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Nitrification-denitrification Process in a Combined AVFF and UAHFF System for Ammonia Removal

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Abstract: High ammonia in the water body will accelerate the growth of aquatic plants as well as eutrophication in the water ecosystem. Domestic wastewater among the culprits of ammonia discharge due to the capability of an existing conventional wastewater treatment system which often unable to remove completely ammonia as mainly will be removed in tertiary treatment. However, tertiary treatment requires a complex chemical process. Therefore, the main objective of this study is to develop an alternative treatment for enhanced ammonia removal from domestic wastewater. A lab-scale L-shaped semi-aerated with the combination of Aerated Vertical Flow Filter (AVFF) and Unaerated Horizontal Flow Filter (UAHFF) was mainly designed to study the nitrification-denitrification process in an aerated vertical and unaerated horizontal filter, respectively using the different rates of aeration (0.5, 1.0, and 1.5 mg/L). The L-shaped semi-aerated filter was constructed with steel slag as a filter medium in the MPRC laboratory and the wastewater sample was collected from the influents of the UTHM Sewage Treatment Plant (STP). The influent and effluent samples of wastewater were analyzed for pH, Dissolved Oxygen, turbidity, and nitrate twice a week within 3 weeks. Results from this study show that the effluent of the system was alkaline with a pH value range from (7.64 to 9.41) due to the nature of steel slag which is an alkaline media. Turbidity has been successfully removed as the percentage removal range from (75% to 89%). From the observation, the nitrification process taking place in the highly oxygenated AVFF system due to the increased nitrate concentration in the filter effluent whilst denitrification does not occur as the nitrate concentration remains high in the UAHFF effluent. This condition might be due to the reason that the UAHFF do not completely anoxic as the DO remain high, range from (4.87mg/L to 8.18mg/L). In conclusion, the system will be redesigned to enhance the denitrification process.

Keywords: Total Nitrogen Removal, Nitrification, Denitrification

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1. Introduction

Nowadays, untreated domestic wastewater became a major concern to the environment due to the high nutrient release. Nutrients such as nitrogen and phosphorus can be treated in conventional wastewater treatment but require a lot of chemicals using during treatment which causes the chemical release of water bodies and lead to the environmental problem of disposing of a large amount of chemical sludge [1]. The high of nutrients release will cause the increasing of algae growth and eutrophication will occur [1]. Alternative treatment is needed to treat nutrients released [2].

The high concentration of nitrogen in a water body can disturb the ecology system and it will become a serious concern when the nitrogen is high in ammonium ion which will exert an oxygen demand and can be toxic to fish [3]. Nitrogen in wastewater forms from the ammonia (NH_3), ammonium ion (NH_4^+), nitrogen gas (N_2), nitrite (NO_2^-), nitrate (NO_3^-) and organic nitrogen [3]. Nitrogen removal is complex and needs advanced treatment to treat. Thus, this study is to monitor the performances of the nitrification and denitrification process in an L-shape semi-aerated steel slag filter for total nitrogen removal from domestic wastewater using the different rates of aeration (0.5, 1.0, and 1.5 mg/L). This study will summarise on 1) performances of different aeration rate 2) the nitrification and denitrification process.

2. Aerated and Unaerated system

The aerated and unaerated system is a condition that presences of oxygen and without oxygen. This system used to remove the total nitrogen by the biological process at aerobic-anoxic conditions. The aerobic condition where the nitrification process occurs when the ammonia was oxidized to nitrite by ammonia-oxidizing bacteria (AOB) and nitrite is approximately oxidized to nitrate easily by nitrite-oxidizing bacteria (NOB). Then, nitrite or nitrate also will donor the electron with no dissolved oxygen and convert nitrate to nitrogen gas during the denitrification process [4].

2.1 Nitrification

The nitrification process is in practice carried out by a group of autotrophic microorganisms. The process takes place in two stages since the group of bacteria known as *Nitrosomonas* oxidizes ammonium to nitrite and nitrite is oxidized to nitrate by other bacteria known as *Nitrobacter*. These reactions, which they use to produce new biomass, gain energy from both sets of organisms; the carbon for this is provided by the ammonia oxidizers by carbon dioxide fixation [5].

The stoichiometric equation was defines as molar ratios for the oxidation of ammonium (NH_4^+) to nitrite (NO_2^-) are shows in the Eq 1 [6].

$$NH_4^+ + 1.5\,O_2 = NO_2^- + 2H^+ + H_2O \qquad \text{Eq. 1}$$

and the Eq 2 for the second step is which the oxidize nitrite (NO_2^-) to nitrate (NO_3^-) ;

$$NO_2^- + 0.5\,O_2 = NO_3^- \qquad \text{Eq. 2}$$

2.2 Denitrification

Denitrification is important to process in transforming nitrite and nitrate into gaseous products which can reduce the transport of nitrogen downstream to rivers. The rate of denitrification depends on the availability of an electron donor to control the biological response [8]. The biological reduction of nitrate to nitrogen gas in the absence of dissolved oxygen is called a denitrification process. The denitrification process will occur in anoxic conditions [6]. Their two-step the most common reaction for denitrification performed which in Eq 3 and Eq 4 [6].

Denitrification of nitrate to Nitrogen Gas in equation 3

$$NO_3^- + cBOD = NO_2^- + CO_2 + H_2O \quad \text{Eq. 3}$$

Denitrification of nitrite to Nitrogen Gas in equation 4

$$NO_2^- + cBOD = N^2 + CO^2 + OH^- \mp H_2O \quad \text{Eq. 4}$$

3. AVFF and UAHFF setup system

Below show alternative treatment to remove ammonia and nitrate in domestic wastewater with a combination of vertical and horizontal filter systems.

3.1 L-Shape semi-aerated steel slag filter

The purpose of this study is to find an alternative treatment system to remove ammonia and nitrate in wastewater treatment plants. In this system, the nitrification process (aerobic) will take place in an aerated zone, which was located in the vertical flow filter while the denitrification process (anoxic) will take place in an unaerated zone at horizontal flow filter. Figure 1 shows the expected nitrification and denitrification in the L-shape semi-aerated filter system as referred to the previous study [13].

A lab-scale L-shape semi aerated steel slag filter has been designed in the Micropolluant Research Centre (MPRC) laboratory FKAAB UTHM. The size of the designed system is 0.13m x 0.165m x 0.34m for UAHFF and for AVFF is 0.41m high and the diameter is 0.15m. This system uses steel slag as the filter for AVFF and UAHFF. Steel slag is perfect for the elimination chemical reaction of the various contaminants in wastewater as adsorption [9]. The schematic of the lab-scale semi-aerated steel slag filter is shown in Figure 2. Domestic wastewater sample was collected from the influents of the UTHM Sewage Treatment Plant. The wastewater used for this system is 30 l/day which the volume of wastewater remains at AVFF is 2.6L. The influent and effluent samples of wastewater were analyzed for pH, Dissolved Oxygen, turbidity, and nitrate twice a week for 3 weeks. Process of nitrification and denitrification in the system has been observered.

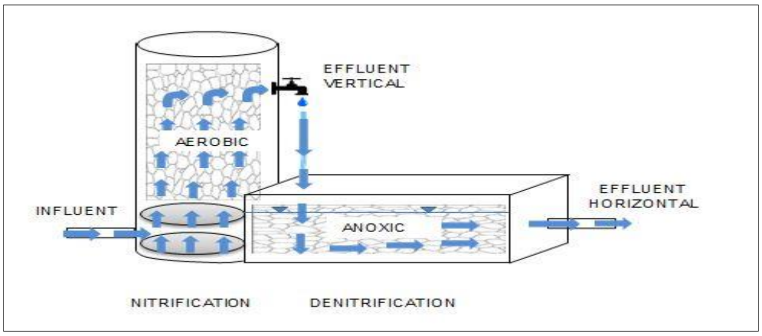


Figure 1: Expected nitrification and denitrification in the L-Shape Semi-Aerated Filter System [13]

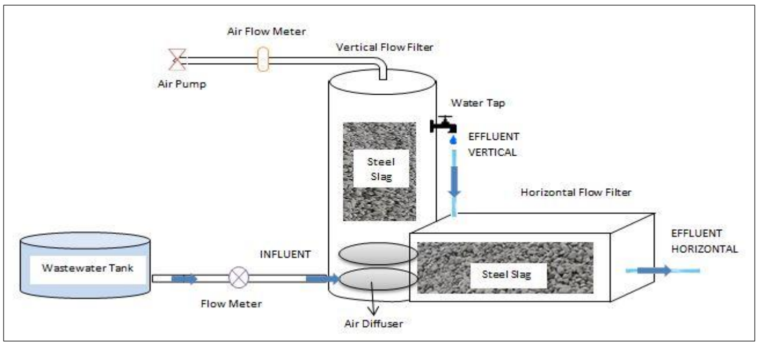


Figure 2: L-shape semi-aerated steel slag filter schematic diagram

4. Result and Discussion

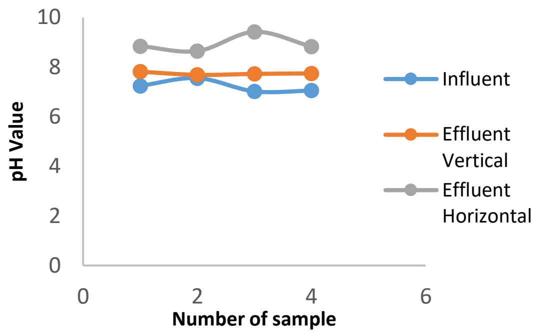
The steel slag that was brought from Antara Steel Mills Sdn. Bhd. located at Pasir Gudang, Johor, Malaysia was been analysed using X-ray Fluorescence Spectroscopy (XRF) to obtain the chemical composition in steel slag. Table 1 below shows the results of XRF from the previous study.

Table 1 : XRF Result for Chemical Composition of Steel Slag [10]

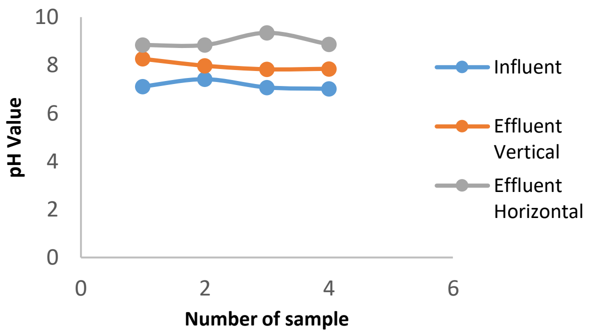
Element	Concentration (%)
CaO	49.50
SiO_2	18.00
C	0.10
MgO	4.32
SO_3	2.58
Al_2O_3	2.23
Fe_2O_3	1.64
MnO	0.38
TiO_2	0.22

The chemical composition of CaO are higher in calcium which was 49.50% and this indicates that steel slag contain high amount of calcium [10]. The alkaline composition is suitable to provide alkalinity and control pH in filter for nitrification and denitrification process [4].

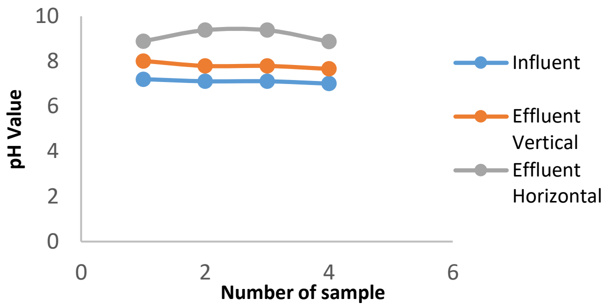
Figure 3 (a-c) shows the pH value for influent and effluent of domestic wastewater for rate 0.5 L/min, 1.0 L/min, and 1.5 L/min. The pH value of influent is between 7.02 to 7.24 while at the effluent AVFF is between 7.64 to 8.27 and at effluent UAHFF is between 8.82 to 9.41. The pH at effluent was alkaline because the filter used in AVFF and UAHFF was steel slag which had a higher composition of calcium oxide (CaO). According to Amatya et al., (2011) [4], the alkaline substances in steel slag will affect the enhancement of pH reading from AVFF to UAHFF. Therefore, steel slag was the dominant mechanism as adsorption the pH neutral to alkaline.



(a)



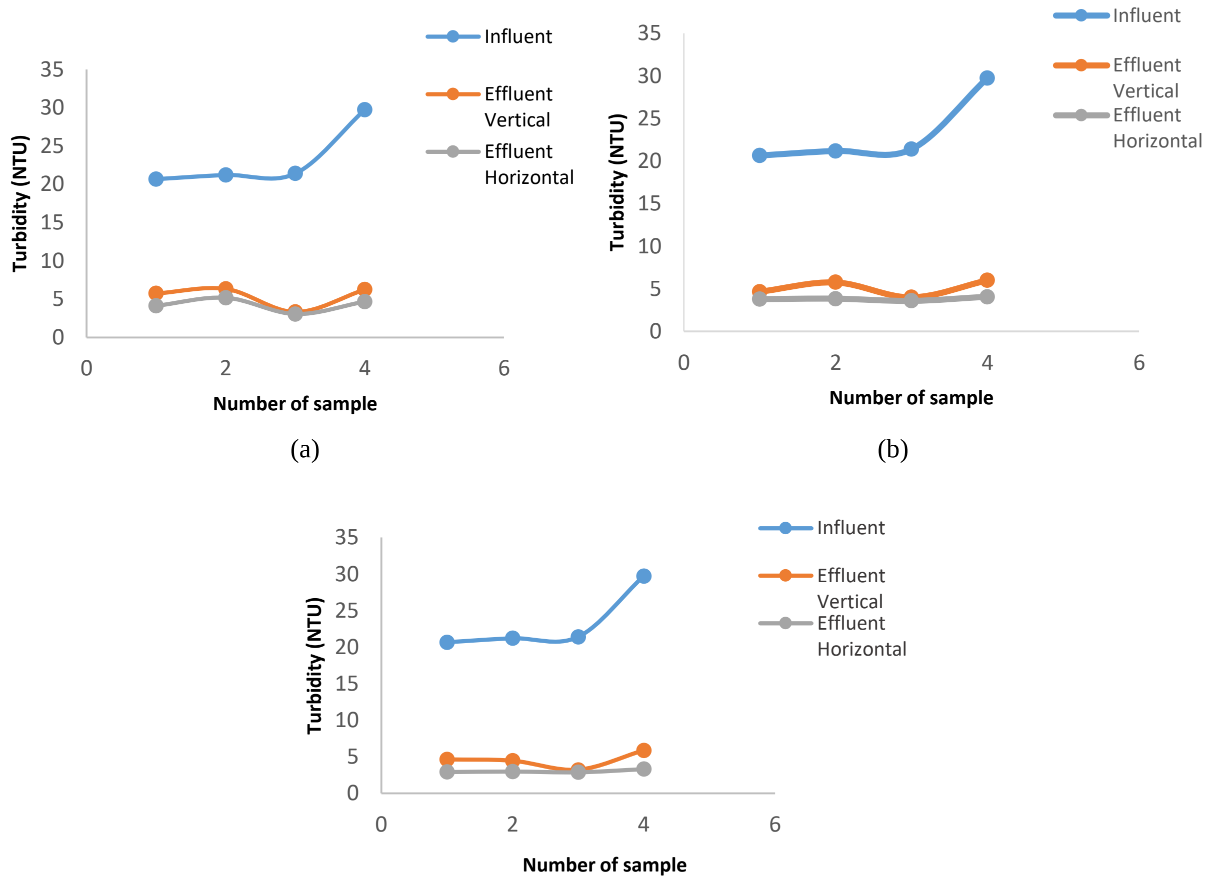
(b)



(c)

Figure 3 (a)-(c) : Value of pH concentration for rate 0.5, 1.0 and 1.5 L/min

Figure 4 (a-c) show the reading of turbidity for rate 0.5L/min, 1.0L/min, and 1.5 L/min. The reading at effluent is lower than the reading at influent in the raw sample because the aeration rate supplied at AVFF was helping the bacteria nitrify organic matter and after that, it will form to floc and settle down at the bottom. This concept also occurs in secondary treatment when the oxygen was supplied in the aeration process [11].



(a) (b)

(c)

Figure 4 (a)-(c) : Turbidity concentration for rate 0.5, 1.0and 1.5 L/min

Figure 5 (a-c) shows the reading of Dissolved Oxygen at AVFF for rate 0.5 L/min, 1.0 L/min, and 1.5 L/min. The reading of DO at influents is between 4.01 to 4.83 mg/L because no oxygen was supplied while at effluent vertical filter the DO was increased to 7.51 to 8.03 mg/L because the oxygen was presences by the air pump. The reading for DO at rate 1.5L/min is higher than the rate of 0.5L/min because high oxygen produces.

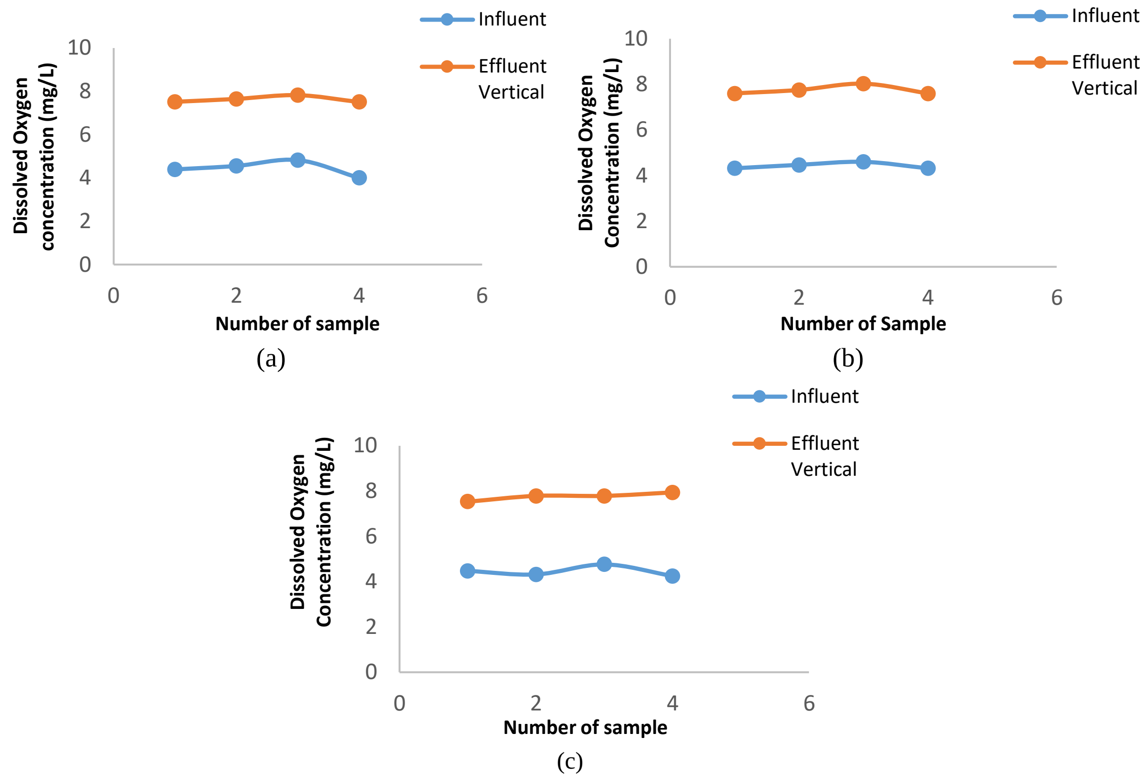


Figure 5 (a)-(c) : Dissolved oxygen concentration at AVFF for rate 0.5, 1.0 and 1.5L/min

The DO value at AVFF is between 7.0 to 8.0 mg/L which is higher than 2.0mg/L, indicating an aerobic condition that favor the nitrification process. Figure 6 (a-c) shown the nitrate was formed in the presence of oxygen. The value of nitrate at influent is ranged from 4.01 to 4.76 mg/L while at AVFF the reading of nitrate is 4.9 to 12.58 mg/L. The reading nitrate at influent is lower because the concentration of DO was low.

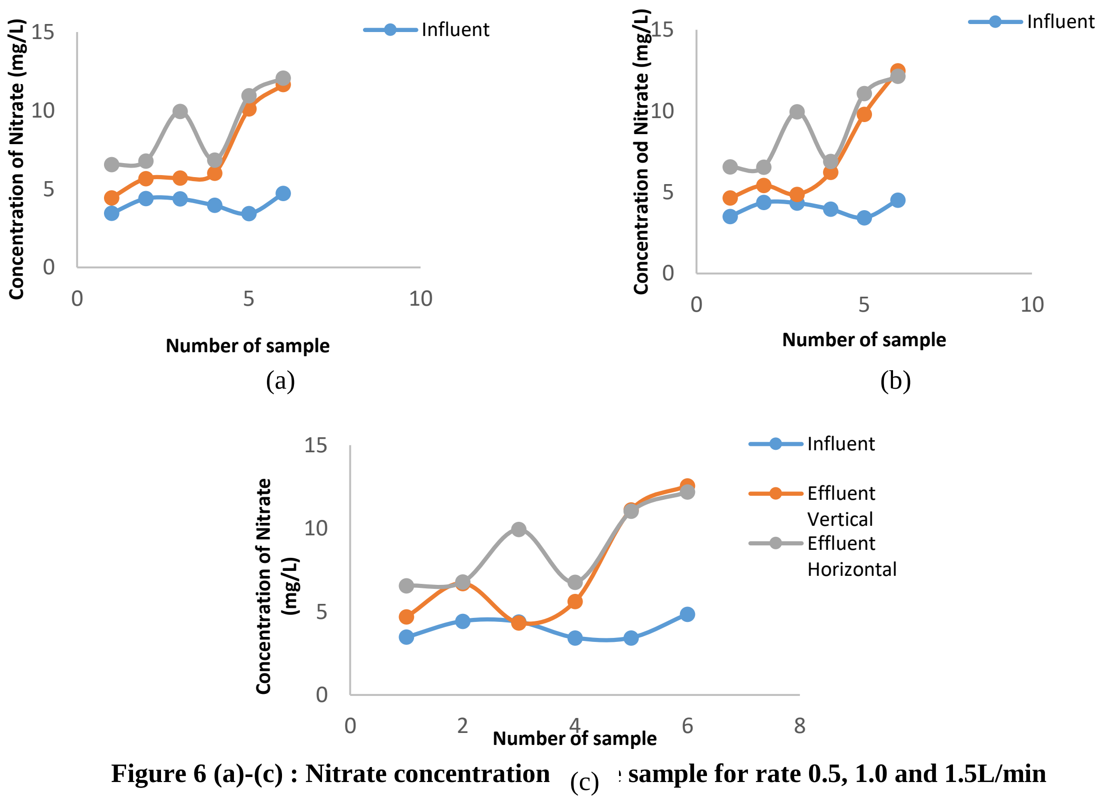


Figure 6 (a)-(c) : Nitrate concentration (c) **: sample for rate 0.5, 1.0 and 1.5L/min**

The biological reaction occurs in which the ammonia reacts with oxygen and oxidizes to nitrate. From the results shown that the process of nitrification occurred at AVFF in aerobic conditions. Table 2 shows the previous study of nitrate at influents domestic wastewater at STP UTHM. From the studies, the concentration of ammonia in domestic wastewater at STP UTHM is 35.8 mg/L cause higher release nutrients from the community. The concentration of nitrate was low at the influents of domestic wastewater which is 0.899 mg/L because there no oxygen was supplied [10].

Table 2: Details Data in Previous Studies of Domestic Wastewater at STP UTHM [10]

Parameter	Concentration
Alkaline, mg/L $CaCO_3$	146.67
Temperature, °C	28.7
pH	6.96
Dissolved Oxygen (DO), mg/L	0.89
COD ,(mg/L)	262.08
BOD, (mg/L)	87.36
Ammonia-Nitrogen ,(mg NH_3-N/L)	35.28
Nitrite ,(mg/L)	0
Nitrate ,(mg/L)	0.899

Early in the nitrification process, the ammonia concentration effluent was primarily associated with the influent values. Efficiency was then achieved when the dependencies were reduced, showing an increase in biomass and achieved stability over time. The results show that the starting concentration was 12 mg/L and, at the end of the period, the average nitrification efficiency is 60 percent, and this is shown in figure 7 [12].

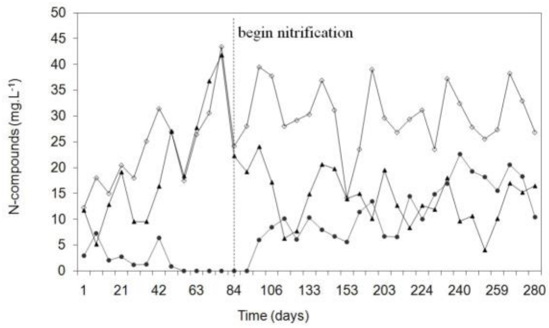
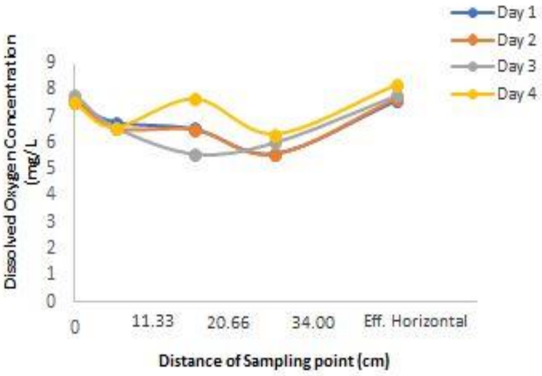
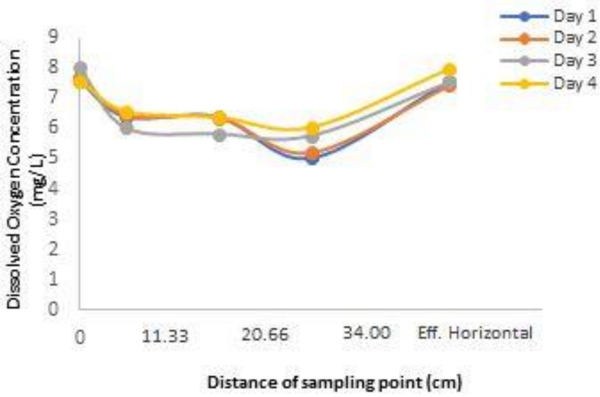


Figure 7: Nitrogen compound variation in the aerobic compartment [12]

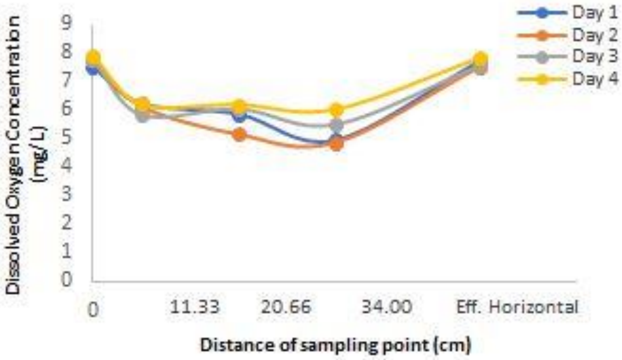
Figure 8 (a-c) shows the reading of Dissolved Oxygen at UAHFF for rate 0.5 L/min, 1.0 L/min, and 1.5 L/min. At UAHFF, the measurement of DO was divided into three-part of the filter which the reading at each part shows decreasing from the first part at vertical effluent and the last part of the horizontal effluent filter. The DO reading at the horizontal effluent show inclined from the reading at UAHFF because the oxygen still exists in UAHFF.



(a)



(b)



(c)

Figure 8 (a-c) : Dissolved Oxygen concentration at UAHFF for rate 0.5, 1.0, and 1.5L/min

Denitrification is the process that converts nitrate to nitrogen gas. At UAHFF the DO value just slightly decreasing at 5.0 to 6.0 mg/L which not favor condition for the denitrification process occurs . According to Victoria & Foresti, (2011) [12] denitrification occurs under anoxic conditions when oxygen levels are depleted which a DO value smaller than 0.2mg/L and once the nitrification starts, the biogas supply was started. Nitrifying biomass has now been extracted from the aerobic compartment and placed in the denitrifying compartment. The denitrification process improved when the media was submerged on day 217th. The concentration of NO3-N effluent decrease to 8 mg/L and the average efficiency in denitrification was 52%. This shown in figure 9.

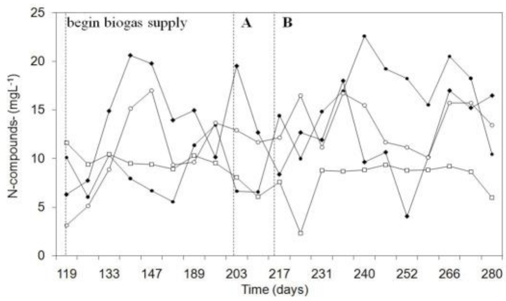


Figure 9: Nitrogen compound variation within anoxic compartment [12]

5. Conclusion

In conclusion, the presences of nirate was low in absence of oxygen condition but when the oxygen was supplied the reading of nirate incerease. The system will be redesigned to enhance the denitrification process.

Acknowledgement

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