Recent Trends in Civil Engineering and Built Environment Vol. 1 No. 1 (2020) 133–141

RTCEBE

Homepage: http://penerbit.uthm.edu.my/periodicals/index.php/rtcebe
e-ISSN : 2773-5184

Aerobic-Anoxic Filter For Nitrogen Removal From Domestic Wastewater: A Comparison Study

R. Hamdan[1*], Nur Amira Atierah Mohammed Shaikhani[1], Nur Ain Nazirah Mohd Arshad[1]

[1]Department of Civil Engineering, Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor, 86400, MALAYSIA

*Corresponding Author

DOI: https://doi.org/10.30880/rtcebe.2020.01.01.012
Received 22 September 2020; Accepted 08 December 2020; Available online 13 December 2020

Abstract: Treatment plant discharges from the domestic wastewater are among the major environmental sources of nitrogen pollution. However, the removal of nitrogen from wastewater regularly requires high cost of chemical, to prevent the overloading of nutrients into the surface water body. Therefore, the laboratory scale of the semi aerated L-shape steel slag filter has been designed to for remove of total nitrogen from domestic wastewater. The filter system is a combination of vertical aerated rock filter and horizontal rock filter (VARF & HRF) with aeration only supply in the vertical system. The main objective is to evaluate the occurrence of nitrification and denitrification process in the L-shape semi aerated steel slag filter in removing nitrogen from domestic wastewater by comparing with previous developed systems due to the aerobic-anoxic zone. The UASB- trickling filter, aerated submerged fixed-film (ASFF) and Circulating Fluidized Bed Biological Reactors (CFBBR) have been studied for better understanding of nitrogen removal from wastewater. Results from these previous study show that the aerobic-anoxic system were outperformed in removing total nitrogen, ammonia, and nitrate can due to nitrification and denitrification process.

Keywords: Nitrogen Removal, Aerobic-Anoxic, Nitrification, Denitrification

Corresponding author: rafidahh@uthm.edu.my

1. Introduction

In recent years, the cost of wastewater treatment has been increasing by years due to high amount of wastewater generated since the population have increases gradually. Conventional wastewater treatment plants are unable to accommodate the current load of wastewater resulting lower quality of treated water before being discharged. Nutrient such as nitrogen and phosphorus are known to be difficult to be removed as tertiary treatment are needed to remove the nitrogen from wastewater. Lacks of clean water resource worsen the situation as pollution of surface water grows rampant due to anthropogenic activities. High technologies of water treatments are no longer feasible as the high maintenance and cost of the system adds to the problem. Alternative solutions are needed to abate the water resources crisis. Nitrogen and carbon are some of the major sources of pollution contributing to the quality of water in the world. The presence of nutrient such as nitrogen produce significant problems in wastewater treatment system since the removal requires high end technology of treatment system. Due to that, the cost of treatment will also significantly increase.

High concentration of carbon and nitrogen in water body results in the imbalance of the natural ecological system which leads to eutrophication, oxygen depletion in surface waters making it inhabitant for aquatic life and complicate the process of water treatment [1]. The release of nitrogen components into the environment is hazardous to human and animal health and the pollution and remediation of nitrates pose a global problem and challenge [2]. The main forms of organic nitrogen presents in wastewater including ammonia, or ammonium ion (NH_3 / NH_4^+), nitrogen gas (N_2), nitrite (NO_2^-), and nitrate (NO_3^-) are. The removal of nitrogen is complex and prohibitively expensive at a modest scale. Thus, this paper aims to evaluate the occurrence of nitrification and denitrification process in the L-shape semi aerated steel slag filter in removing nitrogen from domestic wastewater by comparing with previous developed systems due to the aerobic-anoxic zone. This paper will summarize on 1) the anoxic-aerobic process, 2) anoxic-aerobic setup system and 3) performance of different anoxic-aerobic setup.

2. Aerobic-anoxic process

Aerobic-anoxic process is the removal of biological nitrogen by aerobic and anoxicsequential nitrification oxidized into ammonium by ammonium oxidizing bacteria(AOB) and then nitrified by nitrate oxidizing bacteria (NOB) during the nitrificationprocess may take place. Nitrite and/or nitrate are denitrified as donor electrons duringdenitrification to organic-carbon nitrogen gas [3].

2.1 Nitrification

Nitrification is a biological oxidation process of ammonium through chemoautotrophic organisms, which convert ammonium to nitrite and consequently to nitrate. Nitrification process involved two decomposition steps of ammonia to nitrite and later to nitrate by nitrifying bacteria, including *Nitrosomonas* and *Nitrobacter*, are ultimately strict aerobes, which use inorganic carbon sources (carbon dioxide).The complete biological oxidation of N through the nitrification process is presented in Figure 1.[5].

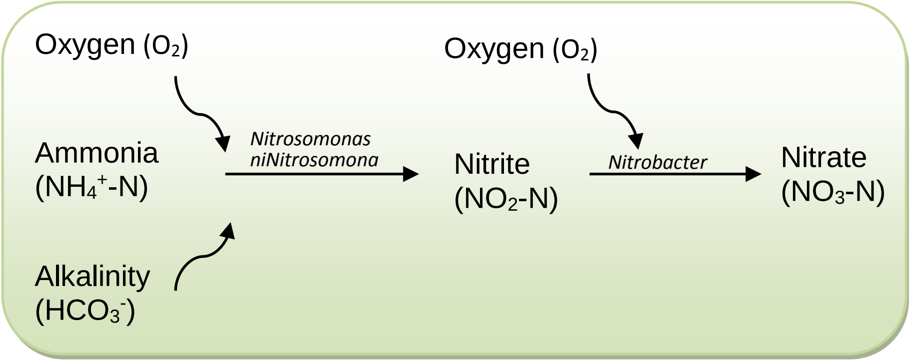

Figure 1: The nitrification processes

2.2 Denitrification

After nitrification, biological denitrification takes place, another mechanism performed by bacteria. It is the final step in the nitrogen cycle, a natural biological process that transfers nitrogen from one type to the next. Denitrification is defined as the "microbial reduction of nitrate or nitrite coupled with phosphorylation of electron transport resulting in gaseous neither as molecular N_2 nor as an N oxide." A wide range of bacteria, including Pseudomonas, Micrococcus, Achromobacter, and Bacillus, can undergo denitrification [5]. Nitrate, the source of nitrogen that occurs in the completion of the nitrification process, is converted into nitrogen gas through the use of optional heterotrophic bacteria in the denitrification process [6]. The denitrification process takes place under the following anoxic conditions as provided in Eq. 1:

$$NO_3\text{-N (Nitrate)} \longrightarrow N_2\text{ (Nitrogen Gas)} + O_2\text{ (Oxygen)} + HCO_{3^-}\text{ (Alkalinity)} \quad (1)$$

3. Anoxic-aerobic setup system

There are several anoxic-aerobic setup were used removing nitrogen from domestic wastewater as explained below

3.1 L-shape Semi Aerated Steel Slag Filter

The main aim of this study is to evaluate the occurrence of nitrification and denitrification process in the L-shape semi aerated steel slag filter in removing nitrogen from domestic wastewater by comparing with previous developed systems due to the aerobic-anoxic zone.

Over the years, steel slag rock filter wastewater treatment systems emerges as a promising solution due to its effectiveness and lower cost of treatment. Reusing steel slag as filter media will reducing the cost for filter materials as well as maintenance.A laboratory scale of L-shape semi aerated steel slag filter has been designed and constructed in Micropollutant Research Centre (MRPC) Laboratory, FKAAB, UTHM. The schematic of the laboratory scale L-shape semi aerated steel slag filter is shown in Figure 2. The filter will be used to treat domestic wastewater for nitrogen removal. Figure 3 shows the expected nitrification and denitrification to occur in the L-shape Aerated Filter System.

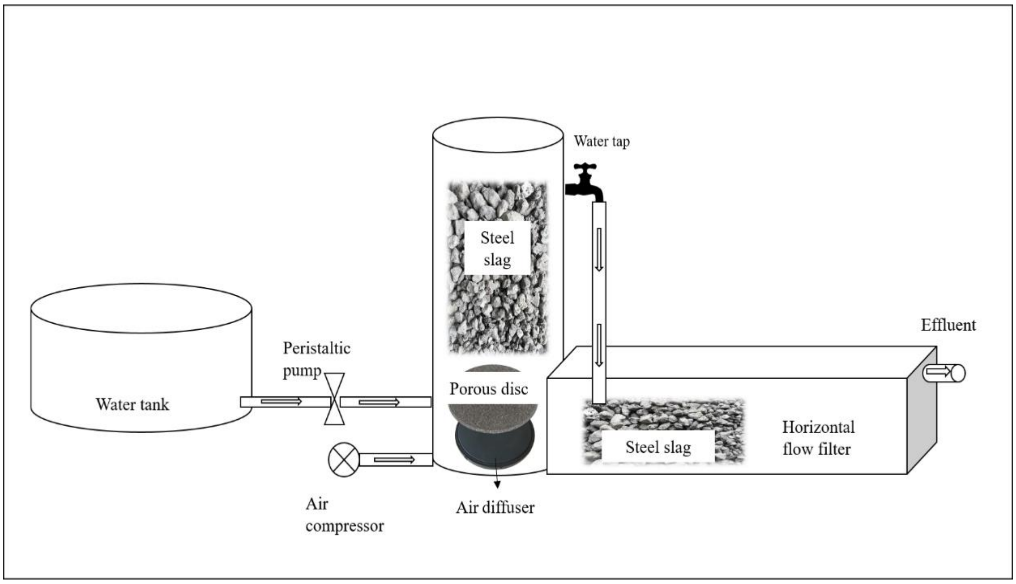

Figure 2: L-shape Semi Aerated Filter Schematic Diagram [7]

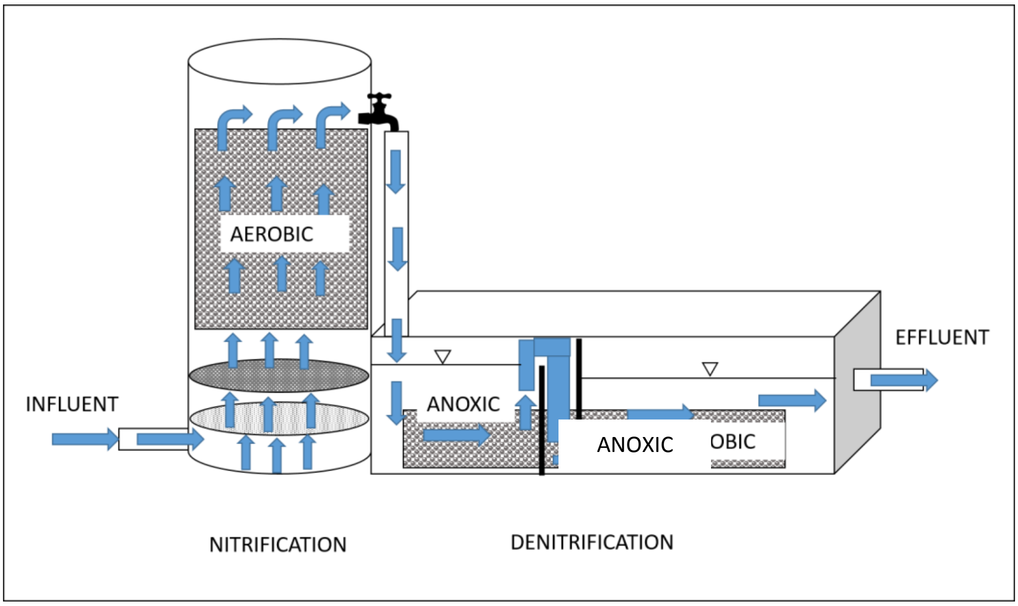

Figure 3: Expected nitrification and denitrification in the L-shape Aerated Filter System [7]

3.2 UASB – Trickling Filter

A few previous studies have been selected for comparison to the L-shape semi aerated steel slag filter system as discussed in this section due to the nitrogen removals that have been developed few years back with nitrification and denitrification process. A novel, two-compartment integrated aerobic-anoxic trickling filter for the post treatment ofeffluents from a UASB reactor treating domestic wastewater has been developed in 2011[8]. The pilot scale treatment plant consisted of two sequentially disposed units (see Figure 4). The first column is a UASB reactor with a working volume of 0.2 m^3 with the dimension of 0.35 m diameter and 2.70 mof total height. The UASB- combined with TF was composed of two vertically disposed compartments. The upper aerobic compartment with working volume of 200 L comprised of a trickling filter for mainly removal of residual COD as well as nitrification. In addition, vertical ventilation windows has been installed in the external wall in order to improve natural aeration within the system. As for denitrification to taking place, the lower compartment was submerged with working volume of 60 L has been operated under anoxic conditions. The wastewater samples have been collected and analysed once a week at different points of the reactor for temperature, pH, COD, ammonia nitrogen, nitrate and nitrite.

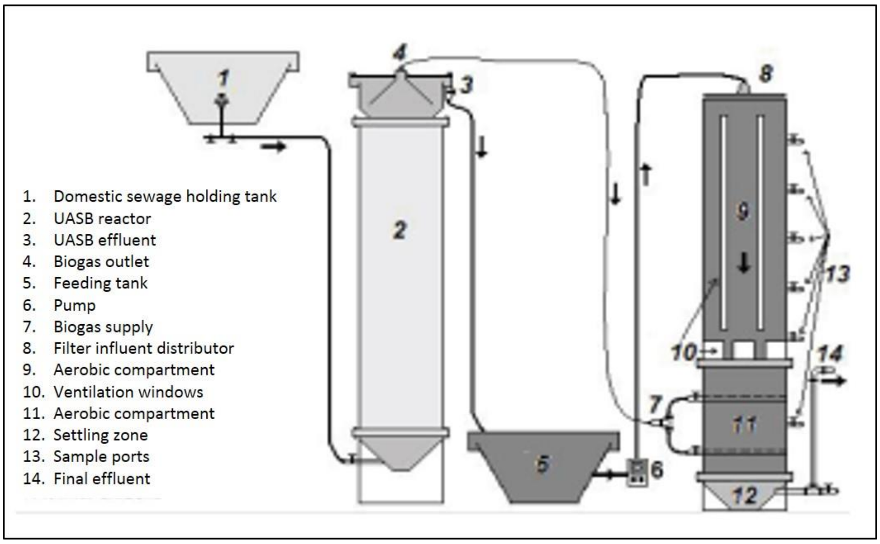

Figure 4: Schematic diagram of pilot-plant UASB reactor

3.3 Aerated submerged fixed-film (ASFF)

Similar studies on aerobic-anoxic has been conducted by Hamoda *et al.*[9] on a pilot-scale of the bioreactor of aerated submerged fixed-film (ASFF). This reactor was made of plexi glass sheets with a thickness of 6 mm and is divided into four compartments of equal size, connected in series with liquid volume of 115 L shown in Figure 5.The ASFF and A/ASFF reactors, has been packed with the 'Biolace'(textile fibres)as support medium. Each reactor was operated continuously at a preset feed flow rate. Different flow rates were tested in each reactor over a total period of 9 months to obtain HRTs (hydraulic retention times) in the range of 0.7 to 8 hours. Aeration was provided in the second to fourth compartments in the A/ASFF and in all compartments in the ASFF reactors through medium-to-fine, tubularmembrane, air diffusers placed underneath the media and operated at a constant pressure of approximately 200– 250 kPa. Samples from each reactor were collected and filtered daily and analyzedfor ammonia-nitrogen, nitrites-nitrogen, nitrates-nitrogen and total oxidized nitrogen.

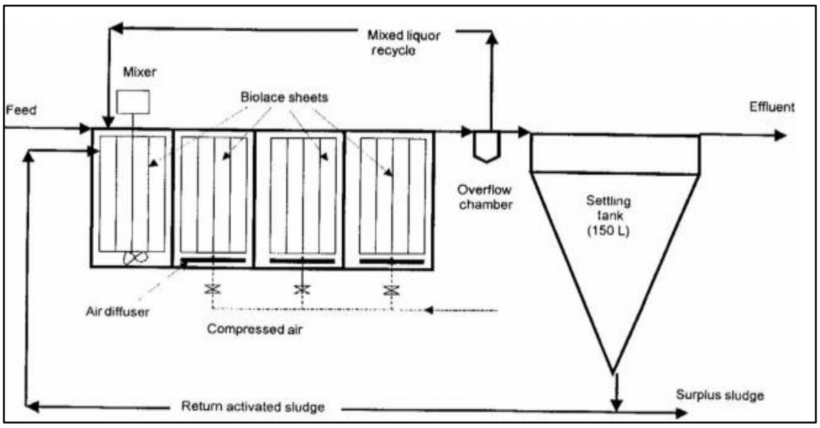

Figure 5: Schematic diagram aerated submerged fixed-film (ASFF)

3.4 Aerobic-anoxic sequencing batch reactor (AO-SBR)

Furthermore, two parallel lab-scale Sequence Batch Reactors (SBRs) with 8L working volume, one ofthe common aerobic-anoxic process and the other of the multiple aerobic-anoxic process, which operated at 25°C has been developed [3]. The operation cycle of the aerobic-anoxic SBRs was 120 min anaerobic phase (including 10 min filling),180 min aerobic phase, and settlement and withdrawal oftreated wastewater of 60 min.30 min aerobic phase, 30 min anoxic phase,30 min aerobic phase, 30 min anoxic phase, 60 min aerobicphase, and settlement and withdrawal of treated wastewaterof60min.During aerobic phases, air pumps with micropore stones has been used to induce air into the system and a heater used to control the temperature. To achieve anoxic oranaerobic phases, aeration was stopped and continued stirring by only using magnetic stirrers. Finally, wastewater samples from the system were collected and analysed for total nitrogen, Kjeldahl nitrogen and nitrate-nitrogen.

3.5 Circulating Fluidized Bed Biological Reactors (CFBBR)

In addition, another study in Canada has developed Circulating Fluidized Bed Biological Reactors (CFBBR) for removing nitrogen from wastewater [10]. The system consists mainly of a riser column (anoxic bed) and a downer column (aerobic bed), named according to the direction of movement of the carrier media; a liquid-solid separator at the top of the riser and a similar clarifier at the top of the downer. Figure 6 is shows the samples from the influents and effluents of the reactors and various sampling ports along the columns were taken twice a week for total nitrogen, Kjdehal nitrogen and nitrate-nitrogen.

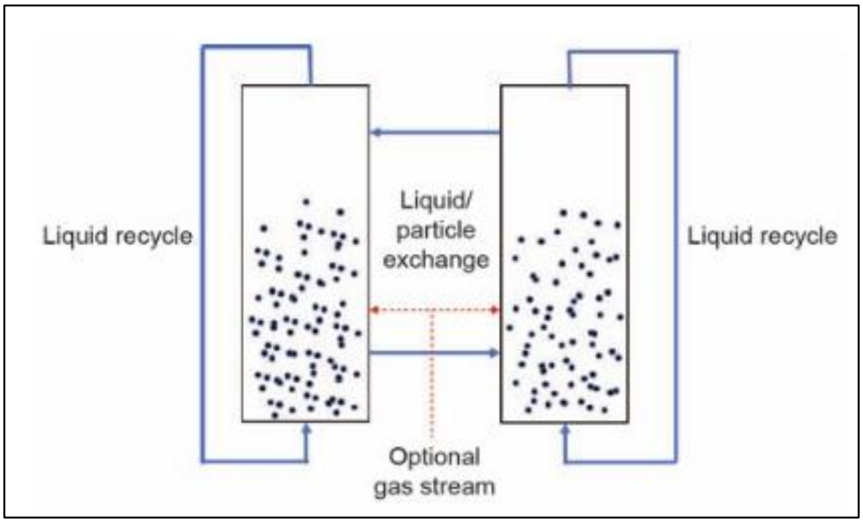

Figure 6: Schematic diagram for CFBBR

4. Aerobic-anoxic setup performance

From the comparison that has been made, it can be concluded that all the aerobic-anoxic has efficiently removed Total Nitrogen (TN) and Ammonia-Nitrogen (NH_4-N) as provided in Table 1. All the systems are able to remove approximately 100% of nitrate except for UASB-Trickling Filter which moderately remove nitrate in the range of 60-74%.

Table 1: Performance of Aerobic-anoxic setup

Reactors		Total Nitrogen (TN) removal	Ammonia-Nitrogen (NH_4-N) removal	Reference
UASB-Trickling Filter		-	60-74%	[8]
Aerated submerged fixed-film (ASFF)			97.0%	[9]
SBR	**AO reactor**	67.9%	99.8%	[3]
	Multiple AO reactor	94.2%	100%	
CFBBR		88.0%	99.0%	[10]

4.1 Total Nitrogen (TN)

Wang*et.al*,[3] stated that with the removal percentages of 67.9%, both reactors efficiently removed TN in the AO reactor and 94.2%, in the multiple AO reactor. In both reactors, there was a little difference in TN concentrations for the filtered and unfiltered effluent because of the low SS concentration (below 10 mg / L) effluent. On the other hand, Cui, Y. *et al.*,[10] stated that, this system has achieved over 95% TKN removal when the kinetics of nitrification are good because the system has been able to remove 0.37 and 0.45 kg N $m^{-3}d^{-1}$ at influential 26.9 and 30.7 mg l^{-1} TKN concentrations at a 1.5 hour HRT nitrification process, in wastewater samples. This system has achieved 80% more total nitrogen removal than other similar procedures by comparing denitrification. Similarly, kinetics of denitrification are good, because it is possible for the system to removed 1.05 and 1.17 kg N m^{-3} d^{-1} in synthetic wastewater and municipal wastewaters at an influential TKN concentration of 26.9 and 30.7 mg l-1 at 0.5 hours HRT denitrification processes. It is important to achieve total effluent nitrogen less than 5 mg l^{-1}. In individual aerobic beds and anoxic beds nitrification and denitrification occurred simultaneously with an influential total nitrogen concentration of about 30 mg l-1, and the removal of overall nitrogen of 88% without extra carbon at an extremely short 2 hour HRT [10].

4.2 Ammonia-Nitrogen (NH_4-N)

Wang *et. al.*,[3]found that the wastewater measured contained concentrations of 38.3 mg/L for NH_4-N. Both reactors effectively removed NH_4-N, with 99.8% removal percentage in the AO reactor and 100% removal percentage in multiple AO reactors. The NH_4-N reduction rate for activated AO reactor batch nitrification was 6.6 mg N/g VSS/h and for activated sludge from the multiple AO reactors, the NH_4-N reduction rate was 8.1 mg N/g VSS/h and its concentration was under 1 mg/L after a reaction of 90 minutes . Based on Victoria *et al.*, [8] results, effluent ammonia concentrations were mainly related to the effectual values at the beginning of nitrification. Such dependency was then decreased and efficiencies improved, showing the growth of nitrifying biomass and achieving stability over time. The average concentration of the effluent ammonia-N was 13 mg L^{-1} by the end of the operation period. The concentrations of ammonia in nitrification TFs are expected to decrease along with the reactor height. Besides, Hamoda*et al.*,[9]stated that the effluent of the A/ASFF bioreactor was characterized by not more than 1.0 mg l^{-1} NH_3-N which can easily meet the requirements for applications for non-potable agricultural or industrial reuse. In comparison to ASFF bioreactor, ammonia removal efficiencies were higher, especially in shortened HRTs. From Cui *et al.*,[10]experiment results, the concentrations of ammonia nitrogen in feed were gradually rises from 7 mg l^{-1} to 30 mg l^{-1}. Even in the maximum loading rate of 0.4 kg NH_4-N m^{-3} d^{-1} the efficiency of the ammonia nitrogen removal was around 99% in all cases. Removal of ammonia nitrogen was primarily through consumption into biomass. It must be asserted that, despite the relatively low pH of 7.5 to 8.0, volatilization due to the high airflow rate may have contributed marginally to ammonia removal.

4.3 Nitrificationin aerobic system

Wang *et. al.*,[3] obtained the batch nitrification results from activated sludge taken at both the AO reactor and the multiple AO reactor. Nitrate production for activated sludge taken from the AO reactor with only a small amount of nitrite accumulated with the reduction of ammonium. The reduction rate for NH_4-N was 6.6 mg N/g VSS/h and a production rate for NO_3-N was 5.6 mg N/g VSS/h. The NO_3-N production rate over the whole reaction phase was 2.3 mg N/g VSS/h. In batch denitrification experiments, the NO3-N reduction rate for activated sludge taken from the AO reactor was 31.9 mg N / g VSS / h during the initial 30 minutes with adequate acetate supply and then decreased afterwards. The external Organic Carbon as an electron donor has been denitrified slowly and has a reduction rate of NO_3-N of 10.2 mg N/g VSS/h for activated sludge from the multi AO reactor. The NO_3-N reduction rate of 2.2 mg N/g VSS/h for activated sludge derived from a reactor of AO was slow for batch denitrification experiments with internal organic carbon in the electron donor. The NO_3-N reduction rate for activated sludge taken from the multiple AO reactor was 5.6 mg N/g VSS/h in the initial 30 minutes, while the NO3-N reduction rate was 1.9 mg N/g VSS/h in the latter

30 minutes. Denitrification was very slow for activated sludge taken from the AO reactor, and the rate of reduction for NO_3-N was 0.89 mg N/g VSS/h. The NO_3-N reduction rate for activated sludge taken from the multiple AO reactor was 0.78 mg N/g VSS/h. The ammonium concentration was stable under all conditions, indicating that there had been no anaerobic oxidation of ammonium.

According to Victoria *et. al*,[8] at the start of nitrification, concentrations of effluent ammonia were related mainly to the influential values, where the average effluent NO_3-N concentration was 12 mg L^{-1} at the end of the operating period with an average nitrification efficiency of 60%. After nitrification was obtained, the supply of biogas was started, in order to establish the process of denitrification, with the average concentration of NO_3-N effluent fell to 8 mg L^{-1} and the average efficiency in denitrification was 52%. Based on Hamoda *et al.*,[9] the effluent from the A / ASFF bioreactor was characterized by < 12.2 mg l^{-1} NO_3-N, which can easily meet the requirements for non-potable agricultural or industrial reuse. A concentration of NO_3-N effluent <3 mg l^{-1} exists in fully nitrified and denitrified wastewaters. An effluent that is fully nitrified but not denitrified will generally contain a concentration of NO_3-N of around 20 mg/L. In addition, Cui, Y. *et al.*,[10] stated that, the percent of nitrifiers in the mixed liquid of the activated sludge tank which treat municipal waste water is usually 2%-5% because of the low rates of yield and the substrate level associated with ammonia oxidation. The nitrate and ammonia fluctuation were similar, responding to the variation in the rate of nitrified liquid recycling. Higher final effluent nitrate concentrations were mainly due to a lower wastewater recycling rate in anoxic bed. The lower effluent nitrate concentration contributed to greater efficiency in the removal of total nitrogen.

5. Conclusion

In conclusion, the nitrification and denitrification process that occurred in aerobic-anoxic system has sparks the interest in many researchers which leads to strong evidence for the complete removal of nitrogen from wastewater. Based on the observation from previous studies, the presence of aerobic-anoxic condition in the system has a great influence in removing the total nitrogen from domestic wastewater due to the biological conversion with the presence of nitrifying and denitrifying bacteria.

Acknowledgement

I would like to express my sincere appreciation to Faculty of Civil Engineering and Built Environment for the supports.

References

[1] Ishizuka, K., Hisajima, S., and Macer, D. (1996). Nitrification and Denitrification in the Wastewater Treatment System. Retrieved July 13, 2020, from https://www.eubios.info/TTEC/TTECPY.htm

[2] Shiva, D. K., Srikantaswamy, S., Abhilash, M. R., and Nagaraju, A. (2015), A Comparative Study of Aerobic and Anaerobic Wastewater Treatment. International Journal for Research in Applied Science & Engineering, 3(V), 994–1007.

[3] Wang, H. Guan. G., Li. L and Wu G., (2015) 'Characteristics of Biological Nitrogen Removal in a Multiple Anoxic and Aerobic Biological Nutrient Removal Process', BioMed Research International, 2015. doi: 10.1155/2015/531015. (8)

[4] Vymazal, J., Brix, H., Cooper, P. F., Green, M. B. and Haberl, R. (1998). Constructed Wetlands For Wastewater Treatment In Europe. Backhuys Publishers, Leiden, The Netherlands.(3)

[5] Hamdan, R. (2010). Aerated blast furnace slag filters for enhanced nitrogen and phosphorus removal from small wastewater treatment plants. University of Leeds, UK: Thesis PhD.4

[6] Ibrahim, I. I., and Hamdan, R. (2013). Study of Aeration Rate Effects on Total Nitrogen Removal from Domestic Wastewater. (1989), 152–158. 5

[7] Nur Amira Atierah Mohammed Shaikhani (2019). L-shape semi aerated filter for nitrogen removal from domestic. Universititun Hussein Onn Malaysia: Thesis.

[8] Victoria, J. R. and Foresti, E. (2011) 'A novel aerobic-anoxic biological filter for nitrogen removal from UASB effluent using biogas compounds as electron donors for denitrification', RevistaFacultad de Ingenieria, (60), pp. 72–80. 6

[9] Hamoda, M. F. and Bin-Fahad, R. A. (2012) 'Nitrogen removal from wastewater in an anoxic-aerobic biofilm reactor', Journal of Water Reuse and Desalination, 2(3), pp. 165–174. doi: 10.2166/wrd.2012.015. 7

[10] Cui, Y., Nakhla, G., Zhu, J. and Patel, A., (2004) 'Simultaneous carbon and nitrogen removal in anoxic-aerobic circulating fluidized bed biological reactor (CFBBR)', Environmental Technology, 25(6), pp. 699–712. doi: 10.1080/09593330.2004.9619360. 9