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Outstanding Potential for Treating Wastewater from Office Buildings Using Fixed Activated Sludge with Attached Growth Process

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Abstract: The application of fixed activated sludge with an attached growth process (FASAG) with optimal operating conditions (hydraulic retention time (HRT) of 7 h, dissolved oxygen (DO) of 6 mg/L, and alkalinity dosage of 7.14 $mgCaCO_3/mgN\text{-}NH_4^+$) treats wastewater generated from office buildings to meet discharge requirements (as per the regulation in the nation where the study was conducted) with typical parameters such as pH of 6.87–7.56, chemical oxygen demand (COD) of 32–64 mg/L, suspended solids (SS) of 8–11 mg/L, $N\text{-}NH_4^+$ of 1–7 mg/L, and denitrification efficiency reaches 53%. In addition, the FASAG is an outstanding integration that makes both economic and environmental sense when applied in local wastewater treatment systems. In particular, this process combines aerobic and anoxic processes in a creation tank. This explains why this approach can save investment and operating costs, energy, and land funds. In office building regions, where land area is frequently limited, saving land funds presents numerous options to enhance the density of green cover. Furthermore, as a new aspect, investing in reusing wastewater after treatment to irrigate plants or flush toilets in office buildings contributes to a decrease in the quantity of wastewater released into the environment, saving water resources and supporting sustainable development.

Keywords: nitrification–denitrification; fixed media; sustainable development; simultaneous treatment; reuse potential; municipal wastewater

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1. Introduction

Urbanization is happening more quickly in almost every area in the world. The primitive agricultural civilizations changed into modern urban civilizations that concentrated on contemporary services and industries, typified by modern utility systems and urban infrastructure, and the number of office buildings also increased significantly [1]. Sources of wastewater generation in office buildings come from all daily activities of people working in the building, including wastewater generated from eating, drinking, and living, such as washing, cleaning hands, and other home-related uses, as well as defecation and micturition. Consequently, the composition of wastewater from office buildings is similar to that of municipal wastewater, frequently including organic matter (an estimated equivalent amount as chemical oxygen demand (COD) or biochemical oxygen demand (BOD)), nutrients such as nitrogen, suspended solids, and bacteria [2].

The activated sludge process has been widely used in many areas. This is one of the traditional technologies commonly used and has been considered an optimal process for municipal wastewater treatment for many decades. The elimination of pollutants in the activated sludge process is carried out by a bacterial biomass suspension (activated sludge) [3]. Typical pollutants in municipal wastewater are COD and nitrogen, which require different treatment processes: aerobic and anoxic treatments, respectively. In an aerotank using the wastewater's constituent parts as food, the bacteria participate in biochemical processes that transform the soluble and colloidal material fraction into disposable microbial aggregates. These can be called flocs, eliminated by gravity settling in a secondary settling tank [4]. The procedures are similar for the anoxic process but need to control different operating parameters. With similar components and properties, the wastewater from office buildings is also commonly applied aerobic (with or without carrier material) and anoxic biological treatment processes in each reactor. After going through these two processes, ammonia is transformed into nitrate and becomes nitrogen. However, the characteristics of office buildings are that the amount of wastewater generated is not too much, and the land fund is limited. Therefore, setting up many treatment processes like those listed above causes many difficulties for most office buildings. To solve the above specific problems, this study integrates aerobic and anoxic treatment processes in the same system, which is called fixed activated sludge with an attached growth process.

The fixed activated sludge with an attached growth process (FASAG) has an advantage over the aerobic activated sludge-suspended growth process (ASG) in that it does not require sludge recirculation because of the adhesion of sludge on the carrier material, which lowers the amount of money needed for pumps and energy to run them [5,6]. It is effective in removing dissolved organic carbon and a significant degree of nitrification and denitrification [7]. Additionally, since activated sludge does not need to be mixed with wastewater, less air is supplied, resulting in a lower blower capacity and energy consumption. Nitrification is stable year-round and has the potential to enlarge, as mixed liquid suspended solids (MLSS) can increase [8]. Moreover, the characteristic of the FASAG process is that the biofilm carrier materials are filled into the reactor, making them unable to move. Through this process, a thicker biofilm is formed, and it is kept from peeling off the carrier materials. The thick layer of biofilm creates conditions for the anoxic and aerobic processes to occur simultaneously from the inside to the outside of the biofilm because the ability to receive oxygen gradually decreases from the outside to the inside. This is an outstanding feature that allows nitrification and denitrification to occur in the same reactor. Office buildings have the potential to become more environmentally friendly and enhance sustainable development. However, the treatment technology using FASAG with ASG will occur simultaneously with nitrification and denitrification. This leads to competition in the adaptation and development of the microorganisms of each process [9]. Maintaining appropriate conditions to achieve optimal treatment efficiency of both processes will be more challenging. So, this study was conducted to evaluate the optimal potential of the fixed activated sludge with an attached growth process compared to traditional technology.

2. Materials and Methods

2.1. Experimental Device

The experimental device is a fixed activated sludge with attached growth process (FASAG) and aerobic activated sludge-suspended growth process (ASG) to evaluate the efficiency of integrating aerobic and anoxic processes in the same reactor (Figure 1). FASAG and ASG reactors are made of plastic with the same dimensions (length $\times$ width $\times$ height) of 38 cm $\times$ 30 cm $\times$ 35 cm. The working volumes of each reactor are 31 L (FASAG) and 30 L (ASG). The volume displaced by the biofilm carrier materials results in a greater working volume in the FASAG reactor. The two equalization reactors, 1 and 2, are also made of plastic with volumes of 70 L and 20 L, respectively. Soft plastic piping systems for allocating water and air distribution materials are installed to distribute oxygen in each reactor.

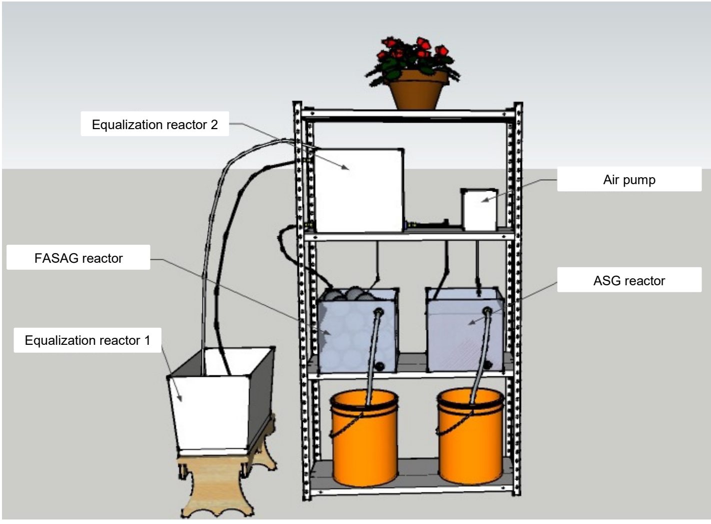

Figure 1. Experimental device.

2.2. Influent Water and Activated Sludge

Wastewater and activated sludge used for this study were taken, respectively, from the equalization tank and from the second sedimentation tank of the wastewater treatment plant at the PVFCCo Tower—an office building in Ho Chi Minh City, Vietnam. Activated sludge has a moisture content ranging from 94% to 97% and a volatile solids/total solids (VS/TS) ratio between 0.86 and 0.93. The wastewater composition is presented in Table 1.

Table 1. The composition of influent wastewater.

No.	Parameter	Unit	Value
1	pH	-	6.60–7.69
2	SS	mg/L	34–80
3	COD	mgO_2/L	144–432
4	$N\text{-}NH_4^+$	mg/L	49–90
5	$N\text{-}NO_2^-$	mg/L	0.2–8.0
6	N-organic	mg/L	9–15
7	Alkalinity	$mgCaCO_3/L$	160–480

2.3. The Biofilm Carrier Materials

The biofilm carrier material is made from polypropylene (PP) and polyvinylchloride (PVC) plastic (Figure 2). Polypropylene exhibits superior resistance to chemicals. It is a polymer made catalytically from propylene. The high-temperature resistance is one of its main advantages [10]. The qualities of PVC include resistance to abrasion, corrosion, weathering, and chemical deterioration. It is very resistant to aliphatic hydrocarbons, diluted alkalis, and acids. It is the preferred material because of its long life [11]. The durable and stable properties of the material's constituents make it the choice for environmentally friendly use. The characteristics are shown in Table 2.

Table 2. Properties of biofilm carrier material.

Parameter	Unit	Value
Diameter	mm	105
Occupied volume	L/m^3	23–33
Surface area	m^2/m^3	150–180
Porosity	%	90–92

Source: https://www.wtc.com.vn/2019/12/01/vatlieudinhbam/, accessed on 2 July 2024.

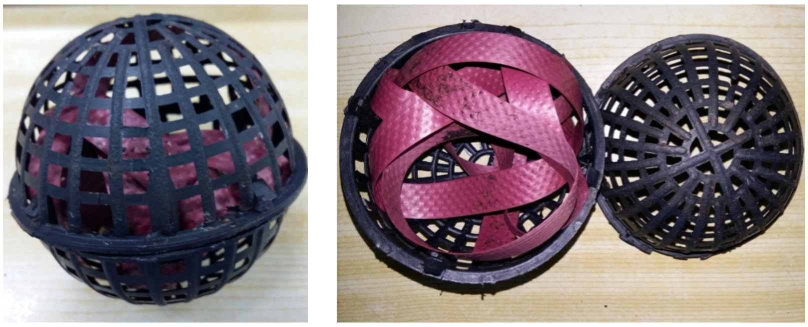

Figure 2. The biofilm carrier materials used in research.

2.4. Operating Conditions

The experimental reactor was run for 36 days with operational parameters selected within the allowable range, according to theoretical calculations, such as hydraulic retention time of 7 h and alkalinity consumption of 7.14 mg $CaCO_3$/mgN-NH_4^+, corresponding to the chemical $NaHCO_3$ needed to be added is 173 mg/L. The dissolved oxygen concentration is maintained at about 6 mg/L, and the volatile suspended solids (VSS) concentration is 2000 mg/L [12]. Every day, effluent samples were collected from the FASAG and ASG reactors to examine the effectiveness of treatment.

2.5. Experimental Analysis Methods

pH and DO were measured using a Toledo MP 220 pH meter (Mettler-Toledo International Inc, Columbus, OH, USA), a Hach Sension 6 DO meter (Hach Company, Loveland, CO, USA), and a Hach HQ 30D DO meter (Hach Company, Loveland, CO, USA), respectively. The APHA method was used to determine the concentrations of total suspended solids (TSS), VSS, VS, TS, COD, alkalinity, N-NH_4^+, and N-NO_3^- [13].

3. Results

The feasibility of combining the FASAG and ASG processes in a reactor is demonstrated by the experimental findings. The Figure 3 shows that the pH of the influent wastewater ranged from 6.62 to 7.17, and it increased to 7.25 to 7.91 after chemicals were added to provide alkalinity. The measured pH values were suitable for biological treatment [14]. After going through the biological treatment process, the pH in FASAG was generally 6.98–7.67, slightly higher than in ASG, which was 6.87–7.56. Anoxic conditions created by activated sludge adhered to the substance of biofilm carrier materials prevent the anoxic zone (inner layer) from receiving enough oxygen, leading to denitrification, which returns alkalinity and raises pH [15].

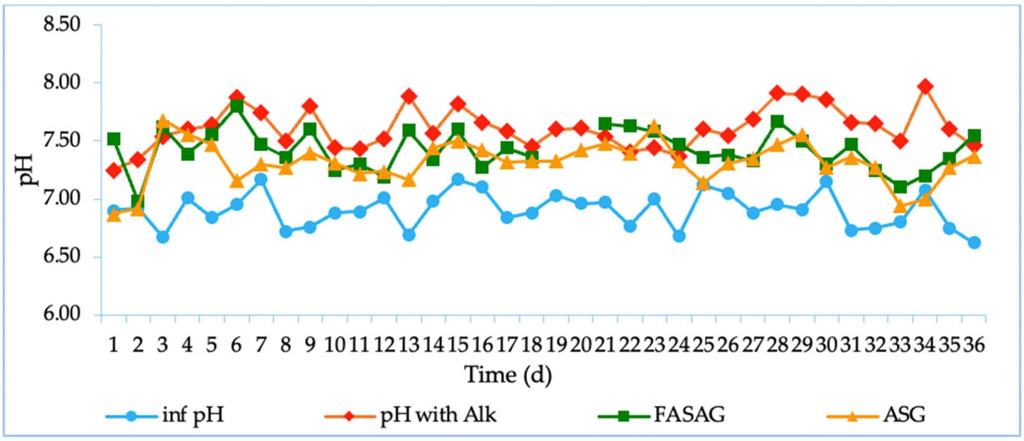

Figure 3. pH values during the experiment.

The COD of wastewater fluctuated a great deal, relatively speaking (160–432 mg/L). However, the common influent COD value was 160–288 mg/L (Figure 4. The ASG reactor had a COD concentration of 80 mg/L on the 11th day and reached stability in the 32–64 mg/L range, equivalent to a treatment efficiency of 64–86% (Figure 5). With the FASAG reactor, the COD concentration after treatment decreased to 144 mg/L on the first day of operation and gradually decreased to 80 mg/L on the ninth day. Sample analysis results from the 10th to 16th day showed that COD concentration after treatment was stable in the range of 48–80 mg/L (Figure 4). This highest efficiency is equivalent to the research results of Dang et al. when applying loofah sponges as bio-carriers in an integrated fixed-film activated sludge system [16]. However, on days 17 and 18, COD suddenly increased to 160 mg/L. The increase in COD values is due to chironomid mosquitoes that are often present in wastewater treatment systems or lagoons and lay eggs. Eggs develop into red worm larvae [17]. Red worms do not live separately but stick together in patches (Figure 6). Their cycle of growth and development then continues until they turn into pupae, float to the surface, and develop into adult mosquitoes. The presence of red worms that fed on sludge flocs caused the microorganism density to decrease; the sludge flocs became loose and peeled off from the biofilm carrier materials, leading to reduced COD and nitrogen treatment efficiency. The air pump was turned off for two days to stop providing oxygen, inhibiting their growth and development [18]. After that, the model operated normally again, and the COD treatment efficiency reached a stable level of 82% until the end of the experiment, relatively higher than in the study of Dohdoh et al. [19].

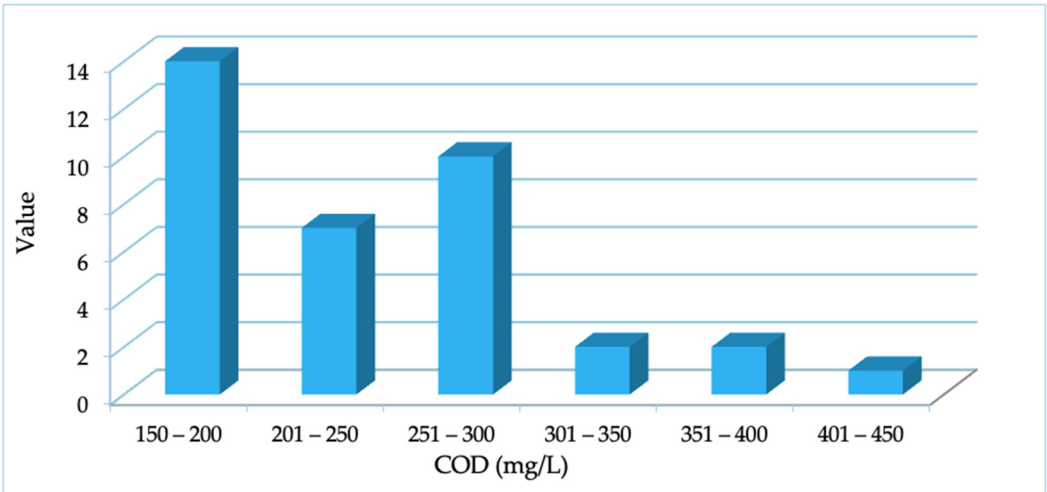

Figure 4. Frequency of appearance of influent COD concentration.

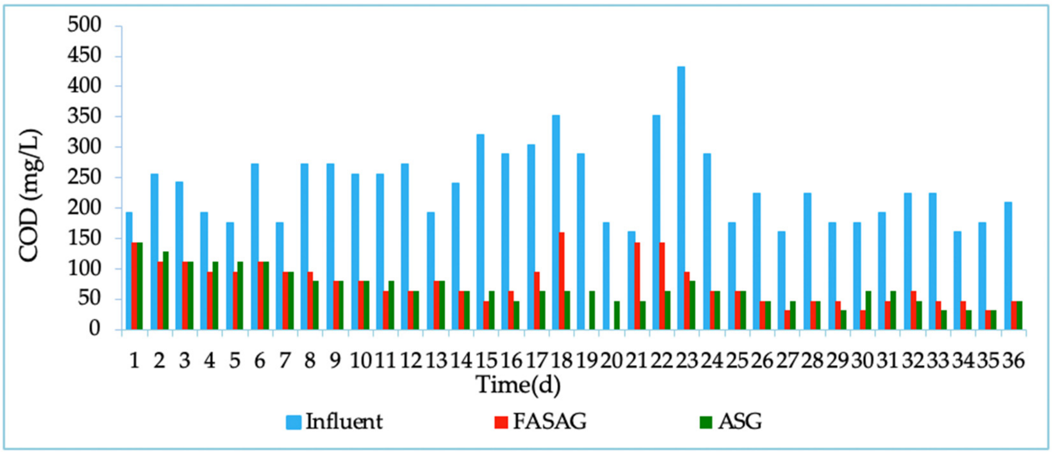

Figure 5. Effective COD treatment.

Figure 6. Red worms form in the treatment reactor.

The influent wastewater contained between 34 and 80 mg/L of total suspended solids. In the stable stage, the TSS value in the treated wastewater of the ASG reactor was between 8 and 11 mg/L, and in the treated wastewater of the FASAG reactor, it varied from 9 to 12 mg/L. In general, the TSS concentration after treatment of both processes was similar. The range of treatment effectiveness was 77% to 88% (Figure 7).

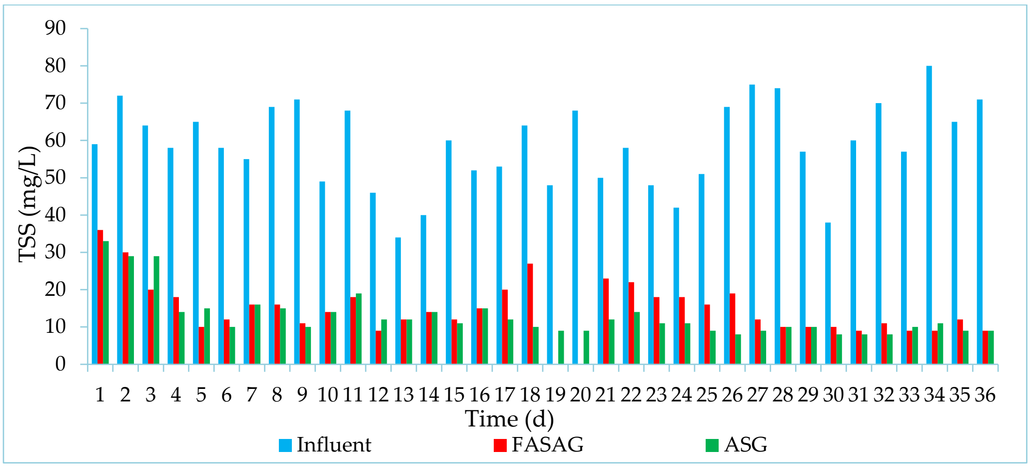

Figure 7. Effective SS treatment.

The graphs in Figures 8 and 9 indicate that the ammonia of wastewater had a concentration between 54 and 81 mg/L. However, the most frequent value was between 66 and 80 mg/L. The ammonia conversion efficiency of the ASG reactor grew steadily throughout the first eight days of operation, from 43% to 85%, with the ammonia content after treatment decreasing gradually from 38 mg/L to 11 mg/L. Because no red worms developed in the experimental reactor, the ammonia concentration of the effluent wastewater remained constant between 1 and 7 mg/L from the 9th day until the completion of this study. The stable conversion efficiency of ammonia reaches 90% to 99%. Moreover, on the first day of operation, the ammonia content of the FASAG reactor dropped from 67 mg/L to 44 mg/L. The treatment effectiveness grew over the next few days, stabilizing on the ninth day with an ammonia content of 7 mg/L. After treatment, the nitrification process proceeded steadily, with ammonia content varying between 1 and 8 mg/L until the 17th day. The concentration and quality of sludge in the model were impacted by the appearance of red worms on the eighteenth day, which consumed nitrifying bacteria. As a result, the ammonia concentration rose to 26 mg/L following treatment. After ceasing to run for two days without supplying oxygen to kill red worms, the reactor kept running in the same condition. Ammonia levels started at 18 mg/L on the 21st day of operation and progressively reduced to 5 mg/L on the 26th day and were stable in the range of 1–6 mg/L until the end of the model. Treatment efficiency reached a high 91% to 99%, relatively higher than some research that treated ammonia with the aerobic integrated fixed-film activated sludge process (IFAS) [19–21]. In general, the nitrification efficiency of the two reactors is equivalent (the highest treatment efficiency is 99%, corresponding to an ammonia concentration after treatment of 1 mg/L). In comparison, ASG takes 8 days to adapt and is most effective on the 11th day, but FASAG takes 9 days and is most effective on the 15th day.

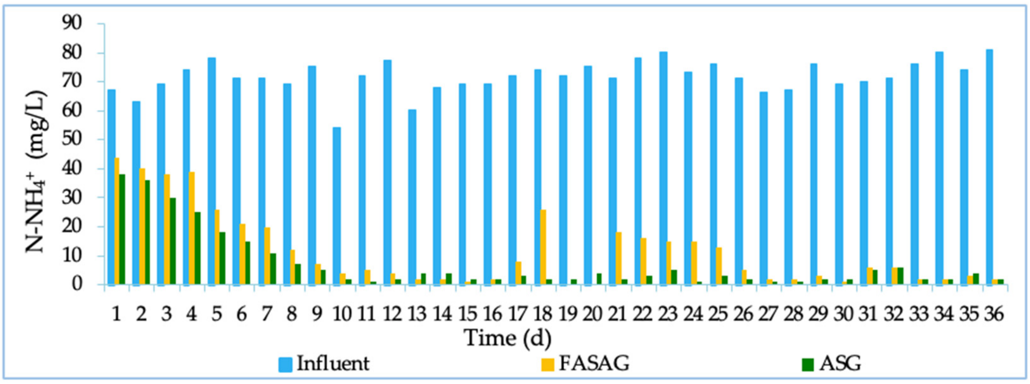

Figure 8. Effective ammonia treatment.

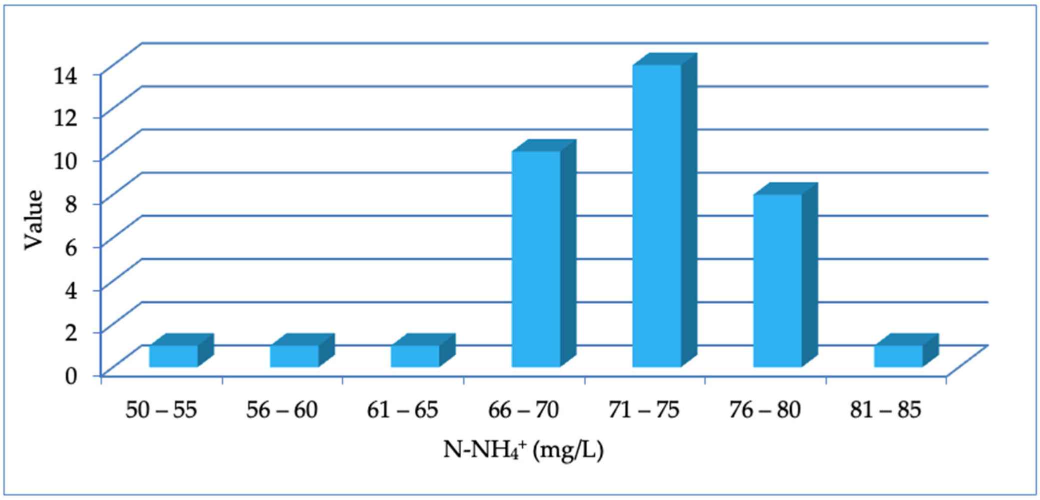

Figure 9. Frequency of ammonia appearance in influent wastewater.

The ammonia concentration in the influent wastewater (54–84 mg/L) was always more than the total ammonia and nitrate concentration after treatment of the FASAG reactor (31–50 mg/L) in the adaption stage, as shown in Figure 10. A 10-day treatment period was affected by the presence of red worms as described. After that, the total concentration of ammonia and nitrate in the effluent water was always smaller than the influent ammonia concentration, proving that the denitrification process occurs simultaneously in the [22,23]. The fixed activated sludge with an attached growth system reaches the highest efficiency on day 34 with a treatment efficiency of 53%. A common explanation for this phenomenon is that denitrification occurs in the inner layer, supported by the existing DO gradients, while autotrophic nitrification occurs simultaneously on the surface of the microbial film that adheres to the carrier material [24,25]. In contrast, in the ASG reactor, the total ammonia and nitrate concentration after treatment (57–91 mg/L) and the input ammonia concentration (54–84 mg/L) are approximately equal or higher due to the amount of organic nitrogen (N- org) that was converted into ammonia and then further nitrified. It is also evident that denitrification does not occur in the aerobic-activated sludge-suspended growth process.

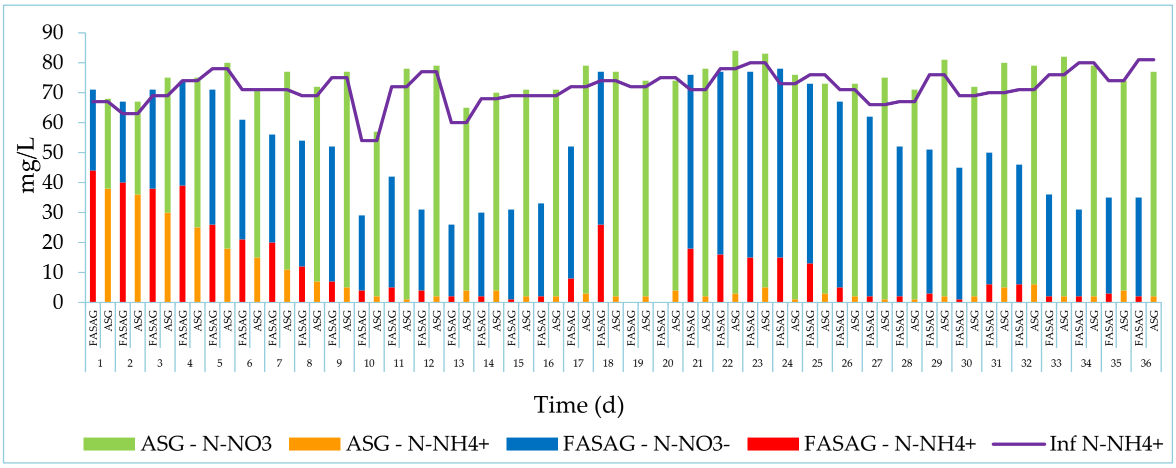

Figure 10. Effective nitrate removal.

Analysis results from Figure 11 show that the available alkalinity in the influent wastewater ranges from 284 to 486 mg/L. The alkalinity after adding $NaHCO_3$ is 7.14 $mgCaCO_3/mgN\text{-}NH_4^+$, enough to convert the amount of ammonia in the influent wastewater [26]. The ammonia conversion efficiency with both experimental reactors is 91–99% (1–7 mg/L), and following FASAG treatment, the remaining alkalinity (88–212 mg/L) is comparatively higher than that of ASG (88–136 mg/L) due to alkalinity formed during the denitrification process at FASAG [24]. The significant use of alkalinity from denitrification for nitrification makes the integration of aerobic and anoxic process research a promising solution. It helps reduce chemical use and is more environmentally friendly.

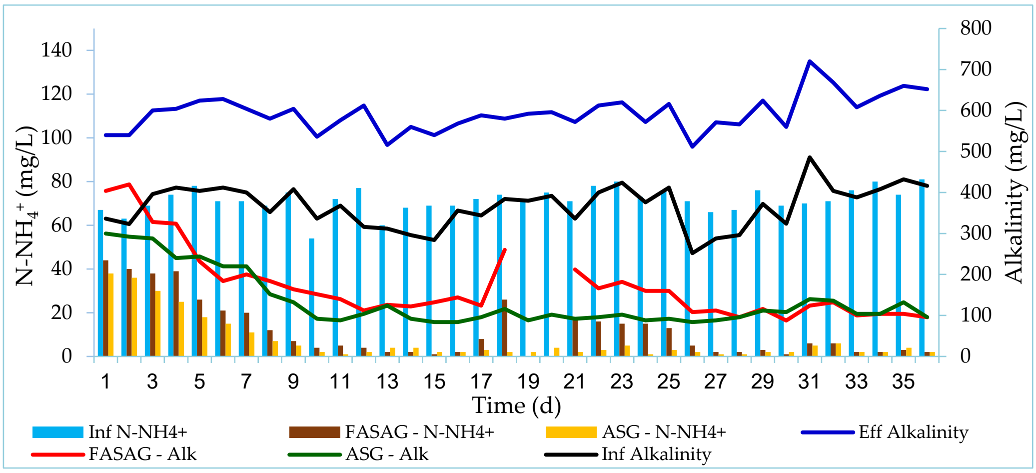

Figure 11. Ratio between ammonia concentration and required alkalinity.

4. Discussion

Municipal wastewater from office buildings can be treated by applying the fixed activated sludge with an attached growth process, especially the ammonia component, which can be treated well without using the denitrification process. The optimal operating conditions that should be maintained are a hydraulic retention time of 7 h, dissolved oxygen of 6 mg/L, and alkalinity dosage of 7.14 $mgCaCO_3/mgN\text{-}NH_4^+$. Immobilizing the carrier materials in the reactor helps form a thicker biofilm and causes nitrification and denitrification to occur simultaneously in a reactor. This method also helps reduce investment and operating costs and is less dependent on energy use. The land fund saved from integrating the two processes can be utilized to develop green areas and reuse treated wastewater for irrigation. It is a feasible concept that will help office buildings move toward a sustainable future. In addition, utilizing as much of the alkalinity and carbon source supply from the internal treatment process as possible also benefits the environment and lowers operational expenses because of the unnecessary supply of chemicals from outside.

5. Conclusions

To further develop the application of this integrated technology, further research should be conducted on reducing the water retention time and dissolved oxygen concentration and on the kinetic mechanism of pollutant removal or determining the formation and peeling time of activated sludge on biofilm carrier materials to ascertain the best operating practices that are appropriate for the current situation.

In addition, there should be more research to clarify the impact of red worms on treatment effectiveness and to devise methods to manage their presence. Moreover, an evaluation of the energy consumption and economic efficiency of the FASAG system compared to traditional ASG systems should also be performed to provide sustainable wastewater management strategies.

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