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Research Article

Application of an Anaerobic–Anoxic–Oxic–Oxic (AAO/O) Model to the Treatment of Real Domestic Wastewater

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Untreated or inadequately treated domestic wastewater has adversely affected the aquatic environment and public health in many cities in Vietnam. A conventional anaerobic–anoxic–oxic (AAO) process is recognized as an easy-to-handle approach that constrains chemical use during the procedure. Herein, we improve an AAO system by adding more oxic orders in association with a biological membrane in order to increase the hydraulic retention time (HRT) of the oxic zone in the system. The investigated system was applied to the treatment of real domestic wastewater during 168 days of operation. The performance of the system reached a stable state after 60 days of operation. The removal efficiency of total nitrogen (TN), total phosphorus (TP), total suspended solids (TSS), biological oxygen demand (BOD_5), and chemical oxygen demand (COD) was found to be $93.6 \pm 3.0\%$, $91.9 \pm 3.5\%$, $88.6 \pm 1.2\%$, $82.6 \pm 1.4\%$, and $71.8 \pm 0.7\%$, respectively. After the operation process, the TN, TP, and TSS contents in the wastewater effluents met the A level in accordance with the QCVN 14-MT:2015/BTNMT regulation, and the effluents of COD and BOD_5 almost satisfied the requirement, with only some points being slightly higher than the limit values. The obtained data revealed that the AAO/O system was capable of treating domestic wastewater in small and medium-sized domestic wastewater treatment facilities.

1. Introduction

Wastewater treatment is one of the most pressing challenges for developing nations [1, 2]. Due to the rapid pace of population growth, organic compounds and nutrients from municipal wastewater have increased day by day and have contaminated the watercourses. More seriously, the untreated wastewater is mostly discharged into sewage sludge systems without any suitable treatment [2, 3]. Disqualified domestic wastewater is the most terrifying cause of water pollution and the leading threat to the global environment [4]. In Vietnam, the full-design capacity of the 24 existing centralized wastewater treatment plants is about 670,000 m^3/day; however, only 10% of urban wastewater is treated [5]. As a result, many cities in Vietnam have confronted negative effects not only on the quality of the surface water sources but also on the life and health of the residents [6]. Therefore, the development and application of domestic wastewater treatment before disposal is a necessary and urgent task in this developing country.

The constituents of wastewater originating from households consist of nitrogen, phosphorus, and broad groups of organic matters [7]. Common technologies for the treatment of this type of wastewater are anoxic–oxic (AO) [8, 9], AAO [10–12], University of Cape Town (UCT) [13, 14], the sequencing batch reactor (SBR) [15, 16], and membrane bioreactor (MBR) [13, 17]. When applied to domestic wastewater, they have shown relatively high performance towards several bulk parameters, including COD, TN, TP, and TSS [8, 15, 16]. Many prevalent technologies based on this combination have been developed. Each method has its own advantages and disadvantages. The most appropriate method can be chosen based on cost-efficiency and the properties of the wastewater [18, 19]. Among those techniques, many researchers have indicated the superiority of the AAO process which involves biological processes conducted in anaerobic, anoxic, and oxic conditions [20]. This process has superior properties, such as being simpler than other simultaneous nitrogen, organics, and phosphorus removal processes. It has a short hydraulic retention time, a strong impact load resistance, and low operating management costs [21].

In the AAO process, the hydraulic retention time (HRT) is a critical operating parameter affecting the biological treatment, the infrastructure, and the operational cost in the design and operation of wastewater treatment plants (WWTPs) [22, 23]. HRT that is too short can result in less contact time between the substrates and microorganisms, thereby decreasing the treatment efficiency of the pollutants in wastewater [23, 24]. The HRT is influenced by the geometric dimensions of the reactor [25]. In order to increase the HRT in WWTPs, an additional tank volume is normally required [26], possibly leading to an increase in the overall operational cost and difficulty in controlling the HRT. Modifying a conventional AAO model is, therefore, a promising way to improve the efficiency of the system.

In this study, the AAO model was modified by adding an oxic zone in association with a biological membrane to increase the HRT in order to provide more contact time between the microorganisms and substrates. The investigated system is called the AAO/O model. The designed system was applied for the treatment of real domestic wastewater from a household in Vietnam. The investigated parameters including pH, BOD_5, COD, TN, TP, and TSS were evaluated based on the allowable pollution parameters of Vietnamese environmental standards.

Table 1: The influent range of pollution parameters and their limitation values according to Vietnamese environmental standards.

No.	Pollution parameters	Unit	Influent range of pollution parameters	Limitation values of pollution parameters according to Vietnamese environmental standards[a]
1	pH	—	5.5–7.1	6–9
2	COD	$mg{\cdot}L^{-1}$	42.9–280.2	75
3	BOD_5	$mg{\cdot}L^{-1}$	25.7–168.2	30
4	TSS	$mg{\cdot}L^{-1}$	16.4–146.0	50
5	TN	$mg{\cdot}L^{-1}$	29.1–94.1	30
6	TP	$mg{\cdot}L^{-1}$	13.8–57.2	6

[a]The national technical regulation on domestic wastewater (QCVN 14 : 2015/MT-BTNMT) discharging into the water sources serving the tap water supply.

Table 2: Designed specification of the AAO/O model.

No.	Designed specification	Unit	Threshold values	Designed values
1	Flow Q	$L{\cdot}day^{-1}$	—	200–250
2	Food to microorganism ratio (F/M)	—	0.15–0.25	—
3	MLSS	$mg{\cdot}L^{-1}$	3000–5000	—
4	Anaerobic retention time	h	0.5–1.5	1.0
5	Anoxic retention time	h	0.5–1.0	1.0
6	1^{st} oxic retention time	h	3.5–6.0	6.0
7	2^{nd} oxic retention time	h	3.5–6.0	6.0
8	Ozone processing time	h	—	0.1
9	Sludge circulation	$m^3{\cdot}day^{-1}$	20–50	50
10	Inner circulation	$m^3{\cdot}day^{-1}$	100–300	300

2. Materials and Methods

2.1. Materials. Raw wastewater was collected from the influent waste pipe of a household located in Phu An Commune, Ben Cat town, Binh Duong Province, Vietnam. The influent ranges of pollution parameters in the investigated domestic wastewater are given in Table 1. According to Vietnamese environmental standards, the national technical regulation on domestic wastewater (QCVN 14 : 2015/MT-BTNMT) discharging into the water sources serving the tap water supply is given in Table 1. These values were used to compare and determine whether the influent and effluent of the pollution parameters satisfied the requirement in order to evaluate the effectiveness of the AAO/O system.

2.2. Reactor Setup and Operation. The applied AAO/O model was designed as a small and multisection system with an average treating capacity of 0.5 m^3/day, which is suitable for wastewater treatment of 5-member households. The designed specifications, schematic, and simulation diagrams of the studied model are given in Table 2 and Figures 1 and 2, respectively.

In the operation of the investigated AAO/O model, the influent wastewater was first discharged into an anaerobic zone for degradation of the complex organic matter. The next anoxic zone was used to reduce the nitrogen and phosphorus load from the wastewater. Then, the wastewater was further transferred to the two oxic zones in association with the biological membrane. This treatment allowed for the thorough disposal of the remaining organic matter, COD and BOD_5 content, and N and P with proportions of nutrients of $BOD_5 : N : P = 100 : 5 : 1$. The membrane offered a complete barrier to sedimentary sludge and suspended solids. At the 4^{th} zone, the activated carbon powder was deployed as an absorbent to remove color and odor in order to enhance the quality of the effluent. Finally, sterilization of the wastewater using ozone was conducted to remove all existing harmful and pathogenic microorganisms.

2.3. Analysis Methods. The investigated parameters in this study included pH, BOD_5, COD, TN, TP, and TSS. The system treatment performance was continuously evaluated for 168 days. During this period, a qualitative measurement

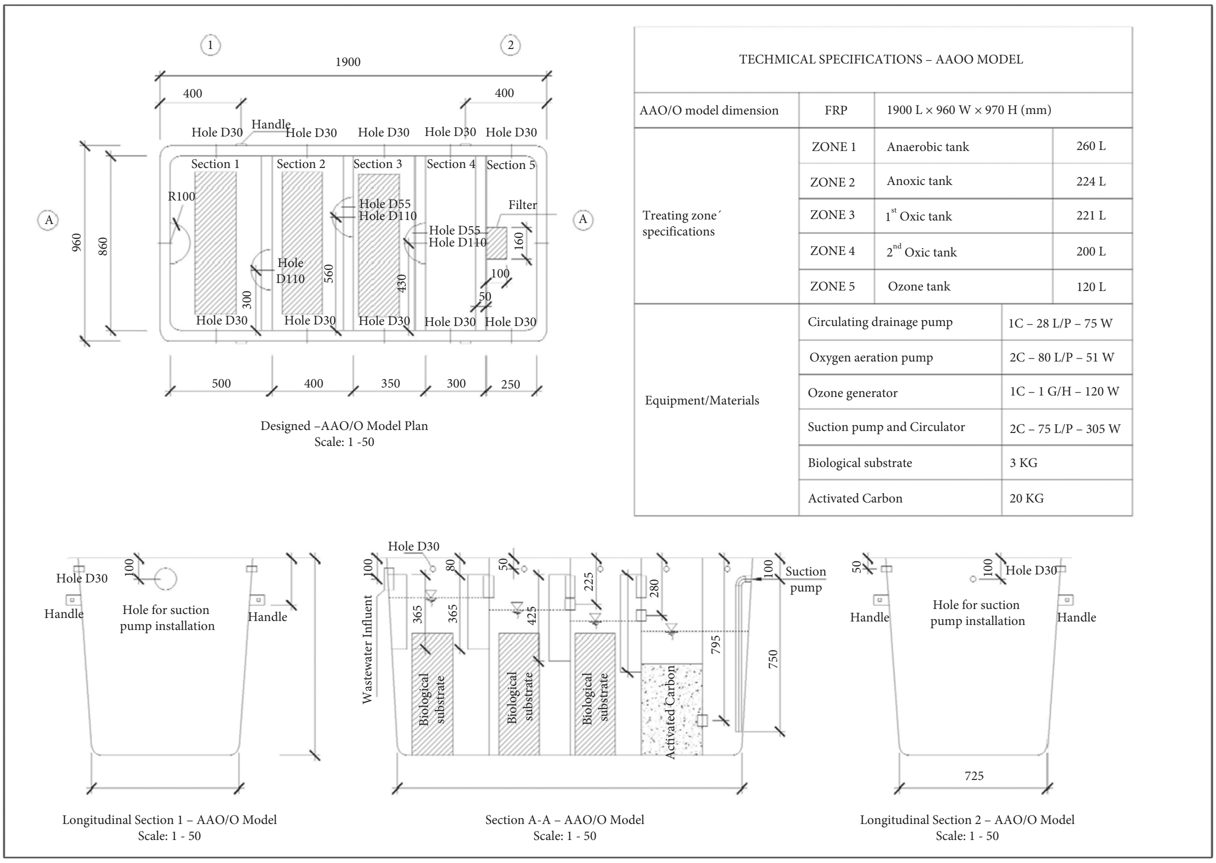

Figure 1: Schematic diagrams of the AAO/O model.

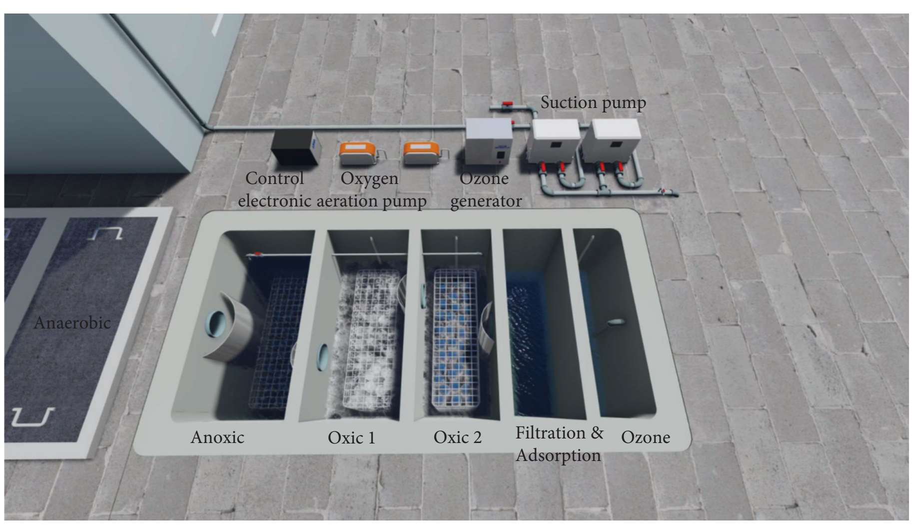

Figure 2: A simulation diagram of the AAO/O model.

was carried out every 7 days. The analysis was performed according to the standard method for the examination of water and wastewater (APHA, 2005) [27]. The pH level was monitored using a hand-held Mettler–Schwerzenbach meter (Switzerland). COD, TN, and TP were measured by UV-vis spectroscopy. The BOD_5 content was determined based on the annealing method at 20°C for 5 days. TSS was measured by filtering wastewater using 0.45 μm filter paper followed by drying at 150°C.

3. Results and Discussion

3.1. pH. The influent and effluent pH of domestic wastewater are shown in Figure 3. The influent pH during the

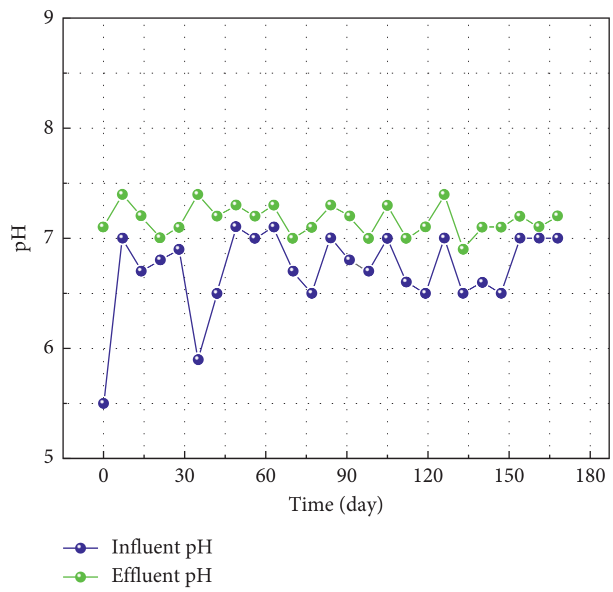

Figure 3: pH during the experimental period.

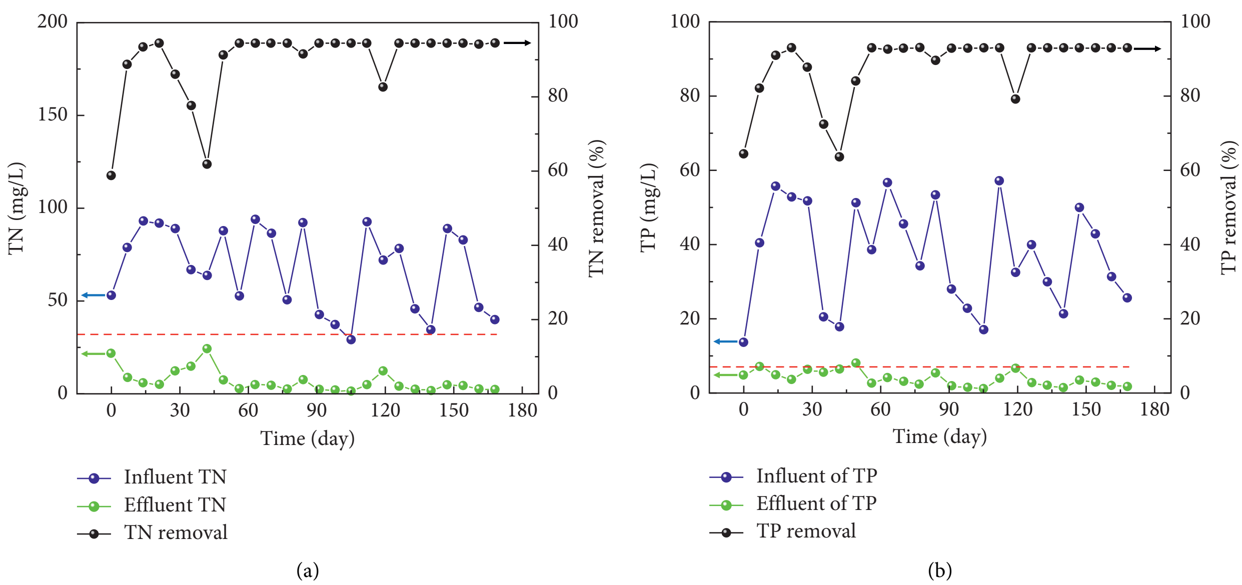

Figure 4: Nitrogen (a) and phosphorus (b) removal during the experimental period.

experimental period was in the range of 5.5–7.1, with some points out of the requirement range. These low and fluctuating values of influent pH could be due to the presence of organic matters in the wastewater entering the treatment system. After the removal of organic matters in the anaerobic tank, the pH level of wastewater was more stable for further treating processes. As a prominent parameter that strongly affects the removal capacity, the pH level in the range of 6.5–8.5 is required for the biological treating system to avoid stress on the microbial community and for optimal biological activity in both anoxic and aerobic tanks [28]. After being treated by the AAO/O system, the effluent pH range was 6.9–7.1, which satisfied the environmental standards.

3.2. Performance of the Nutrient Removal. The influent, effluent, and removal rate of TN and TP using the AAO/O system during the 168 days of operation are shown in Figures 4(a) and 4(b), respectively. The national technical regulation on domestic wastewater (QCVN 14 : 2015/MT-BTNMT) discharging into the water sources serving the tap water supply for TN (30 mg·L^{-1}) and TP (6 mg·L^{-1}) are also represented by the red dashed line in the figure. The results showed that influents of both TN and TP changed day by day and exceeded the Vietnamese environmental standards. During the first 56 days of operation, the removal rate of TN and TP was not stable, ranging 58.8–94.5% and 64.5–93.0%, respectively. This can be explained by the fact that the domestic wastewater contains high concentration of nutrients [29], and

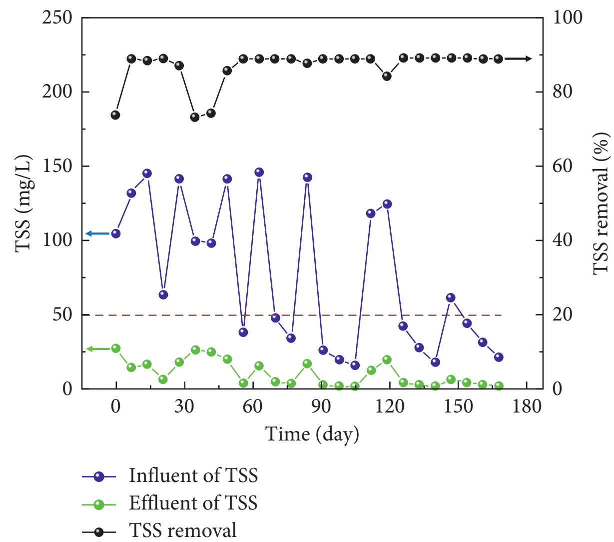

Figure 5: TSS removal during the experimental period.

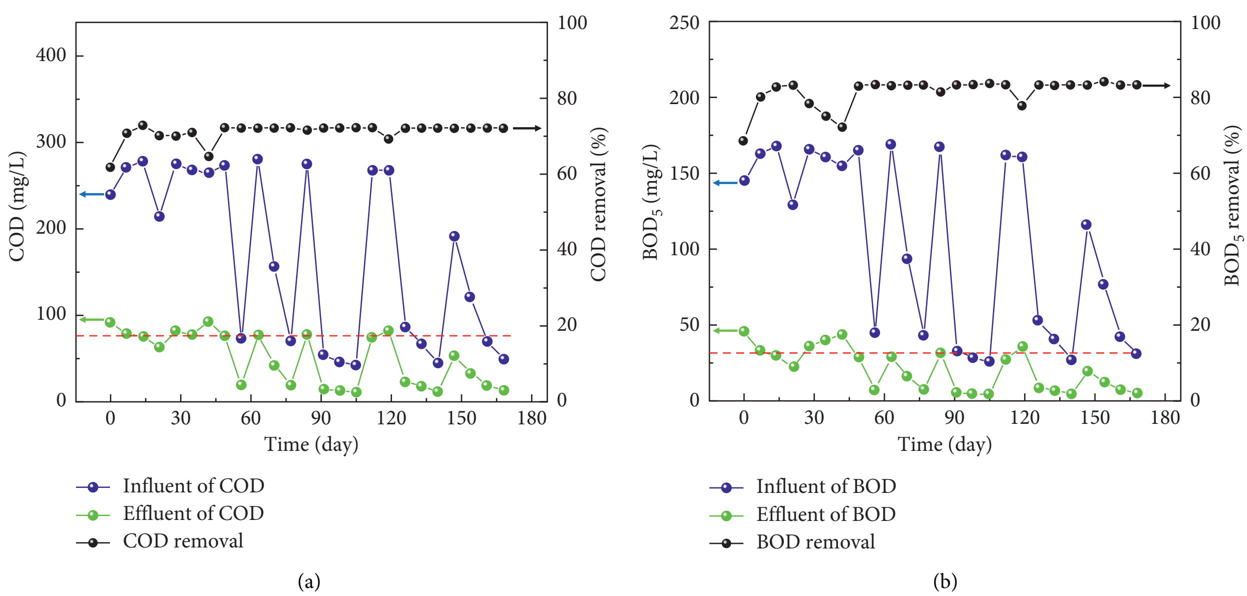

Figure 6: COD (a) and BOD_5 (b) removal during the experimental period.

the ratio of BOD_5 : N : P at 100 : 5:1 is required for aerobic treatment [30, 31]. The beginning period of the treatment is therefore usually needed to produce a proper mass of microorganisms in an aerobic condition and to adjust the procedure to ensure the best operating parameters. The removal efficiency of the AAO/O system for TN and TP reached a stable period after 60 days of operation, with values of $93.6 \pm 3.0\%$ and $91.9 \pm 3.5\%$, respectively. It is worth noting that effluents of TN and TP were lower than the regulated limit standards. Therefore, the AAO/O system was found to be effective and suitable for removing nutrients in domestic wastewater.

3.3. Performance of the TSS Removal. Figure 5 shows the TSS removal performance of the AAO/O system during 168 days of operation. The influent of TSS was in the range of 16.4–146 $mg \cdot L^{-1}$, which mainly exceeded the limit value of 50 $mg \cdot L^{-1}$. Similar to the case of nutrient removal, the system maintained stable profiles after 60 days of operation with a removal efficiency of $88.6 \pm 1.2\%$. The AAO/O system was found to be efficient for TSS removal owing to the fact that the effluent of TSS was lower than the limits of the Vietnamese standards.

3.4. Performance of Organic Removal. The removal of organic matter was mainly based on the activity of microorganisms (activated sludge) in the two oxic zones. The dissolved organic substances can be biodegraded by microorganisms, while nonbiodegradable organic compounds are removed by filtration of suspended particles. The performance of the AAO/O system in removing COD and BOD_5 is shown in

Figures 6(a) and 6(b), respectively. The BOD_5 concentration fluctuated significantly during the investigation period. This is because it depends on personal hygiene needs, such as urination and defecation from time to time of members in the family [29]. The result showed that, similar to other above parameters, both influents of COD and BOD_5 were almost higher than the limit values of the national technical regulation on domestic wastewater. In the first 56 days of operating the AAO/O system, the removal rate of COD and BOD_5 was not stable, ranging from 61.7 to 72.7% and 68.4–83.0%, respectively. The effluents of COD and BOD_5 in this period were higher than the standards. After 60 days of operation, the system became steadier with the removal efficiency of $71.8 \pm 0.7\%$ and $82.6 \pm 1.4\%$ for COD and BOD_5, respectively. With this removal efficiency, the effluents of both COD and BOD_5 almost satisfied the requirement, with only some points being slightly higher than the limit values.

The application of the investigated AAO/O system to domestic wastewater treatment yielded promising results. In particular, the removal efficiency of TN, TP, TSS, BOD_5, and COD of wastewater were $93.6 \pm 3.0\%$, $91.9 \pm 3.5\%$, $88.6 \pm 1.2\%$, $82.6 \pm 1.4\%$, and $71.8 \pm 0.7\%$, respectively. The removal efficiency of COD was found to be lower than other indices. This was because the biological method was the main technique for the wastewater treatment as the ratio of BOD/COD in the domestic wastewater was above 0.5 [32, 33]. This method is more effective for removing BOD and nutrients than COD, resulting in the higher removal rates for these indices. It should be noted that the performance of the system was not optimal during the first 56 days due to poor adaptation of microorganisms, which can lead to inefficient decomposition of contaminants. However, after around 60 days, their performance was highly optimized with stable variation, as their reproduction and expansion were already ensured. In addition to the advantage of possessing a longer HRT, the increase in the oxic order in the AAO/O model also provided a long sludge retention time that can help to prevent the loss of nitrifying bacteria and to improve the nitrification capacity of the activated sludge.

4. Conclusions

The AAO/O model was prepared by adding an oxic zone in association with a biological membrane to a conventional AAO system. The system was specifically designed for household wastewater treatment with a discharge capacity of $0.5\ m^3$/day. The removal efficiency of TN, TP, TSS, COD, and BOD_5 using the system was relatively high and almost satisfied the Vietnamese environmental standards. The qualified output can be circulated and reused for household sanitation or watering purposes. The obtained results showed that AAO/O exhibited great potential not only in maintaining water reservoirs but also in addressing notorious environmental issues.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they no conflicts of interest.

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