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Using biofilter aerobic reactor for optimizing the hydraulic loading rate in nitrification process for tofu-manufacturing wastewater management

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ABSTRACT

The working anaerobic reactor in the tofu-manufacturing industry generates wastewater as the effluent which contains high organic nitrogen, the largest pollutant to the surrounding irrigation system of tofu-manufacturing industries. To minimize the environmental problems, this type of wastewater requires a waste management strategy that can transform organic nitrogen from ammonia into nitrate through the nitrification pathway. This study aimed at optimizing the hydraulic loading rate (HLR) of tofu-manufacturing wastewater nitrification employing an aerobic biofilter reactor. The liquid waste was collected from the active hybrid upflow anaerobic sludge blanket reactor of the tofu-manufacturing industry located in Polonia Medan, Indonesia. Using laboratory-standardized techniques, the waste was characterized based on the suspended solids, volatile suspended solids, chemical oxygen demand (COD), ammonia, and nitrate. The result indicated that higher HLR was ineffective for ammonia and COD removals. Treating the wastewater using a biofilter reactor resulted in a brownish-yellow color, suggesting the success of the treatment. The elevation of nitrate content from 55.06 mg/L in the influent to 190.25-225.25 mg/L in the effluent suggests an effective nitrification process. Moreover, the optimizing HLR up to 38 hours at 0.1397 m^3/m^2 is considered the best condition for operating a biofilter reactor for the nitrification process of tofu wastewater treatment. Finally, effective HLR for nitrification using an aerobic biofilter reactor significantly reduces the danger of environmental pollution from the tofu-manufacturing industries through ammonia and COD minimization.

1. Introduction

HLR is an important parameter in the design and operation of wastewater treatment systems. HLR refers to the amount of treated wastewater per unit area or volume per unit of time and greatly affects the efficiency of the treatment system [1-2]. To achieve optimal treatment efficiency, HLR must be selected and regulated based on several important factors, such as wastewater characteristics, process type, monitoring and regulation.

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Wastewater characteristic factors are determined by measuring the concentration of COD to determine the organic load to be treated. Adjusted HLR based on variations in incoming wastewater characteristics are adapted to the type of treatment process used [1]-[3].

Wastewater from the tofu industry is one of the largest contributors of organic nitrogen to the irrigation system because it contains high protein that can be quickly decomposed. The characteristics of tofu industrial wastewater in Medan-Polonia, Indonesia, include a high organic load and a low acidity degree of 5 [4], [5]. Therefore, it is a potential source of pollution if the wastewater produced is directly discharged into water bodies. When ammonia from industrial waste enters water bodies, its toxicity threatens the water's ecosystem. Ammonia is soluble in water and can be considered as a chemical reaction, which functions as an alkali to acquire hydrogen ions from water molecule to produce ammonium ions (NH_4^+) along with hydroxide ions (OH^-) [6]. Based on these characteristics, the processing has been carried out using an anaerobic system via a HUASB reactor [7], [8]. However, anaerobic systems used to treat tofu wastewater have not been able to degrade ammonia-N compounds (NH_3-N), so the treated wastewater is not suitable for disposal into water bodies as it highly contains organic mattes that can danger the ecosystem, especially aquatic ecosystem [7], [9]. To produce effluent that is safe for the environment, it is necessary to design and develop a suitable bioreactor to maximize the reaction or process without giving a potential of environmental disturbances. The further processing of tofu industrial liquid waste includes the process of processing effluent from the results of the anaerobic reactor process to set aside NH_3-N. The content of NH_3-N can be decomposed and oxidized by the nitrification system.

Optimizing HLR in the nitrification process of the tofu-manufacturing industry wastewater employing an aerobic biofilter reactor involves the analysis and adjustment of several parameters. Aerobic biofilter reactors use microbial activity to oxidize ammonia (NH_3) into nitrite (NO_2-) and then into nitrate (NO_3^-) [10]. This process requires a biofilm of nitrifying bacteria (such as Nitrosomonas and Nitrobacter) that adheres to the medium in the reactor, providing a broad surface area for bacteria to grow. The liquid waste from the tofu-manufacturing process contains high levels of organic matter and nutrients, especially ammonia. The key characteristics that need to be considered are the high organic load, the high concentration of ammonia due to the protein-rich tofu industrial wastewater, and the pH for nitrifying bacteria must be maintained within the optimal pH range of 7.5-8.5 [11]-[14].

HLR affects the wastewater treatment system due to the HRT; when the HLR is high, it can reduce HRT because the wastewater moves faster through the system, reducing the time available for microorganisms to process pollutants. A low HLR increases HRT, giving microorganisms more time to break down organic matter and other pollutants. HLR affects the distribution of organic loads in the treatment system [15]-[18]. With a high HLR, the organic load per unit of time to be treated increases, which can overload microorganisms and reduce processing efficiency. At low HLR, the applied organic load is more distributed and can be processed more efficiently by microorganisms.

The observed increase in nitrification abundance shows that the process of using a nitrification biofilter can efficiently remove ammonium through nitrification. A biofilter (biofilm reactor) is a layer of media in which the microorganisms will get attached before growing to shape a biological layer called a biofilm. This creates better nitrification conditions than suspended biomass reactors [19]. The maximum nitrogen loading rate can achieve an ammonium allowance efficiency of 99% [20]. The nitrification process consists of two stages biological reaction, which is started with ammonium (NH_4-N) oxidation into nitrite (NO_2-N) and is followed by the oxidation of nitrite into nitrate (NO_3-N) [21]. In an autotrophic condition, new biomass is generated employing NO_2 as the electron donor along with the nitrate (NO_3) as the by-product [22].

This study evaluated the hydraulic loading rate optimization process during the nitrification experiment utilizing the effluent of the wastewater of the tofu-manufacturing process using a well-designed aerobic biofilter reactor. Tofu industrial wastewater, as a substrate, comes from the effluent of the anaerobic reactor process [4], [23],

[24]. Since the anaerobic process could not set aside organic nitrogen content, it was necessary to carry out oxidation using the nitrification process. A biofilter aerobic reactor was used to obtain the optimal process, where the nitrification reactor was filled with bioball media for the growth medium of microorganisms as an attached growth medium and as a biofilm. The aerobic treatment performance of biofilters was explored against ammonia and COD allowances under HLR level limits. The implementation stage of the nitrification process begins with designing the biofilter nitrification reactor device using bioball attached media as a bacterial growth medium. Then, the following were considered in the nitrification implementation stage: HRT optimization parameters, influent concentration, and HLR; these were important parameters for the seeding and acclimatization stages, as well as the running stage, when the optimization conditions were stable, and the pH was maintained in the optimal range of 7.5-8.5.

2. Materials and Methods

2.1 Research design

The work procedures in this research were divided into the preparation, process performance monitoring, and data analysis stages. This research was conducted at the Prima Indonesia University Research Laboratory. Samples were obtained from the HUASB reactor effluent, specifically processed wastewater generated by a tofu manufacturing company located in Polonia Medan, Indonesia. The wastewater, as a substrate obtained from the effluent of the HUASB Reactor unit, contained 195-215 mg/L NH_3-NNH_3-N and COD 860-920 mg/L [18]. The process of measuring wastewater parameters used in this research refers to testing standards to obtain appropriate data. The sample assessment method and protocols were established according to the American Public Health Association's (APHA) Guidelines for Evaluating Water and Wastewater [19].

2.2. Preparation phase

The preparation stage began with designing an activated sludge reactor and determining the type of wastewater. The reactor used in this research was a bioreactor with a culture system attached to a biofilter, as shown in Figure 1, so microorganisms such as *Nitrosomonas* and *Nitrobacter* were retained in the media. The growth process was supported by continuous air supply (aeration) into the reactor through an air pump of the Resund 40 type. The aerobic autotrophic bacteria were responsible for decomposing NH_4-N activated sludge through biofilm processes. The operational capacity of the nitrification system was 10 L, which featured 169 black bio-balls as biofilters, having a diameter of 4 cm, a specific area of 230 m^2/m^3, and a 90 cavity porosity of 0.92. The process began with seeding, start-up, and acclimatization in a batch reactor. The original pH measurement of the substrate had been amended to 8.5, which was found to possess the most effective one for nitritation [20].

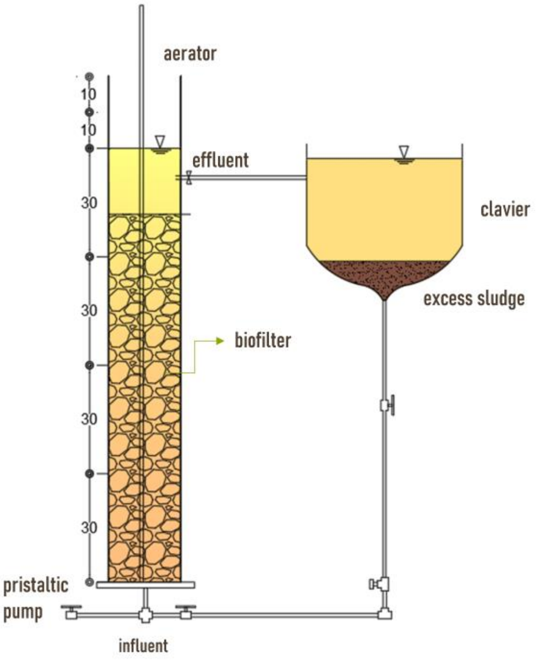

Fig. 1. Reactor of biofilter aerobic.

2.3. Performance monitor stage

The influent COD concentration of the wastewater was controlled at 50%, 75%, and 100% of the influent concentration through a dilution process to reduce the rate of the organic load. The operational HRT of the activated sludge reactor was run for 38, 30, and 24 hours. Each variation of HRT was carried out for seven days, followed by process monitoring. The seeding and adaptation phase lasted 121 days (17 weeks), followed by the running process for obtaining the best HLR and HRT values. Control of the HRT and HLR variations was done by changing the discharge in the activated sludge unit. The influent debit on aeration was influenced by the liquid waste discharge from the tofu industry (coming from the anaerobic reactor clarifier) and recirculation so that the effluent debit on aeration would be the same as the influent debit on aeration.

2.4. Data analysis

The influent and effluent from the biofilter reactor were collected daily, followed by filtration through a 0.45 m membrane to monitor NH_4^+, NO_2, NO_3, and COD by deploying the standard method. The suspension of activated sludge and biofilm attaching to the substrate in the biofilter reactor were taken for analysis after each phase to identify biomass. The biomass present in the reactor was evaluated following the Standard technique for volatile suspended solids (VSS), specifically the gravimetric technique. The pH was determined using a pH meter. [20].

3. Results and Discussion

3.1 Effluent characteristics of tofu industrial waste

The nitrification process was carried out through the biological treatment process, including the preparation, seeding-acclimatization, and running phases. This process used an aerobic biofilter activated sludge reactor, as illustrated in Figure 2. Furthermore, the particle deposition in the clarifier unit contributed to the reduction of ammonia, which indicated the nitrification process was running well and produced a brownish-yellow effluent, as shown in Figure 3.

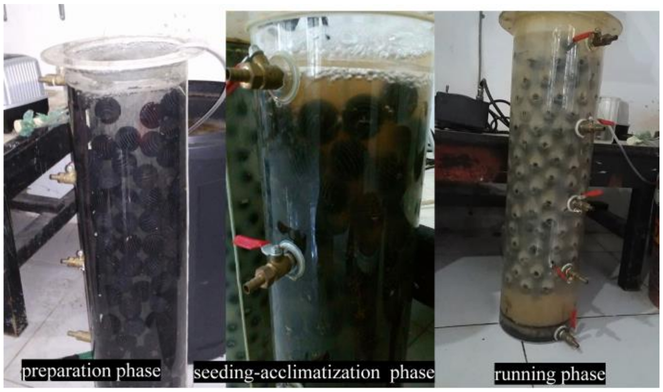

Fig. 2. Reactor of biofilter aerobic process.

Fig. 3. Nitrification process.

The process of culturing microorganisms was carried out by continuously flowing treated effluent water from the HUASB reactor to the inlet of the nitrification reactor. The breeding and acclimatization processes were carried out simultaneously from the smallest concentration to the effluent concentration (COD of effluent = 860-920 mg/L). The acclimatization process was also done at variations of HRT 24, 30, and 38 hours. The growth process of microorganisms was supported by continuous aeration. Acclimatization was run for 121 days and carried out with variations of HRT to variations in concentration. The previously processed NH_3-N content from the HUASB reactor was still high in the range of 195-215 mg/L, and COD was 860-920 mg/L, so further processing must be carried out to remove the ammonia content [20], [21].

The key factors to consider during the seeding-acclimatization phase in the bioreactor included inoculum quality, environmental conditions of the nitrification reactor (pH maintained, 7.5-8.5), aeration maintained (DO > 2 mg/L), temperature maintained at 20-30C, nutrients, sufficient hydraulic retention time, and substrate concentration. The addition was carried out in stages, and the inflow was regulated according to the reactor capacity. The availability of essential nutrients during the acclimatization phase was also ensured in the nitrification process, which involved initial wastewater analysis, external nutrient addition, regular monitoring, and dosage adjustments. Optimization of environmental conditions included pH, temperature, and aeration. The use of special nutritional supplements involved adding microbial cultures to speed up the acclimatization phase. With these steps, the growth and activity of nitrifying microorganisms could be supported optimally so that the efficiency of the nitrification process in wastewater treatment could be increased.

Figures 2 and 3 show the performance of the apparatus in ammonium removal and nitrate production during all phases of the experiment, demonstrating ammonium removal and nitrification. During the preparation and initial seeding process, the water in the reactor was still clear; then, the reactor water turned brownish yellow after the nitrification process, as depicted in Figure 3. Generally, a particle in the water medium carries an electric charge that is often called the zeta potential. Zeta potential provides a measurable value indicating potential water treatment problems; high zeta potential has an impact on increasing pollutant reduction efficiency [22]. Particle interactions that occur in the sedimentation unit affect the decrease in the concentration of NH_3-N and COD. The zeta potential evaluates the strength of repulsion across particles with an identical charge when they are nearby enough. If the zeta potential is elevated, the colloid is electrically steady; if the zeta potential is poor, flocculation emerges since the attraction outweighs the repulsion, causing the dispersion to disintegrate. Zeta might affect the management of processes, quality control, and product standards, allowing it to track the consistency of goods and potentially enhance quality and performance [19], [23]-[25].

3.2 Effects of HLR on pollutant removal efficiencies

During the first operating period, pollutant loading rates of 1.008 mg COD/dm^3 d and HLR 0.1397, 0.177, and 0.221 m^3/m^2 d were presented to examine the effect of HLR on pollutant removal. As seen in Figure 4, HLR clearly had a negative influence on ammonia removal in the activated sludge system biofilter reactor. NH_3–N removal efficiency decreased from 87.55% at HLR 0.1397 m^3/m^2 d to 64.06% at HLR 0.177 m^3/m^2 d to 36.06% at HLR 0.221 m^3/m^2 d and increased again after being returned to HLR 0.1397 m^3/m^2 d. In Figure 3, HLR also had a negative effect on COD removal. The COD removal efficiency of 70.44% at HLR 0.1397 m^3/m^2 d decreased to 56.08% at HLR 0.177 m^3/m^2 d, and 33.7% at HLR 0.221 m^3/m^2 d, and increased again after being returned to HLR 0,1397 m^3/m^2 d. Based on the behavior of HLR, running was carried out on HLR 0.1397 m^3/m^2 d.

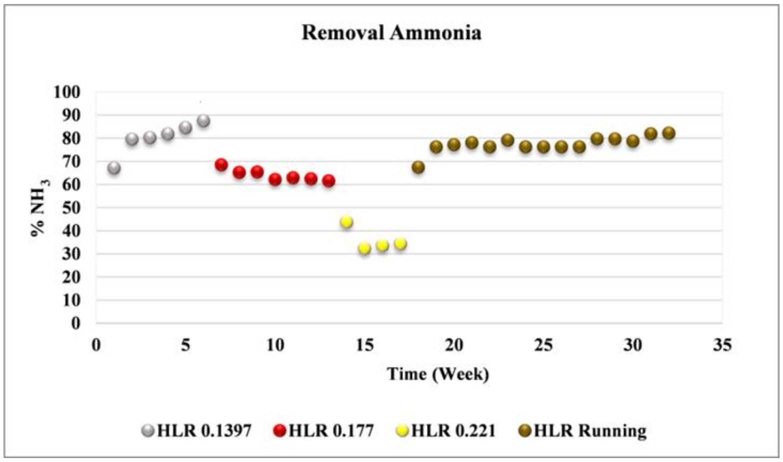

Fig. 4. Effect of HLR on NH_3 removal.

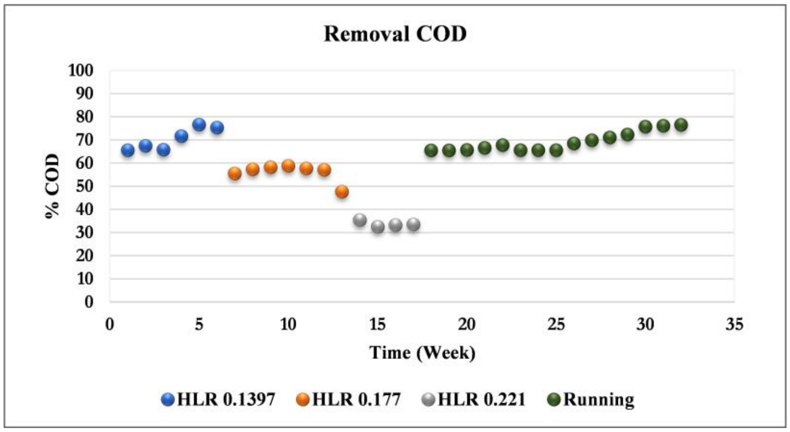

Fig. 5. Effect of HLR on COD removal.

The average COD removal efficiency was 70.44% at HLR 0.1397 m^3/m^2 d, which somewhat decreased to 56.08% at HLR 0.177 m^3/m^2 d and 33.7% at HLR 0.221 m^3/m^2 d. The concentration of effluent COD dropped to 215.7 mg/L, as can be seen in Figure 5. The influence of HLR on COD removal was likewise significant; as the HLR increased, the HRT was insufficient to decrease the wastewater substrate. HRT has a major impact on the removal.

As shown in Figure 6, an HRT of 38 hours indicates that the time is proportional to reducing COD and ammonia. The running process was conducted at an HRT of 38 hours, resulting in an HLR of 0.1397 m^3/m^2 d (Figures 4-5 and Table 1). When HRT was reduced to 24 hours, the efficiency of COD and NH_3-N was reduced. Thus, the running process was started at week 18, as shown in Figure 7.

The nitrification process takes place in a high percentage, and the production of nitrate is shown in Figure 8. The level of nitrate elevated from 55.06 mg/L in the influent to 190.25-225.25 mg/L, demonstrating that entire nitrification had occurred

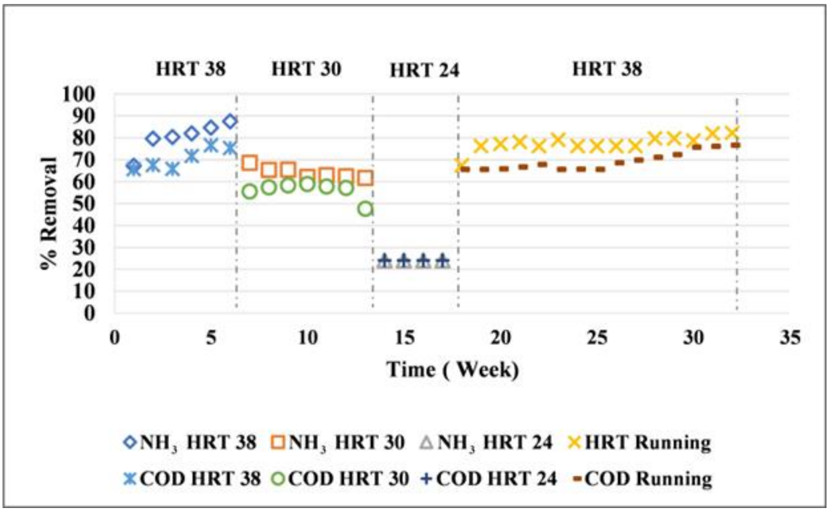

Fig. 6. Removal of NH_3-N and COD on HRT.

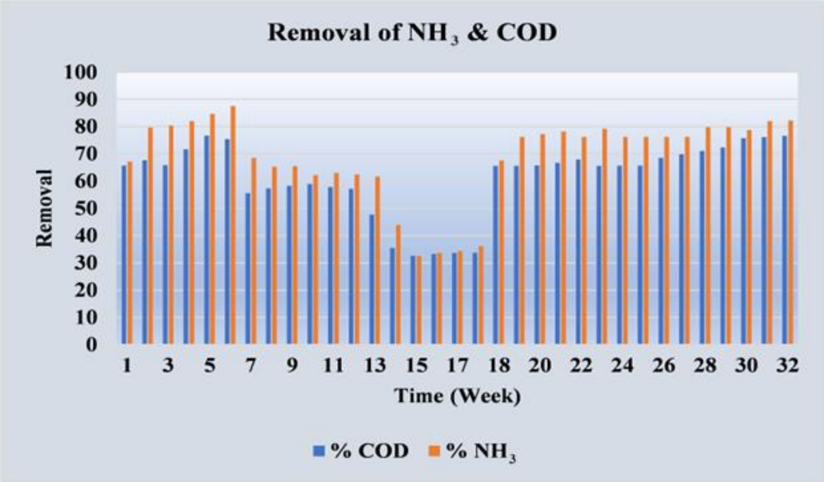

Fig. 7. Removal of NH_3 and COD to time.

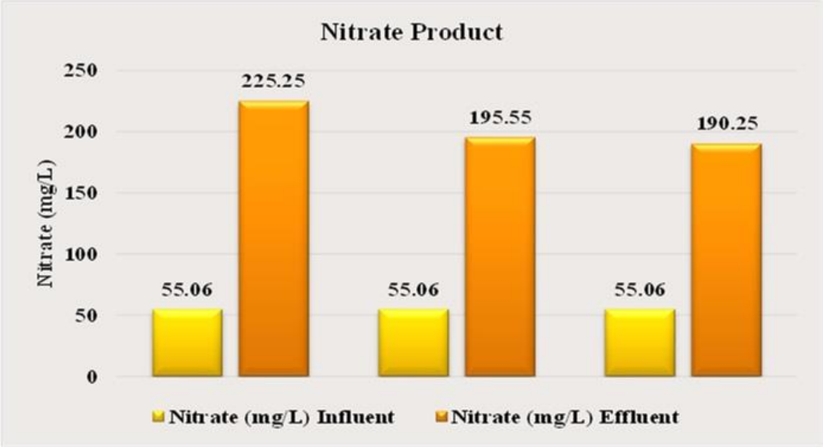

Fig. 8. Nitrate production.

The concentration of effluent ammonia and COD decreased after passing through the aeration unit, reaching 24.2 mg/L for NH_3-N with an efficiency of 87.55% (Figure 4) and 215.7 mg/L for COD with an efficiency of 76.55% (Figure 5) at HLR 0.1397 $m^3/m^2/d$, as summarized in Table 1. At HLR 0.1397 m^3/m^2 d NH_3-N, removal was high because nitrifying microorganisms were in a favorable position in the living space with heterotrophic bacteria compared to HLR 0.177 m^3/m^2 d and HLR 0.221 m^3/m^2 d [26,27]. At HLR 0.177 m^3/m^2 d and HLR 0.221 m^3/m^2 d, the substrate HRT was shortened so that the adsorption of NH_3-N from the biofilter reactor in the nitrification process decreased and reduced ammonia removal. Similarly, the average COD removal efficiency showed a decline, as illustrated in Figure 5; HLR also had a negative effect on COD removal so that HLR had a negative effect on NH_3-N removal and COD [18], [28], [29].

COD reduction efficiency at HRT 24 hours, 30 hours, and 38 hours respectively reached 33.7%, 56.08%, and 70.44%. However, the COD reduction efficiency value in this study had not yet reached the expected efficiency because biological treatment should be able to reduce COD levels in wastewater by up to 95% [28]. This condition could be caused by excess filamentous microorganisms in the wastewater, making it more difficult to separate solids (bulking sludge) so that the ability of settling and compacting bioflocs decreased [30]-[32]. Bulking sludge appeared when the sludge age SRT was high and was accompanied by an increase in nitrate concentration due to the release of denitrification gas, thereby reducing floc density. Although an increase in HRT of up to 38 hours provided an increase in COD efficiency of 70.44% and a large enough reactor volume, the increase in biomass will have implications for the risk of bulking sludge occurring at high SRT.

pH is a parameter that greatly influences both stages of nitrification. The optimal activity of the enzymes occurs at neutral to slightly alkaline pH (around pH 7.5-8.5). Outside this range, enzyme activity decreases, reducing the rate of nitrification. Therefore, this study maintained the pH at 7.5 ± 0.5, which is the optimal range for routine monitoring and the use of buffering agents [46]-[49].

Table 1. Comprehensive analysis of nitrification process approaches in the biofilter reactor.

Week	Influent	NH_3-N effluent	NH_3-N	Influent	COD effluent	COD	HLR	HRT
	mg/L	mg/L	%	mg/L	mg/L	%	m^3/m^2d	hour
1	215	70.65	67.14	915	314.3	65.65	0.1397	38
2	215	43.75	79.65	920	298.54	67.55	0.1397	38
3	203	39.89	80.35	920	324.64	65.8	0.1397	38
4	197	35.56	81.95	915	259.4	71.65	0.1397	38
5	205	31.47	84.65	905	211.32	76.65	0.1397	38
6	195	24.2	87.55	910	224.31	75.35	0.1397	38
7	195	61.32	68.55	915	406.53	55.57	0.177	30
8	195	67.76	65.25	895	381.72	57.35	0.177	30
9	195	67.33	65.47	895	373.66	58.25	0.177	30
10	195	73.8	62.15	895	368.29	58.85	0.177	30
11	210	77.8	62.95	895	378.14	57.75	0.177	30
12	215	80.73	62.45	895	383.51	57.15	0.177	30
13	215	82.45	61.65	905	473.59	47.67	0.177	30
14	210	117.94	43.84	905	584.18	35.45	0.221	24
15	210	141.88	32.44	905	610.42	32.55	0.221	24
16	210	139.39	33.62	905	604.09	33.25	0.221	24
17	210	137.84	34.36	895	594.73	33.55	0.221	24
18	210	68.25	67.5	889	306.26	65.55	0.1397	38
19	215	51.06	76.25	889	306.17	65.56	0.1397	38
20	215	48.91	77.25	875	299.69	65.75	0.1397	38
21	215	46.98	78.15	875	291.81	66.65	0.1397	38
22	210	49.88	76.25	875	281.31	67.85	0.1397	38
23	215	39.83	79.15	875	301	65.6	0.1397	38
24	198	47.03	76.25	875	300.56	65.65	0.1397	38
25	205	48.69	76.25	885	304.26	65.62	0.1397	38
26	215	51.06	76.25	885	278.33	68.55	0.1397	38
27	215	51.06	76.25	885	266.83	69.85	0.1397	38
28	215	43.54	79.75	865	250.42	71.05	0.1397	38
29	205	41.47	79.77	865	239.17	72.35	0.1397	38
30	215	45.69	78.75	920	223.1	75.75	0.1397	38
31	215	38.81	81.95	920	219.42	76.15	0.1397	38
32	215	38.16	82.25	920	215.7	76.55	0.1397	38

3.3 Production of nitrate from the nitrification process

Figure 3 shows that the water that has been treated using the biofilter reactor becomes brownish yellow, implying that the process of nitrification occurred in a significant proportion, and Figure 8 depicts nitrate generation. The nitrate content elevated from 55.06 mg/L in the influent to

190.25-225.25 mg/L, indicate that complete nitrification was achieved. Therefore, to ensure the efficiency of nitrogen removal, an HLR of 0.1397 m^3/m^2 d for the aerobic biofilter system is recommended. In this study, the pH in the matrix of the aerobic biofilter system was 7.5 ± 0.5. Factors that affected the efficiency of the nitrification process were the biological and physico-chemical community of the water. The nitrification process required special conditions, namely a temperature of 30°C, a pH of 6-8.5, and DO > 3 mg/L. In this process, the *Nitrosomonas* microorganism converted ammonia into nitrite, and *Nitrobacter* converted ammonia into nitrite, and *Nitrobacter* converted nitrite into nitrate [33]. The results of the nitrification process produce

COD 494 mg/L, NH_3-N 69.5 mg/L, and high nitrate; therefore, further processing must carried out by denitrification. The effluent in the clarifier was brownish yellow, which indicated the nitrification process was taking place in a high percentage. One of the main factors affecting nitrification in processing is pH. The optimal pH has been found to be between 7.8 and 9.0. *Nitrosomonas* has an optimal pH between 7.0 and 8.0. The optimal pH for *Nitrobacter* is between 7.5 and 8.0 [34]. Nitrifying bacteria are very sensitive to pH [35].

4. Conclusion

The biofilter nitrification reactor can carry out oxidation to remove organic nitrogen content in the effluent produced in the anaerobic process in the HUASB reactor. The best result was optimally gained on HRT 38 hours to produce high nitrate on the removal of COD and ammonia as the tofu industrial wastewater nutrients.

Biofilter media, as a medium attached to microorganisms, is very suitable for supporting the process in the bioreactor. Therefore, this research should be continued using the biofilter denitrification process for advanced processing in removing nitrogen content.

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Conflict of interest

The authors have no conflict of interest to declare.

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