



Nitrogen Removal from an Aerobically Digested Domestic Wastewater using Anoxic/Oxic (A/O) Reactor Packed with Non-woven Filter Materials

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ABSTRACT

This study examined the removal of nitrogen from domestic wastewater through the application of anoxic/oxic (A/O) bio-reactor system. Influent and effluent samples were collected from the system and tested. Chemical oxygen demand (COD), $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ were analyzed. Different hydraulic retention time (HRT) and recycle ratios were applied to assess its influence on removal efficiency of the reactor. The temperature was controlled between 20 to 24°C and pH was 7.7 – 8.2. The result revealed average COD removal efficiencies of 72.1%, average removal of $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ was 92% and 54% respectively. The result obtained reflects that, the A/O reactor is suitable and efficient in nitrogen removal.

Key words: Domestic wastewater, anoxic/oxic (A/O) bio-reactor system; Hydraulic retention time (HRT); Recycle ratios; Nitrification; denitrification.

INTRODUCTION

Over the last two decades, rapid population growth, booming economic growth, low wastewater treatment rate and illegal discharge of domestic and industrial wastewater, and non-point pollution sources have resulted in severe water quality degradation in rural parts of China, expressed by the deterioration of surface water, the eutrophication of lakes and the increase of nitrate in surface and groundwater.

Although domestic wastewater is considered a pollutant, it can also be an important resource when it's properly treated (Otterpohl *et al.*, 1999, 2003; Elmitwalli *et al.*, 2003). Domestic wastewater is the wastewater generated domestically in the households and characterized by low content of nutrients and pathogens (Otterpohl *et al.*, 1999; Jefferson *et al.*, 1999; Eriksson *et al.*, 2002). Domestic wastewater can be categorized into two different groups based on their source of origin as; black water from toilets (faeces, urine) and grey water from bath, wash and kitchen.

In recent days, domestic wastewater has been widely studied by many researchers using different treatment processes, either by application of high-rate aerobic systems, such as rotating biological contactor (Nolde, 1999), fluidised bed (Nolde, 1999), aerobic filter (Jefferson *et al.*, 2000), membrane bioreactor (Jefferson *et al.*, 2000), or by application of low-rate systems, such as slow sand filter (Jefferson *et al.*, 1999) and vertical flow constructed wetlands (Otterpohl *et al.*, 2003).

The potential advantages of A/O bioreactor system for the treatment of domestic wastewater is that, the anoxic treatment will oxidize organic materials in the waste while reducing the concentration of odorous compounds associated with anaerobic treatment. It is also cost effective since oxygen will only be required for ammonia oxidation and not for organic degradation which is far better than that of a totally aerobic system and hence, significant portion of nitrogen contained in the waste will be removed, decreasing land area requirements for supernatant application and lessening concerns over nitrogen contamination of surface and groundwater (Dale G. Frederick, 2002).

In view of the above cited, this study was carried out with an aim of investigating the efficiency of applying A/O bioreactor system for treating domestic wastewater.

MATERIAL AND METHODS

Experimental set-up

The experimental system is made up of a regulating tank (influent tank), three submersible pumps and the A/O bioreactor system. The lay out diagram of the experimental set-up is shown in Fig.1. The anoxic reactor is made of Polyvinylchloride (PVC), with a total effective volume of 60 L and the oxic reactor (waterfall aeration contact oxidation) has three columns (parts) and made of Polyvinylchloride respectively, with a total capacity of 27L. The reactor was connected in series with an internal diameter of 0.2m and a height of 2m for the anoxic columns and width size of 30cm for each oxic column but different effective depth of 10cm, 20 and 30cm for first, second and third oxic column. Both of the reactors column (A/O) was filled with a non-woven fabric filter materials of length 2500mm,

width of 50mm, surface area of $150\text{m}^2/\text{m}^3$ and with porosity of 97%. The main parts of the bioreactor system used in this experimental study composed of the main two columns which is the anoxic column and oxic columns, an air compressor for aeration, longer pump (model BT100) to control the influent flow rate, air flow meter to achieve the desired DO concentration according to the experimental condition requirement, automatic aeration mixers to provide aeration in the anoxic and oxic zones and to maintain the biomass in suspension, influent wastewater valves, effluent water valves, internal circulation valves, sludge discharge, and plastic pipes and others.

Apparatus and flow chart

This research was carried out in Southeast university campus of Taihu Lake environmental program, in Wuxi, Jiangsu Province. Wastewater treatment system was built according to Fig. 1. This system integrated anoxic and oxic (waterfall aeration contact oxidation) column. The column operation was typically run as a complete system under different environment state conditions (anoxic/oxic) based on phase type.

The mean hydraulic residence time in anoxic column was 24 hours. It mostly pretreated the sewage and reduced organic compounds. The oxic (waterfall aeration contact oxidation) columns achieved organic compounds decomposition and nitrogen nitrification. The effluent from the oxidation column was partly recycled to anoxic column for denitrification. By this process, this system integrated A/O methods and consequently enhanced effluent quality.

Schematic structure of oxic (waterfall aeration contact oxidation)

The oxic (waterfall aeration contact oxidation) was estranged into three units (Fig. 2). The height difference between each adjacent unit is 0.5m. The domestic sewage drops to some porous baffles after it was pumped to a certain height. There were many tiny holes with diameter of about 2 mm in the baffles. As the sewage passes through the tiny holes, it fall down in fine flow, which increased the interface with air and encourage oxygen transfer and hence, the sewage was aerated. After waterfall, the aerated sewage entered one oxidation unit

attached with biological fillings. The biofilm on the fillings oxidized organic compound and nitrogen with oxygen.

Wastewater for the experiment

Raw wastewater from a campus main manhole was pumped into a storing tank for sedimentation, and then fed into the reactor. The A/O reactor was inoculated with sludge obtained from Wuxi municipal sewage treatment plant which utilizes a typical change in the environmental state condition (anaerobic, anoxic, or aerobic) to treat municipal wastewater and performs simultaneous nitrification and denitrification as well. COD infiltrated ranges between 57 and 150 mg/l (winter season).

The reactor was operated continuously for 15 days as the start-up period until the reactor performance was stable (acclimatized). The effluent samples of every reactor were collected at the sampling ports of the reactor in separate bottles after every two days and stored in refrigerator at 4°C before experimental tests in the laboratory. The compositions of the studied area domestic raw wastewater are shown in table 1.

Analytical Procedures

The following parameters and methods of testing shown in table 2 were used for this study. All the analyses were carried out in accordance with the Chinese standard methods for determination of municipal sludge in wastewater treatment plant(s) (CJT 221-2005). The samples were filtered through a 0.45-μm membrane filter before experimental analysis. The filtered sample preserved frozen for nitrates, ammonium nitrogen determination, whereas the other samples was then preserved with H₂SO₄. The sample preserved with

acid was used for COD tests; acid added was about 1% of sample volume to be preserved. The influent and the effluent COD, NH₄⁺-N, and NO₃⁻-N were measured according to the standard methods recommended by US Environmental Protection Agency (APHA, 1999). Temperature and pH was measured by dissolved oxygen meter. The flow rate was controlled by a valve and incessantly regulated by the help of a pump.

RESULTS AND DISCUSSION

Organic material removal (COD)

The average concentrations of COD in the influent and effluent during the experimental operations were 62.3mg/L and 17.4mg/L respectively. Fig. 3 indicates the efficiency of the operated reactor in regards to COD removal. Most of the organic materials during the pre-nitrification are removed in the anoxic zone whereas the remaining organic materials will ultimately be degraded in the oxic reactor (Fu *et al.*, 2009).

The average removal efficiency of COD was 72.1%. This result obtained is quite similar to the study conducted by Gurung A, *et al.*, (2011) who observed an average COD removal rate of 85% when the organic loading rate was 0.19 kg

Table 1: Composition of the studied area domestic raw wastewater

Parameter	Min	Max	Average
COD (mg/L)	56.2	148.1	92.5
NH ₄ ⁺ -N (mg/L)	7.13	24.99	11.04
NO ₃ ⁻ -N (mg/L)	3.4	6.2	4.8
pH	7.7	8.2	7.9

Table 2: Test parameters and methods

Parameters	Methods
COD (mg/l)	Potassium dichromate (GB 11914-89)
NH ₄ ⁺ -N(mg/l)	Nessler's reagent (GB7479-87)
NO ₃ ⁻ -N(mg/l)	Sulfamate UV Spectrophotometer (GB7480-87)
pH	pH Meter
Temperature (oC)	Dissolved oxygen meter
DO	Dissolved oxygen meter

COD/m³/d and it is also similar with the result obtained by Rim and Han (2000) who observed an average TCOD removal rate of 80 to 95% when the organic loading rate was maintained in the range of 0.4 to 3.1 kg COD/m³/d. In this study, the average removal of COD was 68, 85, 83, 74 and 85% with effluent concentration of 17.5, 15.9, 7.7, 11.7 and 34mg/l experimented under HRT of 4, 5, 3, 2 and 1.5hrs with recycle ratios of 3, 2, and 1 respectively

(table 3). It can be noted that, COD removal efficiency increases with increase in recycle (R) value and HRT (Fig. 4). From these findings, the result reveals that A/O reactor was efficient in upholding a reasonably high and stable COD removal throughout the experimental period.

NH₄⁺-N and NO₃⁻-N removal

In order to monitor the nitrification process

Table 3: Average COD concentration in the influent, anoxic and oxic reactors and their removal performance with respect to different HRT and recycle ratios

HRT (h)	COD inf tank (mg/l)	COD Anoxic (mg/l)	COD Oxic (mg/l)	Removal efficiency (%)	Recycle
5	148.1	108.7	15.9	85	1
4	86.9	54.3	17.5	68	2
3	56.2	45.7	7.7	83	2
2	69.1	44.4	11.7	74	3
1.5	95.2	58.5	34	42	3

Table 4: Average NH₄⁺-N concentration in the influent, anoxic and oxic reactors and their removal performance with respect to different HRT and recycle ratios

HRT (h)	NH ₄ ⁺ -N inf tank (mg/l)	NH ₄ ⁺ -N Anoxic (mg/l)	NH ₄ ⁺ -N Oxic (mg/l)	Removal efficiency (%)	Recycle
5	8.7	2.9	0.5	94.3	1
4	18.8	3.9	3.5	81.4	2
3	9	1.9	0.3	96.7	2
2	7.8	1.6	0.6	92.3	3
1.5	10.7	1.5	0.6	94.4	3

Table 5: Average NO₃⁻-N concentration in the influent, anoxic and oxic reactors and their removal performance with respect to different HRT and recycle ratios

HRT (h)	NO ₃ ⁻ -N inf tank (mg/l)	NO ₃ ⁻ -N Anoxic (mg/l)	NO ₃ ⁻ -N Oxic (mg/l)	Removal efficiency (%)	Recycle
5	4.4	7.3	12.1	63.6	1
4	6.1	5.8	11.5	47	2
3	4.1	10	6.7	38.8	2
2	4.5	11	12.4	63.7	3
1.5	5.5	11.5	12.3	55.3	3

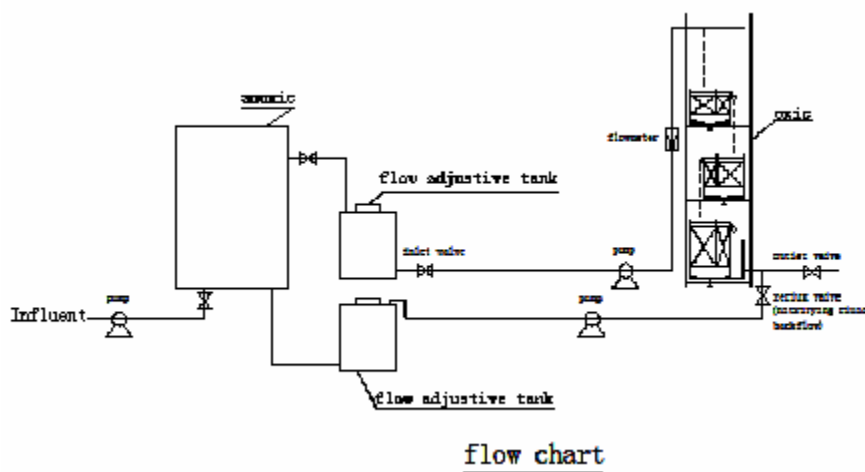


Fig. 1: Schematic flow chart of experimental set-up (A/O reactor)

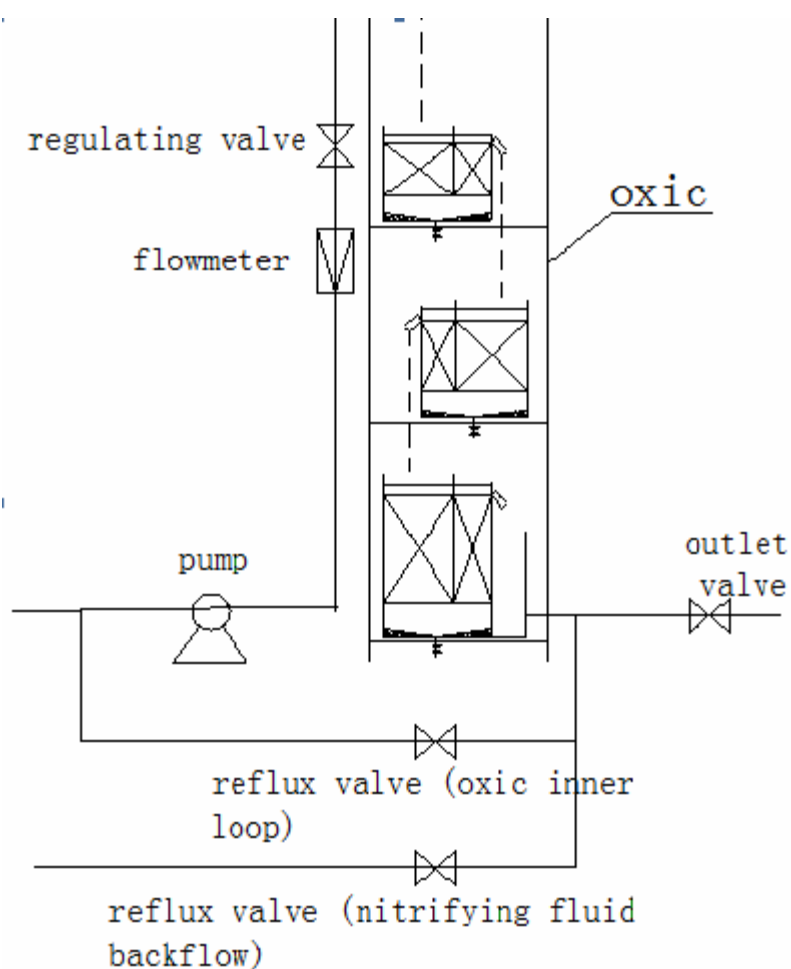


Fig. 3: Schematic flow chart of oxic (waterfall aeration contact oxidation) column

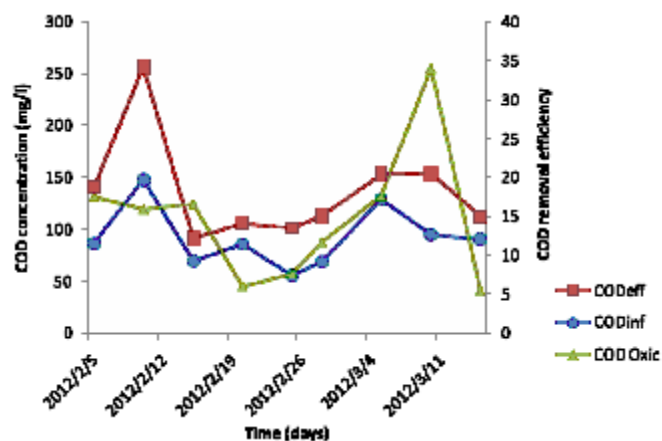


Fig. 3: COD concentrations in the influent, anoxic and oxic reactors

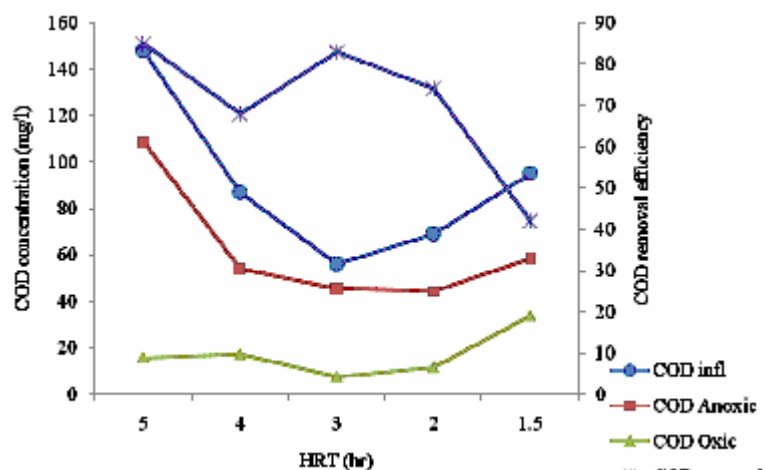
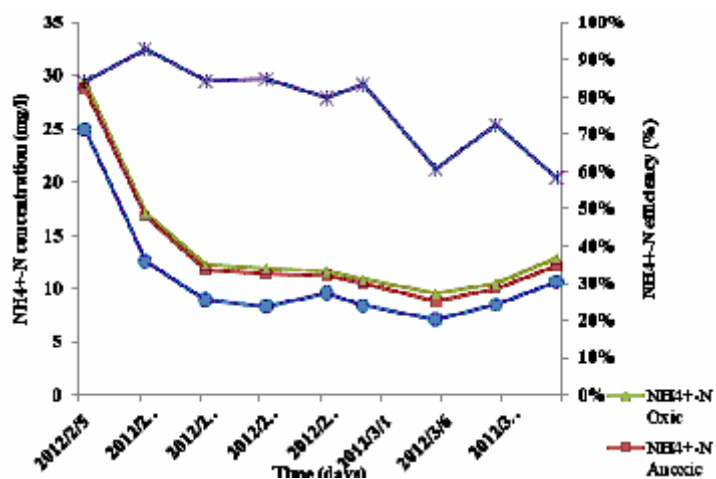
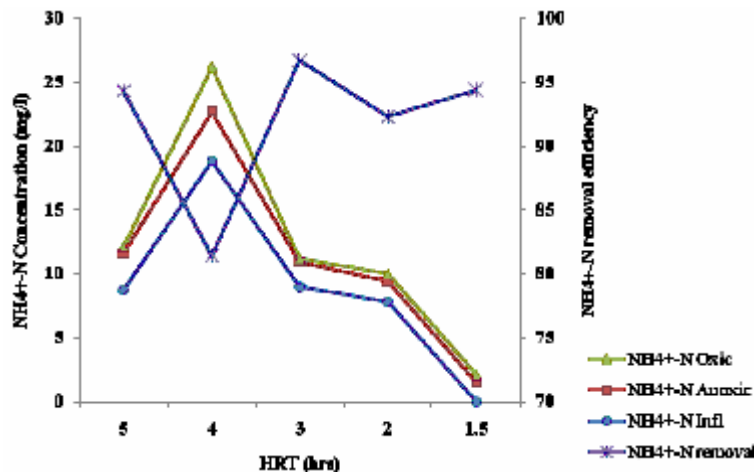
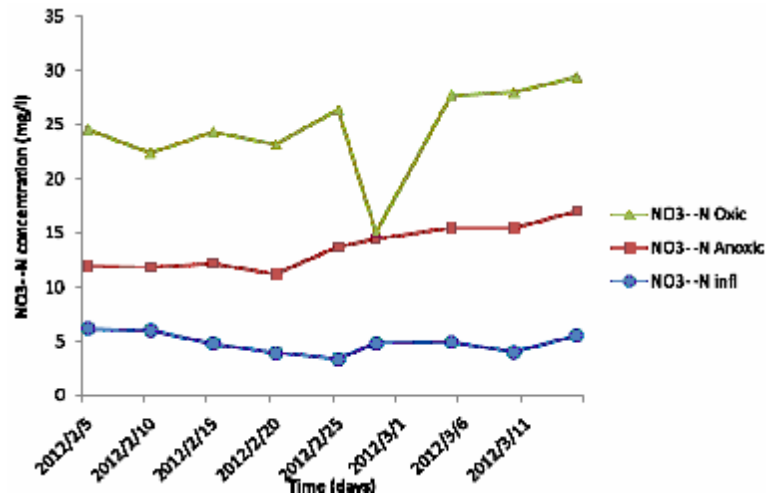
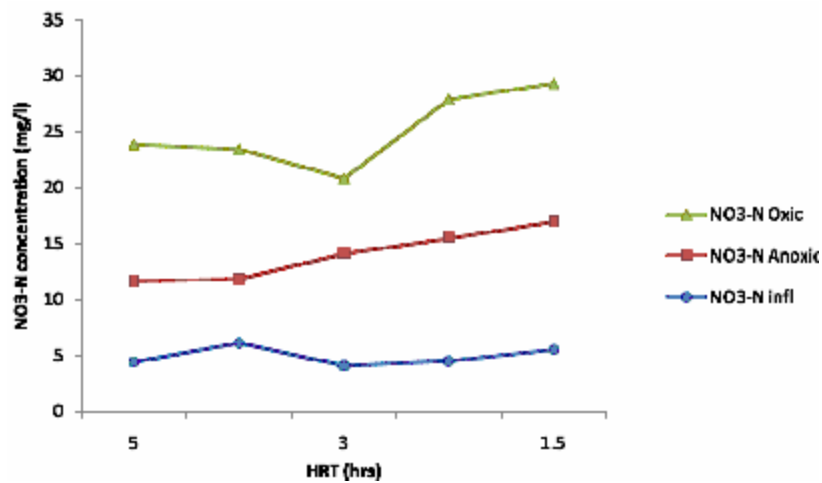


Fig. 3: COD concentrations in the influent, anoxic and oxic reactors

Fig. 5: NH_4^+-N concentrations in the influent, anoxic and oxic reactors

Fig. 6: Average $\text{NH}_4^+\text{-N}$ removal with relation to HRTFig. 7: $\text{NO}_3^-\text{-N}$ concentrations in the influent, anoxic and oxic reactorsFig. 8: Average $\text{NO}_3^-\text{-N}$ removal with relation to HRT

in the reactor, the concentrations of NH_4^+ -N and NO_3^- -N in the effluent of the nitrification reactor were tested. The performance of the A/O reactor with respect to NH_4^+ -N removal under different recycle ratios and HRT is shown in table 4 and figure 5 and 6. In the process of nitrification, the oxidation of NH_4^+ -N releases hydrogen ions (H^+) that reduces the pH in the nitrification reactor and might hinder the nitrification performance (An *et al.*, 2007; Vanotti and Hunt, 2000). The study by Yoo *et al.*, 1999 revealed that, alkalinity plays greater role in nitrification process and thus, lack of alkalinity in the nitrification reactor could lead to poor NH_4^+ -N removal efficiency. In order to minimize such drawback, sodium bicarbonate (NaHCO_3) as an external source of alkalinity was added throughout the study period whenever necessary. Since temperature is one of the important environmental factor in biological treatment and significantly affect the activity of nitrifying bacteria in the nitrification reactor (Zhang *et al.*, 2009), temperature in this study was controlled and maintained in the range of 20 to 26°C using stainless steel heater immersed in the reactor. In the study by Zhang *et al.*, (2009), highest ammonium oxidation rate was obtained at temperature of 31°C and the lowest value was experimented at a temperature of 15°C. The average concentrations of NH_4^+ -N in the influent, anoxic and effluent oxic reactor during the experimental operations were 11, 2.4 and 1.1 mg/L respectively (table 4). The average removal efficiency was 91.8% higher than that obtained by Gurung A, et al (2011). The average removal efficiency of total NH_4^+ -N in the whole reactor was 92%. The average removal of NH_4^+ -N was 81.4, 92.3, 94.3, 94.4 and 96.7 % with effluent concentration of 3.5, 0.6, 0.5 and 0.3mg/l operated with HRT of 4, 2, 5, 1.5 and 3hrs with recycle ratios of 2, 3, and 1 respectively (table 4).

According to literatures and a study by Yoo *et al.*, 1999, the optimum pH condition for nitrifying bacteria is 7.5 to 8.6. For this study, the value of pH was maintained between the ranges of 7.7 to 8.2 indicating satisfactory condition of the reactor. In order for simultaneous nitrification and denitrification to take place in the anoxic reactor, the reactor was intermittently aerated. The average

DO concentration in the reactor was in range of 2.5 to 3.2 mg O_2 /l, respectively.

In figure 7, the average concentration of NO_3^- -N in the influent, anoxic and oxic reactors and the removal efficiency throughout the operation period are illustrated. During the operation, there is high concentration NO_3^- -N in the effluent of the nitrification reactor. Usually, NO_3^- -N accumulates whenever the levels of DO concentration decreases in the nitrification reactor. According to the study by Munch *et al.*, 1996, the activity of Nitrobacter bacteria is inhibited even at the DO concentration of 7 mg/l. The average removal efficiency of total NO_3^- -N in the whole reactor was 54%. The average removal (released) of NO_3^- -N was 38.8, 47, 55.3, 63.6 and 63.7% with effluent concentration of 4.1, 6.1, 5.5, 4.4 and 4.5mg/l operated with HRT of 3, 4, 1.5, 5 and 2hrs with recycle ratios of 2, 3, and 1 respectively (table 5 and figure 7 and 8). Usually increase in recycle leads to high removal efficiency of NO_3^- -N although other factors can influence the reactor performance. But the effluent of the oxic reactor contained relatively high concentration of NO_3^- -N (11mg/l) as compared to anoxic reactor (9mg/l) and this could be attributed to the high DO levels in the oxic reactor. Increase in recycle ratio (R) enhances the denitrification efficiency of A/O but according to Tan and Ng, 2008, high increase of recycle ratio also inhibits denitrification. Recycle ratio (R) greater than 5 is not recommended for the A/O process (Baeza *et al.*, 2004).

CONCLUSIONS

This study used A/O for treatment of campus domestic wastewater at different operating condition such as HRT and recycle ratios. According to the result obtained during the whole experimental operation, the A/O reactor appears to be well suited to the treatment of this kind of low strength campus domestic wastewater. The average COD removal efficiencies were 68, 85, 83, 74 and 85% at HRT of 4, 5, 3, 2 and 1.5hrs respectively. Since heterotroph uses organic substrates as a source of carbon, heterotrophic denitrification is responsible for COD degradation. The average removal of NH_4^+ -N was 81.4, 92.3, 94.3, 94.4 and 96.7 % with HRT of 4, 2, 5, 1.5 and 3hrs respectively. The average removal of NO_3^- -N was 38.8, 47, 55.3, 63.6 and 63.7% with

effluent concentration of 4.1, 6.1, 5.5, 4.4 and 4.5mg/l with HRT of 3, 4, 1.5, 5 and 2hrs respectively. The result revealed that, increase in recycle ratios leads to high removal efficiency in nutrients. The result obtained revealed that, the A/O reactor is suitable and efficient in nitrogen removal

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