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*Article*

# Integrating Suspended Sludge and Fixed Film into a Biological Wastewater Treatment System to Enhance Nitrogen Removal

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**Abstract:** Integrated Fixed Film Activated Sludge (IFAS) technology greatly enhances nitrogen removal effectiveness and treatment capacity in municipal wastewater treatment plants, addressing the issue of limited land availability. Hence, this method is appropriate for treating household wastewater from office buildings. The research was conducted at the wastewater treatment plant in an office building in Ho Chi Minh City, Vietnam. Experiments were conducted to ascertain the most favorable working conditions, including Hydraulic Retention Time (HRT), alkalinity dosage, and Dissolved Oxygen (DO). According to the study, the IFAS system had the highest nitrogen removal effectiveness when operated at a hydraulic retention time (HRT) of 7 hours, an alkalinity dose of 7.14 mg$CaCO_3$/mgN-$NH_4^+$, and a dissolved oxygen (DO) value of 6 mg/L. The nitrification efficiency ranges from 89.2% to 98.8%. The nitrate concentration post-treatment is within the range of 27 – 45 mg/L, which is lower than the allowable discharge limit of 60 mg/L as per Vietnam's wastewater discharge requirements. The research findings have enhanced the efficiency of the office building management process, thereby promoting the sustainable growth of society.

**Keywords:** Integrated fixed-film activated sludge (IFAS); domestic wastewater; office building; simultaneous nitrification and denitrification (SND)

## 1. Introduction

The environment is experiencing significant impacts due to the proliferation of office buildings and the continuous growth of society. The degradation of Earth's ecosystems results from altering natural areas caused by urban sprawl. In addition, the release of untreated residential wastewater from office buildings poses a substantial environmental hazard [1]. Consequently, various environmental problems have arisen, including heightened usage of energy and water, as well as the production of pollutants such as chemical oxygen demand (COD), ammonia nitrogen, sulfur dioxide, and nitrogen oxides [2]. Therefore, treating household wastewater from office buildings is considered a crucial activity in sustainable urban development aimed at reducing the environmental consequences of the growing number of office buildings.

Several investigations have consistently found increased nitrogen levels in the wastewater produced by office buildings [3–6]. This matter is highly significant as it has the potential to contaminate groundwater [5] and threaten aquatic environments [6]. Nitrogen compounds can inflict substantial harm on the environment, such as the reduction of oxygen levels in water bodies or the process of eutrophication [7]. Effective treatment methods are necessary to remove these increased nitrogen levels efficiently. Various technologies and strategies have been examined to treat wastewater effectively. Li et al. studied the operational efficiency and membrane fouling of the A2/O-MBR process in reclaimed water treatment [8]. They highlighted the significance of maintaining stable effluent water quality and the role of microbial diversity in effectively removing organics and

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facilitating the nitrification of ammonia nitrogen. Pedrouso et al. investigated the treatment of digested blackwater in a reactor that uses a partial nitritation-anammox process with alternating periods of starvation and reactivation [9]. Zhang et al. developed a method that combines partial nitritation and denitrification with polishing anammox to remove nitrogen from low C/N residential wastewater. This approach resulted in a high efficiency of nitrogen removal [10]. Huang et al. devised a method combining partial denitrification with anaerobic ammonium oxidation (anammox) in a continuous-flow anoxic/oxic biofilm reactor, significantly increasing nitrogen removal efficiency [11]. In addition, Halicki et al. presented evidence of successfully eliminating nitrogen and phosphorus compounds in household wastewater through natural treatment systems, highlighting the capacity to reduce nutrient levels in wastewater [12]. These studies demonstrate the potential of many techniques to eliminate nitrogen from domestic wastewater efficiently. Nevertheless, every system possesses specific constraints. Given the extensive use of the continuous flow process, it is imperative to examine the efficacy and reliability of the innovative technology before its actual implementation. However, information was scarce, particularly about nitrogen removal's initial and long-term effectiveness in treating real domestic wastewater in office buildings.

The Integrated Fixed-Film Activated Sludge (IFAS) process has numerous benefits in eliminating nitrogen from wastewater. According to Waqas et al., it has been demonstrated that this method may produce a clearance rate of over 90% for combined chemical oxygen demand and ammonia [13]. Additionally, it improves the settling qualities of sludge and enhances operational stability. The technique also facilitates the simultaneous occurrence of nitrification and denitrification, resulting in reduced amounts of chemical oxygen demand, ammonium nitrate, and total nitrogen in the effluent [14]. Furthermore, the IFAS process can effectively remove nitrogen from sewage, exhibiting impressive nitrogen removal rates [15]. Consequently, the IFAS process is appropriate for implementation in wastewater treatment facilities in office buildings. Nevertheless, the specific elements that influence the efficacy of nitrogen removal in office buildings using this technique have not been fully understood.

Therefore, this study assessed the variables that impact the nitrogen removal process in the domestic wastewater of an office building in Vietnam using the IFAS technology. The discussion concerns crucial operational factors such as hydraulic retention time (HRT), dissolved oxygen (DO) concentration, and alkali dosage. The results analyze the primary aspects influencing system stability and provide a strategy to guarantee stable operation, contributing to the sustainable development of society.

## 2. Materials and Methods

### *2.1. The Plant Description*

The research was conducted at a domestic wastewater treatment facility in an office building in Ho Chi Minh City, Vietnam. The plant has a daily capacity of 40 $m^3$/day. Figure 1 displays the diagram of the wastewater treatment process. Following concentration in the equalization tank, the wastewater is fed into an aerobic tank containing carrier material (Figure 2). After aerobic interaction between the wastewater and microorganisms, the wastewater flows automatically to an anoxic tank, a secondary clarifier, and a disinfection tank before being injected into the city's public drainage network. The system has been consistently functioning without any issues, and the post-treatment pollution components comply with the discharge requirements set by the Vietnamese Government.

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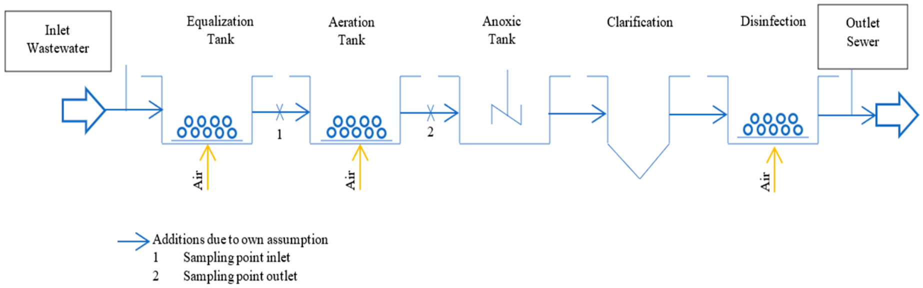


**Figure 1.** Process flowchart for office building wastewater treatment.

### *2.2. The Carrier Materials*

The carrier materials for this study are constructed using polypropylene (PP), as shown in Figure 2. Polypropylene is chemically stable, corrosion-resistant candles, stable to acid and alkali, cheap, and high strength. The diameter is 105 mm, porosity is 90 – 92%, specific surface area is 150 – 180 $m^2/m^3$, and volume is 23 – 33 $L/m^3$.

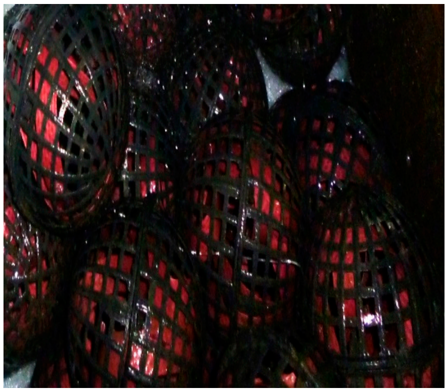

**Figure 1.** The carrier materials used in research.

### *2.3. Seed Sludge and Domestic Wastewater*

The inoculated sludge was obtained from the return ditch of the second settling tank of a domestic wastewater treatment plant, where the sludge maintained a high activity with an SV30 of about 20~30% and a yellowish-brown color. The water for the experiment was obtained from the fine-grating effluent of a domestic wastewater treatment plant at the office building. The quality of the influent water is shown in Table 1.

**Table 1.** Characteristics of influent wastewater.

| Parameters | Unit | Values |
|---|---|---|
| pH | - | 6.6 – 7.7 |
| SS | mg/L | 34 – 80 |
| COD | $mgO_2/L$ | 144 – 432 |
| N-organic | mg/L | 9 – 15 |
| $N\text{-}NH_4^+$ | mg/L | 49 – 90 |
| $N\text{-}NO_2^-$ | mg/L | 0,2 – 8,0 |
| Alkalinity | $mgCaCO_3/L$ | 160 – 480 |

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### *2.4. Factors Affecting Treatment Effectiveness*

#### 2.4.1. Hydraulic Retention Time (HRT)

Hydraulic Retention Time (HRT) is an essential parameter for determining the capacity of a wastewater treatment plant and has significant implications for cost reduction. Reducing the HRT can significantly lower the plant's overall cost, provided the discharge parameters are met. Nevertheless, the choice of HRT will vary depending on the concentration of contaminants in each area [16].

This study was conducted for 11 days, with HRT of 7 hours, 5.8 hours, 4.7 hours, and 3.9 hours, respectively. Each retention time will be studied for a duration of three days. The minimum hydraulic retention period is 3.9 hours (at a flow rate of 3 $m^3$/h) and was only investigated for 2 days. When the hydraulic retention time is altered while keeping the total treatment flow the same throughout the day, the result is an increase in the hourly load while the load during the day and night remains unchanged. The quantity of alkalinity supplement chemicals introduced is 11.5 kg/day, corresponding to an alkalinity consumption of 7.14 mg $CaCO_3$/mgN-$NH_4^+$. This amount is sufficient to fully convert the measured quantity of ammonia in the wastewater. The dissolved oxygen concentration is consistently maintained at around 6 mg/L.

#### 2.4.2. Alkalinity

Alkalinity is a critical factor influencing nitrification, where ammonium (N-$NH_4^+$) is converted to nitrate (N-$NO_3^-$). Scientists have linked alkalinity to nitrification/denitrification for decades, although little is known about its effect on effluent nitrogen content. Because nitrification consumes more alkalinity than denitrification, the fluctuation in alkalinity during treatment may also indicate nitrification/denitrification [17]. The alkalinity requirement is determined based on the bicarbonate needed to counteract the acidity produced during nitrification. Hence, theoretical calculations suggest that an alkalinity consumption of 7.14 mg$CaCO_3$/mgN-$NH_4^+$ is enough to convert all the ammonia entering wastewater into nitrate fully. This study examined the influence of different amounts of alkaline dosage on the effectiveness of ammonia therapy. The alkaline dosages tested were 7.45 mg of $CaCO_3$/mg of N-$NH_4^+$, 7.14 mg of $CaCO_3$/mg of N-$NH_4^+$, and 6.83 mg of $CaCO_3$/mg of N-$NH_4^+$. The duration of the study will be 9 days in total. The DO concentration is 6 mg/L, and the HRT is 7 hours.

#### 2.4.3. Dissolved Oxygen (DO)

Dissolved oxygen (DO) is vital to biological nutrient removal (BNR). Traditional nitrification and denitrification require 1 – 7 mg/L dissolved oxygen (DO). In anoxic-aerobic conditions, the optimal DO demand is 1 – 4 mg/L, compared to 6 – 7 mg/L in fully aerobic conditions [18].

The investigation was carried out using a hydraulic retention time (HRT) of 7 hours and an alkaline intake of 7.14 mg of $CaCO_3$/mg of N-$NH_4^+$. The study examined three DO levels: 6 mg/L, 4 mg/L, and 2 mg/L. The goal was to identify the optimal DO concentration required to treat the office building's wastewater efficiently.

### *2.5. Sampling and Analysis*

Using a HACH HQ30D multiparameter sensor (HACH Instruments, USA), pH and dissolved oxygen were sampled on-site and analyzed six times per day (DO change) and four times per day (HRT change) over many days. Spectrophotometer measurements of N-$NH_4^+$ and N-$NO_3^-$ concentrations were made. Titration was used to measure the alkalinity, BOD, and COD.

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## 3. Results

### *3.1. Effects of HRT on Treatment Efficiency*

The ammonia concentration remained below the permissible discharge level (12 mg/L) throughout the 3-day operation, with treatment efficiency ranging from 85% to 91%. This was achieved with an HRT of 7 hours (Q= 1.67 m3/h, Lorganic = 0.55 – 0.88 kg/m3.day, Lammonia = 0.20 – 0.29 kg/m3.day). This finding was analogous to the research by Singh et al. [19]. However, despite a drop in ammonia concentration after treatment, the effectiveness of ammonia treatment does not fulfill the requirements for discharge based on the remaining HRT values. Therefore, it may be inferred that if the hourly operating flow is increased (resulting in a decrease in HRT) beyond the calculated flow rate of 1.67 m3/h, the treatment efficiency fails to meet the criteria for wastewater disposal. Hence, it is illogical to reduce the duration of daily operations at the treatment station by augmenting the rate of treatment per hour. In addition, the research findings indicate that the treatment process will not yield the intended outcome if there is an increase in the ammonia concentration in the incoming wastewater.

Figure 3 demonstrated that the combined concentration of ammonia and nitrate in the treated wastewater (31 – 72 mg/L) is lower than the influent wastewater's ammonia concentration (57 – 93 mg/L). As a result, nitrification and denitrification occurred simultaneously in the aerobic-activated sludge tank [20]. Nevertheless, when the operating flow (reducing HRT) is increased, the efficiency of the nitrate reduction process also decreases with the operating stages. It is crucial to effectively control nutrient loading rates to prevent system overload or inhibition [21].

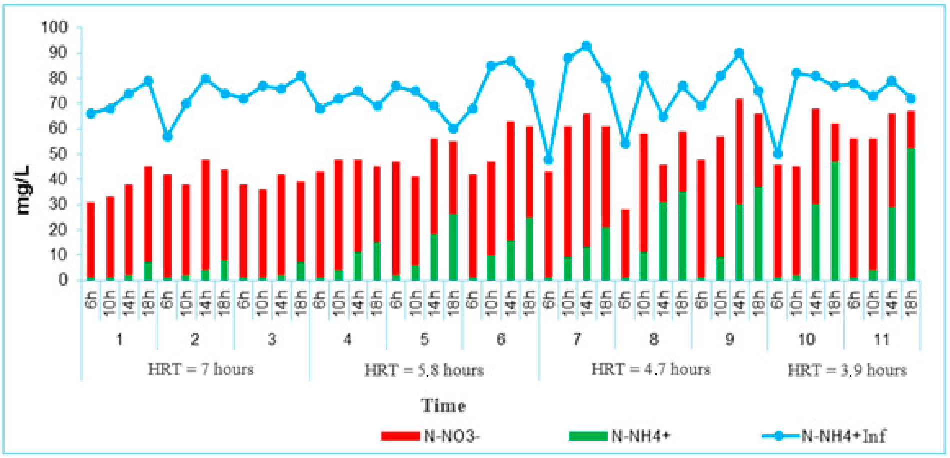


**Figure 3.** Process denitrification effectiveness for various hydraulic retention times.

### *3.2. Effect of Alkalinity on Treatment Efficiency*

Figure 4 demonstrates that the ammonia in the wastewater is virtually entirely eliminated if the amount of alkalinity ($NaHCO_3$) is 7.45 $mgCaCO_3/mgN\text{-}NH_4^+$ and 7.14 $mgCaCO_3/mgN\text{-}NH_4^+$. Ammonia conversion to nitrate efficiency declines over time and fails to meet the discharge standards for an alkaline consumption of 6.83 $mgCaCO_3/mgN\text{-}NH_4^+$ ($N\text{-}NH_4^+$ effluent = 12 – 31 mg/L). Therefore, the calculated alkalinity dose must be added to convert ammonia into nitrate. In addition, adding additional alkalinity is unnecessary because the treatment efficiency is the same, and the leftover ammonia content is still below the discharge standard.

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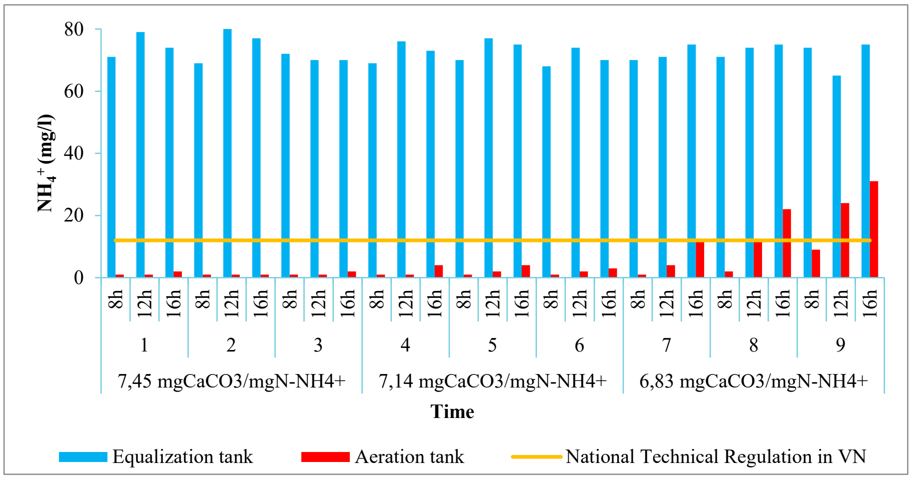


**Figure 4.** The effectiveness of the nitrification process at various DO values.

### *3.3. Effect of DO on Treatment Efficiency*

Nitrifying bacteria need lots of DO to grow. Insufficient DO levels may inhibit nitrification, reducing ammonia removal. Conversely, denitrification, which turns nitrate into nitrogen gas, happens when dissolved oxygen is low. The IFAS systems must have appropriate DO levels to balance nitrification and denitrification. Insufficient oxygen can cause nitrate accumulation and slow denitrification. Optimizing dissolved oxygen levels in process zones improves nitrogen removal. [22,23].

Figure 5 indicates that the higher the dissolved oxygen concentration, the more efficient the nitrification process. If the DO concentration is around 6 mg/L, the ammonia content after treatment is less than the permitted discharge level. Zhang et al. [24] examined the variations in the concentrations of $NH_4^+$, $NO_2^-$, and $NO_3^-$ in the reactor under varied levels of cathodic DO. The findings indicated that $NH_4^+$ removal and nitrification activity exhibited an increase in correlation with increasing DO concentrations. In addition, Lei et al. [25] demonstrated that a low DO level can effectively suppress the proliferation of nitrite-oxidizing bacteria (NOB), resulting in nitrite accumulation. Simultaneously, when the DO concentration is low, the conversion rate of ammoniacal nitrogen is comparatively sluggish.

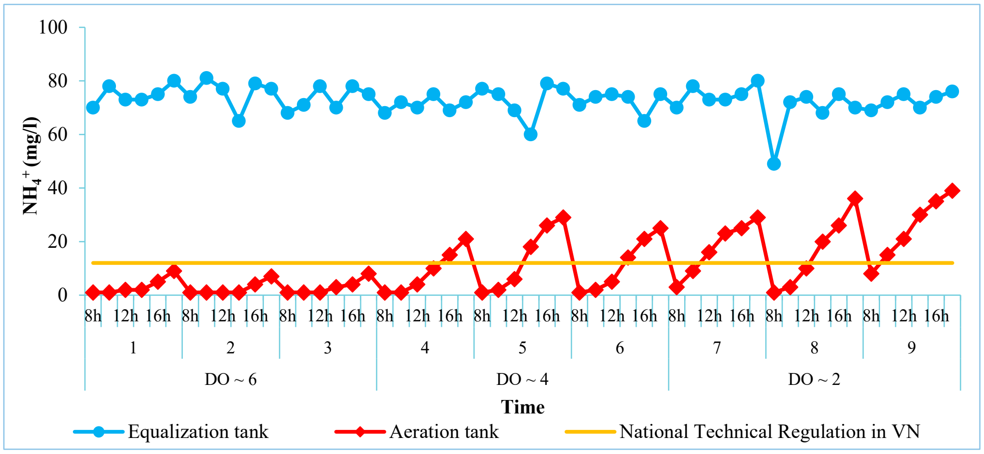


**Figure 5.** The effectiveness of the nitrification process at various DO values.

Suspended sludge and attached biofilm work together to remove organic carbon and improve biological nitrogen removal (BNR) in the IFAS system [26]. IFAS biofilms with a unique multi-layer structure form aerobic and anoxic zones to achieve simultaneous nitrification and denitrification

(SND) by coexisting nitrifiers and denitrifiers [13]. SND, which involves microbiological processes of nitrification and denitrification in the same reactor, is promising for BNR [27]. It can be seen in Figure 6 that denitrification always occurs because the total concentration of ammonia and nitrate after treatment (32 – 49 mg/L) is always smaller than the influent ammonia concentration (68 – 80 mg/L). Besides, DO is maintained at about 2 mg/L, and the nitrate reduction efficiency is better than that of the other two stages. High yields of SND have been demonstrated by Xia et al. [28] and Machat et al. [26] when dissolved oxygen concentrations are kept between 1 and 2 mg/L. Maintaining a high dissolved oxygen concentration in the fixed-growth aerobic-activated sludge tank does not considerably impact the denitrification process. During the study period, the nitrate concentration after treatment (9 – 45 mg/L) is lower than the discharge requirement (60 mg/L). A dissolved oxygen content of roughly 6 mg/L is required for adequate ammonia removal (the post-treatment ammonia and nitrate concentrations do not exceed the prescribed threshold). According to Sriwiriyarat et al. [29], a DO concentration of 6 mg/L was required for SND to maintain efficient nitrification and supply extra nitrous oxides for denitrification in IFAS.

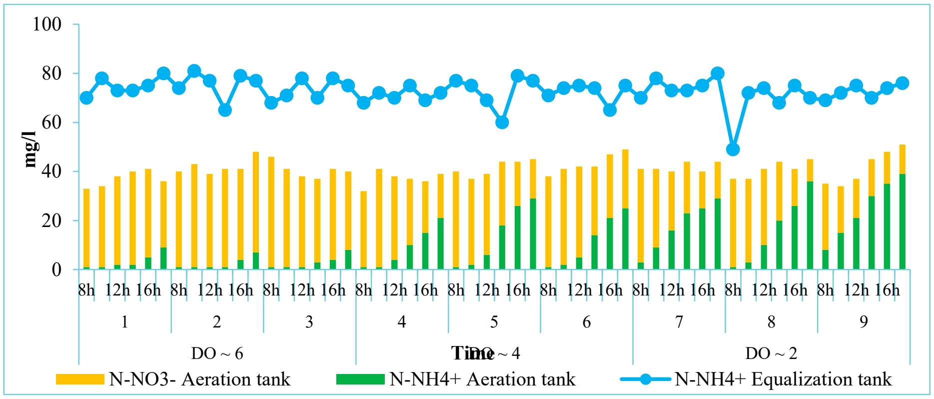


**Figure 6.** The effectiveness of the denitrification process at various DO values.

## 4. Conclusions

In the present study, we highlighted the effect of the operating parameters (the HRT, the alkalinity, and the DO concentration) on removing nitrogen using the IFAS system for a domestic wastewater treatment plant in an office building. The nitrification efficiency obtained a range of 89.2 – 98.8% with an HRT of 7 hours, an alkalinity dose of 7.14 mg $CaCO_3$/mgN-$NH_4^+$, and a 6 mg/L DO level. The nitrate concentration after treatment falls within the range of 27 – 45 mg/L, which is below the permissible discharge limit of 60 mg/L. The research findings significantly enhance the efficient administration of urban wastewater, resulting in cost savings and consequently fostering sustainable development in modern society.

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