

48-hour of HRT, given this section's role as the primary filter. Therefore, the SCOD section measure was chosen so TSS would not interfere. As the HRT decreased, the share of the last sections gradually increased. Compared to ABR, the share of the aeration sector in the IABR increased by 9%, compared to the same sector in the ABR itself. The sulfate and nitrate removal rate. These results showed that the performance of this system in municipal wastewater treatment was more affected by the activity of dominant species in each section because of the environmental conditions of that section, especially the concentration and the type of dominant substrate and oxidation-reduction potential. Therefore, because of the decrease in sulfate and nitrate concentrations and the elimination of COD, it can be inferred that sulfate- and nitrate-reducing bacteria were most active in the first and second sections, and methane-forming bacteria were most active in the final sections.

Efficiency of reactors in removing nitrogen and phosphorus

Figure 4 shows the removal efficiency of TKN and TP. Despite the fluctuations in nitrogen and phosphorus inflow and outflow concentrations in both reactors, TKN removal efficiencies under 48, 36, 24, and 18 hours of HRT were 20%, 15%, 13%, and 9%, and for phosphorus, 30%, 27%, 25%, and 19%, respectively. The outflow concentrations of TKN and phosphorus (in terms of phosphate) under 48 hours of optimal HRT were 59 and 16.5 mg/L, respectively. Therefore, ABR met the standard phosphorus outflow of 16.8 mg/L of phosphate. According to the nitrogen and phosphorus removal efficiency graph, it was directly related to HRT. Their correlation intensity under HRT is 0.98 and 0.95, respectively, which shows that the effect of reducing HRT on nitrogen removal was more effective than phosphorus. The removal efficiencies of these materials in the IABR increased parallel to the increase in COD removal; therefore, the removal of TKN and phosphorus were 14.5% and 35%, respectively, with mean nitrogen and phosphorus outflow concentrations of 52.7 and 12.5 mg/L, respectively. In this study, 76% of the inflow TKN was ammonium, and the rest was organic nitrogen, while 98% of the outflow TKN was in the form of ammonium, which can be attributed to the ammonification phenomenon that occurs under anaerobic conditions.

Comparing the efficiency of both systems

According to Table 2, the IABR provided its standard outflow with half the optimal ABR retention time, i.e., 24 hours of HRT, while increasing the COD and BOD removal by 6%. It also positively affected the elimination of nutrients, as 2% more nitrogen and 10% more phosphorus was removed. Therefore, it became the standard outflow of phosphate amine, but it could not meet the standard of nitrogen outflow because of its high inflow concentration and slight elimination in the anaerobic phase. This increase in speed and efficiency can be attributed to the integration of the aerobic media filter, which has acted as a complementary filter.

4. Discussion

Similar studies have reported ABR launching times of 57 to 128 days, depending on the type of wastewater, climatic conditions, wastewater temperature, and other factors [1, 10]. This study has a relatively long launching time. In addition, dilute organic wastewater, such as

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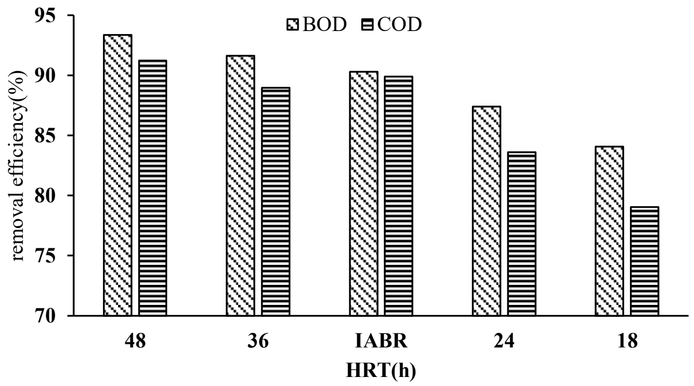

Figure 2. Efficiency of ABR and IABR in BOD and COD elimination at stable final conditions of each period

ABR: Anaerobic Baffled Reactor; HRT-h: Hydraulic Retention Time-hour; TSS: Total Suspended Solids; COD: Chemical Oxygen Demand; BOD: Biochemical Oxygen Demand; TKN: Total Kjeldahl Nitrogen; TP: Total Phosphorus

sanitary wastewater, because of the low concentration gradient, creates a low mass transfer force between the substrate and the biomass and causes methane-forming slow-growing bacteria to predominate in the methane-forming stage, which is the most important step in the anaerobic treatment [11]. TSS removal efficiency had the lowest correlation intensity (R^2=0.85) to HRT compared to other parameters; i.e., it was independent of HRT when reaching the highest efficiency (fixed efficiency). That is because of this reactor's type, which causes suspended particles to settle in the sludge blanket, even during a low HRT such as 18 hours.

Nevertheless, the 58% VSS/TSS ratio at the reactor outflow indicated that part of the biomass was released along with the organic suspended particles, which could be attributed to the leaching of the sludge blanket in the last section. This leaching is because of the production of biogas and the breakdown of clots and cell mass mortality, especially in the last section of the reactor. On the other hand, it can be related to the increase in the speed of sewage movement (an increase in hydraulic load) and, as a result, the leaching of microbial mass in the last section of the system. According to the relationship between speed, distance, and time, the speed of sewage movement is inversely proportional to the HRT, so 48, 36, and 24 hours of HRT were calculated as 5, 6.6, and 10 cm/h, respectively. The supply of TSS outflow standard at all HRTs can be attributed to the filter role of the dense sludge blanket that gradually formed during launching. By installing media in the last section, the effluent of suspended particles was minimized. Similar results of TSS removal have been reported in the literature [9].

Two important parameters affecting the efficiency of the wastewater biotreatment process include the rate of substrate transfer (mass transfer coefficient) to cell mass and microbial metabolism. Because of the low meta-

Table 3. Partial contribution (from one) of the sections of both reactors in COD removal based on the sample taken from the outflow of each section

Sections	ABR			IABR
	HRT (48h)	HRT (36h)	HRT (24h)	HRT (24h)
C1	0.47	0.42	0.40	0.37
C2	0.33	0.17	0.15	0.17
C3	0.06	0.15	0.12	0.12
C4	0.06	0.12	0.15	0.26
C5	0.08	0.14	0.18	0.08

ABR: Anaerobic Baffled Reactor; IABR: Integrated ABR; HRT-h: Hydraulic Retention Time-hour.

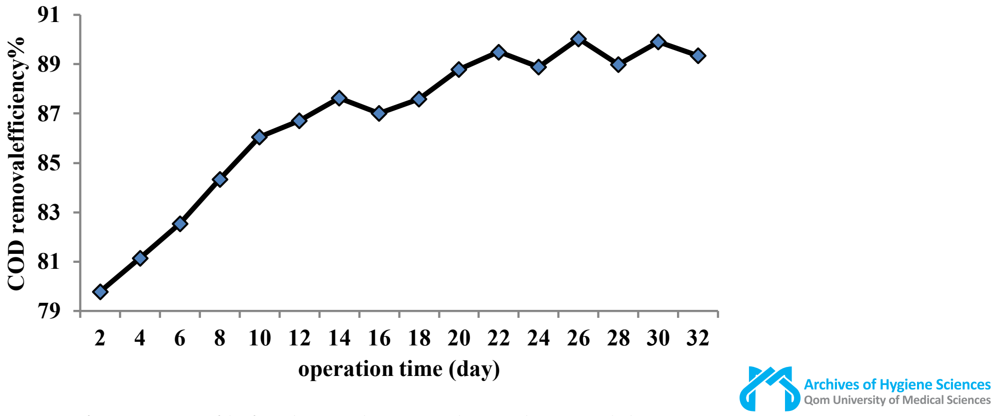

Figure 3. Integrated system performance profile for chemical oxygen demand removal during operation

bolic rate of the anaerobic process, the role of substrate transfer is more remarkable. On the other hand, dilute wastewater creates a low mass transfer force between the substrate and the biomass; therefore, the activity and microbial growth, according to the Monod equation, is low, and more contact time is needed to absorb and remove the substrate. This issue is more pronounced in the case of ABR, which has a flow regime, and the substrate concentration gradually decreases throughout the system [12].

In attached growth processes such as ABR, the performance limiting stage of the system is usually the transfer of the substrate to the biofilm. The filtration efficiency is mainly dependent on the HRT and concentration gradient of the substrate, and as the contact time decreases, the amount of impact and penetration of the substrate in the biofilm decreases. Also, reducing HRT because of the turbulence and short circuit current increases the hydraulic dead space and, consequently, the biological dead space (inactive section). On the other hand, because of the slow metabolism of methane-forming bacteria, this decrease disturbs the dynamic balance of their activity with acid-forming bacteria. As a result, methane-forming bacteria cannot absorb all organic matter, especially volatile fatty acids. Therefore, COD outflow, especially SCOD outflow, increases with decreasing HRT. This finding is consistent with the research findings [13].

Because of the presence of oxygen in their composition, nitrate and sulfate in wastewater maintain the oxidation potential of wastewater and can disrupt and reduce the efficiency of the anaerobic process. Therefore, it is necessary to reduce the reduction conditions by removing these materials by bacteria in the first sections of the system to provide methane-forming conditions in the final sections of the reactor. On the other hand, despite sulfate, sulfate-reducing bacteria compete with methane-forming bacteria and consume part of the acetate, which is the main feed of methane-forming bacteria [14]. Accordingly, the concentration of sulfate and nitrate was monitored during the study. On average, 65.7% of sulfate and 39.3% of nitrate were removed, and their maximum removal, i.e., 75%, was under 48 hours of HRT. The sulfate and nitrate removal processes were downward in the reactor, and their removal occurred mainly in the second and third sections. Sulfate and nitrate concen-

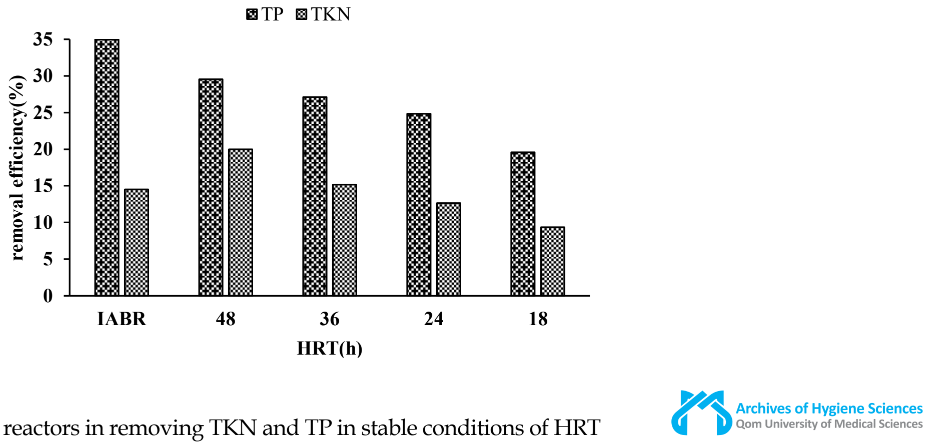

Figure 4. The efficiency of the reactors in removing TKN and TP in stable conditions of HRT
ABR: Anaerobic Baffled Reactor; IABR: Integrated ABR; TKN: Total Kjeldahl Nitrogen; TP: Total Phosphorus.

trations were 29.6 and 1.59 mg/L on average during the study. These results show that sulfate- and nitrate-reducing bacteria were mainly active in the early sections, and methane-forming bacteria were predominant in the late reactor because of the conditions.

Research records show that, in general, the linear velocity of sewage, sludge height, initial sludge characteristics, and its type, distribution of microbial and hydraulic species of flow, and the way of launching affect the performance of ABR reactors and their optimal amount, the amount of organic matter removal increases significantly [15]. According to previous similar studies that have worked with ABR on sanitary wastewater [9, 13], the COD removal efficiency in this study was under 48 hours of HRT, longer than some of them, which achieved 68% to 79% COD removal efficiency. The reason can be attributed to high HRT, successful launching, and high active biomass concentration [16].

At the reactor outflow, on average, 85% of COD was SCOD. The most important reason was the high removal of particulate COD and the conversion of organic particles into solution inside the reactor. SCOD outflow can be because of the failure to decompose or remove some resistant soluble organic compounds such as lignin, surfactant, humic acid, and synthesis of microbial products. The mechanism of organic matter removal in this system is a total of almost complete removal of particulate COD in the sludge blanket, especially in the first section of the reactor, consumption of a part of COD to reduce sulfate and nitrate, especially in sections 2 and 3 of the reactor, and conversion of another section to methane in the final sections of the reactor. In the integrated reactor, which was, in fact, a combination of anaerobic-aerobic phases, a large part of the anaerobic decomposition products in the aerobic sector has been eliminated [17].

By comparing the process and removal ratio of COD in the system sections, it was found that the operation of this type of reactor under 24 hours of HRT and more, especially for medium wastewater such as municipal type, is largely independent of its baffling properties. This is because the separation of the acid phase and methane-forming does not occur completely; therefore, most of the organic and nutrients are removed in the initial sections, and the system's efficiency does not differ much in its length. These results have been obtained in similar studies [5]. Therefore, it can be concluded that ABR baffling, design, and operation should be optimized according to the type of use and type of wastewater, supposing that this system is used for wastewater treatment with medium intensity, such as municipal type. In that case, it should be designed according to the HRT of each anaerobic treatment phase, i.e., with the appropriate volume of sections, so that the last sections are larger than the others. Because of the slow metabolism of methane-forming bacteria, the system should be designed with more baffles. In an IABR, even better efficiency can be achieved by increasing the volume of the aeration section and reducing the reactor retention time to less than 24 hours.

The rate of nitrogen and phosphorus removal is usually a function of the rate of COD removal and the type of process, aerobically or anaerobically [18]. On average, the ratio of C:N:P removed during the 48 hours of HRT was 300:8:4. This result indicates that according to the ratio of C:N:P=300:5:1 required in the anaerobic process, more nitrogen than required for cell synthesis is removed; so, other removal mechanisms such as anaerobic oxidation of ammonium may have occurred [19]. Adsorption and cellular metabolism (energy acquisition and cell synthesis) are also two major processes for phosphorus removal [20]. because of the removed C:N:P ratio, phosphorus is removed relatively more than COD and nitrogen, which can be attributed to the additional phosphorus removal because of the adsorption of clots and its precipitation in the form of calcium phosphate, magnesium, or organic compounds. In addition, under anaerobic conditions, the mechanism of nitrogen removal, unlike phosphorus, is only low cellular synthesis [21]. The effect of aeration on phosphorus removal was also greater than nitrogen because phosphorus is removed more in successive anaerobic-aerobic conditions. The removal of more phosphorus than nitrogen is consistent with the results of a similar study that found 19% and 30% removal of nitrogen and phosphorus in ABR [22].

The weakness of this system, like conventional methods of anaerobic treatment, requires high HRT and failure to meet the standard of nitrogen outflow [23]. However, the system was upgraded to standard filtration with integrated processes such as aerobic phase integration with a media filter. In the combined aerobic phase, the remaining products of anaerobic decomposition are consumed by aerobic microorganisms, resulting in a significant reduction in COD and, consequently, other pollutants. Researchers in successive anaerobic-aerobic wastewater treatment systems have increased organic matter removal efficiency by up to 10% compared to anaerobic reactors alone [24].

5. Conclusion

The optimal HRT of ABR for reaching the effluent BOD, TP, and COD outflow standard was 48 hours, but the reactor could not reach the nitrogen outflow standard. The last sections of the ABR should be larger than the others due to the slow metabolism of the methane-forming bacteria, and the system should be designed with more baffles. In an IABR, even better efficiency can be achieved by increasing the volume of the aeration section and reducing the reactor retention time to less than 24 hours. The IABR achieved the effluent disposal standards by increasing the efficiency and improving the quality of the effluent during the half-HRT of ABR, i.e., 24 hours. Accordingly, this suitable system can be used for municipal wastewater treatment.

Ethical Considerations

Compliance with ethical guidelines

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Authors' contributions

Both authors equally contributed to preparing this article.

Conflict of interest

The authors declared no conflict of interest.

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