

Research Article

Experimental Study on Anoxic/Oxic Bioreactor and Constructed Wetland for Rural Domestic Wastewater Treatment

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Abstract: This study examined the removal of nutrients from the domestic wastewater through the application of integrated anoxic/oxic (A/O) bio-reactor and constructed wetland system. Influent and effluent samples were collected from the system and experimented for Chemical Oxygen Demand (COD), NH_4^+ -N, NO_3^- -N and TP in the laboratory. Different Hydraulic Retention Time (HRT) and recycle ratios were applied in the reactor to evaluate their influence on removal efficiency of nutrients. The temperature was controlled between 20 to 24°C and pH ranges was 7.6-8.1. The result revealed average COD removal efficiencies of 47, 68, 74, 83 and 85% at HRT of 1.5, 4, 2, 3 and 5 h. The average removal of NH_4^+ -N was 60.3, 63.0, 64.4, 71 and 91.8 % operated with HRT of 2, 3, 5, 1.5 and 4 h, respectively. The average removal of NO_3^- -N was 92, 94, 95 and 97% run with HRT of 2, 1.5, 3, 5 and 4 h, respectively. The average removal of TP was 78, 85, 88 and 89% operated with HRT of 5, 3, 2 and 1 h. This system removed up to 74.1, 94.4 and 85% of NH_4^+ -N, NO_3^- -N and TP with proper pH control using external source of alkalinity. The result showed the optimum recycle ratio of 3. The results obtained attest that, the integrated anoxic/oxic bioreactor and constructed wetland is feasible and efficient for wastewater treatment.

Keywords: Alkalinity, denitrification, Hydraulic Retention Time (HRT), nitrification, recycle ratios

INTRODUCTION

Rural domestic wastewater treatment is vital to avert water pollution, which has drawn great attention for both researchers and government officials (Ichinari *et al.*, 2008). According to the World Health Organization (WHO) estimates and the Water Supply and Sanitation Collaborative Council shows that less than 18% of rural populations have access to sanitation services in developing countries (Massoud *et al.*, 2009). According to the study by Pan *et al.* (2007), the amount of domestic wastewater treated in China is just 11% for county towns and less than 1% for rural villages. 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).

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, 2002).

Constructed wetlands are artificially created ecosystems that would not otherwise exist without significant human intervention, such as earthworks or hydrologic manipulation. They are generally designed to mimic many of the conditions and/or processes that occur in natural wetlands. Constructed wetlands may be

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an appropriate technology for treating domestic sewage in the rural areas of China with climatic, population and socioeconomic considerations (Min *et al.*, 2010). But there are still some questions and limitations to broader application of constructed wetlands. Among the problems is the poor performance of outdoor constructed wetlands in the cold climates. Cold temperatures rigorously affect microbial activities and water purification performance of constructed wetlands. Low aeration and oxygen levels are among the limiting factors for a better performance of constructed wetlands, mostly due to the dieback of aquatic macrophytes that could transport oxygen for microbial respiration (Kadlec and Reddy, 2001).

The integration of A/O bio-reactor system and constructed wetland is the best alternative for small scale rural domestic sewage treatment. However, there have been limited reports on using integrated anoxic, Oxic (waterfall contact aeration) and constructed wetland systems as a pretreatment for rural domestic wastewater. In order to meet the standard effluent quality discharge of China, single operation process

can't achieve that standard, hence, integrated process is considered to be the best option. In view of the above cited this study was carried out with an aim of investigating the efficiency of applying integrated A/O bioreactor system and constructed wetlands for treating domestic wastewater.

MATERIALS AND METHODS

Experimental set-up: The experimental system is made up of a regulating tank (influent tank), four submersible pumps, the integrated A/O bioreactor system and constructed wetlands. The lay out diagram of the experimental set-up is shown in Fig. 1. The anoxic reactor has a total effective volume of 60 L and the oxic reactor (waterfall aeration contact oxidation) has three columns (parts) with a total capacity of 27 L. The reactor was connected in series with an internal diameter of 0.2 m and a height of 2 m for the anoxic columns. The oxic column has width size of 30 cm for each section but different effective depth of 10 cm, 20 and 30 cm for first, second and third oxic column. Both

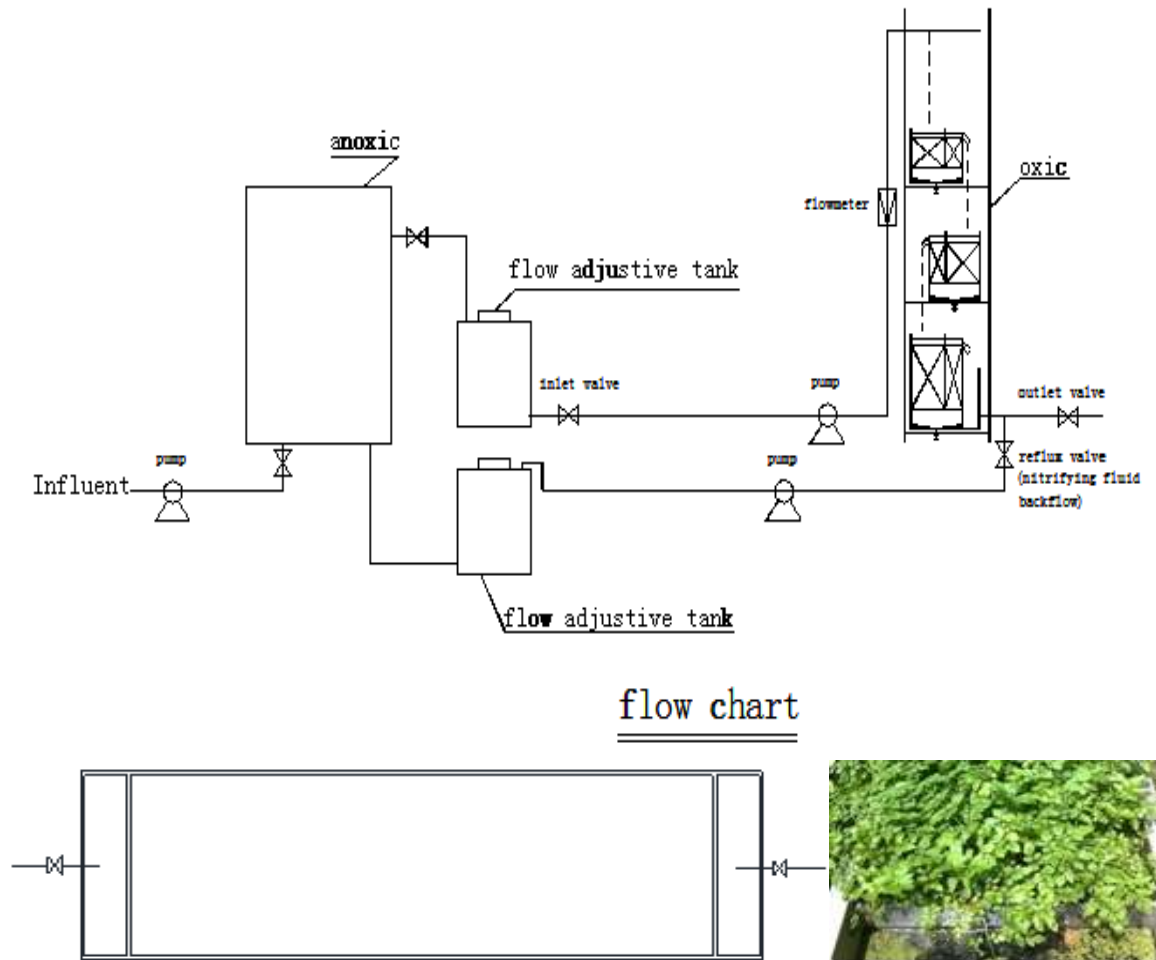


Fig. 1: Schematic structure of anoxic, oxic (waterfall aeration contact oxidation) and CW

of the reactors columns (A/O) was filled with a non-woven fabric filter materials of length 2500 mm, width of 50 mm, surface area of 150 m²/m³ and with porosity of 97%. The constructed wetland has a plot area of 1.2 m². It has a bottom slope of 0.003%. Each chamber was composed of three different layers of matrix particles of different sizes: the 200 mm layer of coarse gravel (20 to 40 mm in diameter) and the 250 mm layer of grit gravel in the bottom, in the upper is a 100 mm layer of fine sand (0.5-1.2 mm in diameter). The constructed wetland was planted with Chinese celery (*Oenanthe javanica*).

The main parts of the bioreactor system used in this experimental study composed of the main three columns which is the anoxic column, oxic columns and constructed wetland, 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 oxic zones and to maintain the biomass in suspension, influent wastewater valves, effluent water valves, sludge discharge and plastic pipes.

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, oxic (waterfall aeration contact oxidation) column and constructed wetlands. 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 h. 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 and the rest is discharge to constructed wetland for further treatment and mostly for TP removal.

The oxic (waterfall aeration contact oxidation) was divided into three units (Fig. 2). The height difference between each adjacent unit is 0.5 m. 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 nutrients with oxygen.

Wastewater for the experiment: Raw wastewater from a campus main manhole was pumped into a

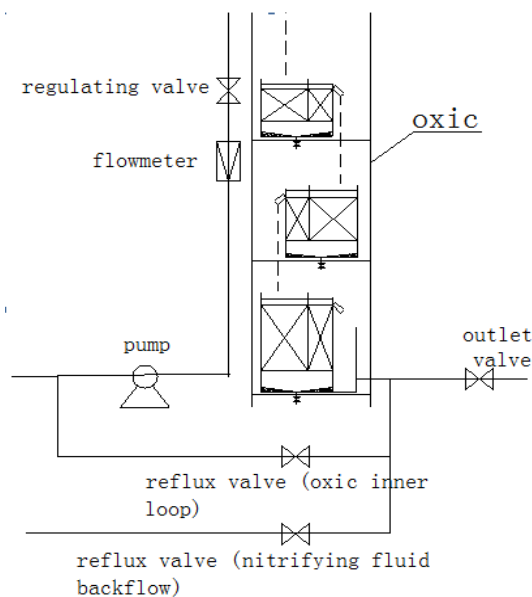


Fig. 2: Schematic flow chart of oxic (waterfall aeration contact oxidation) column

Table 1: Composition of the studied area domestic raw wastewater

| Parameter | Min | Max | Average |
|----------------------------------------|------|-------|---------|
| COD (mg/L) | 56.2 | 207.2 | 105.4 |
| NH ₄ ⁺ -N (mg/L) | 14.3 | 49.9 | 22.1 |
| NO ₃ ⁻ -N (mg/L) | 3.4 | 6.2 | 4.8 |
| TP | 2.9 | 5.4 | 3.8 |
| pH | 7.7 | 8.2 | 7.9 |

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 60 and 150 mg/L (winter season). The raw domestic wastewater composition is shown in Table 1. The reactor was operated continuously for 25 days as the start-up period until the reactor performance was stable (acclimatized). The effluent samples of every reactor and from constructed wetland were collected at the sampling and effluent discharge 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 experiments evaluate organic and nutrient concentrations with variable loading using different recycle ratios. The internal recycle ratio, R, can be defined as the ratio of returned flow rate (Q_r) to that of the main influent flow rate (Q₀):

$$\text{Recycle ratio } (r) = \frac{Q_r}{Q_0} \quad (1)$$

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

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 (GB 7480-87) |
| pH | pH Meter |
| Temperature (oC) | Dissolved oxygen meter |
| DO | Dissolved oxygen meter |

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 and other unfiltered was use for TP determination, whereas the other sample 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, NO₃⁻-N and TP 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.

Efficiency of the Reactor: For example, the removal of COD in the system refers to the difference between the influent and the effluent COD, thus the COD removal percentage is expressed by:

$$COD(\%) = \frac{COD_{inf} - COD_{eff}}{COD_{inf}} \times 100 \quad (2)$$

The equation is also applied for calculating the efficiency of the reactors in regards to the nutrients.

RESULTS AND DISCUSSION

Organic material removal (COD): The average concentrations of COD in the influent and effluent during the experimental operations were 104.3 mg/L

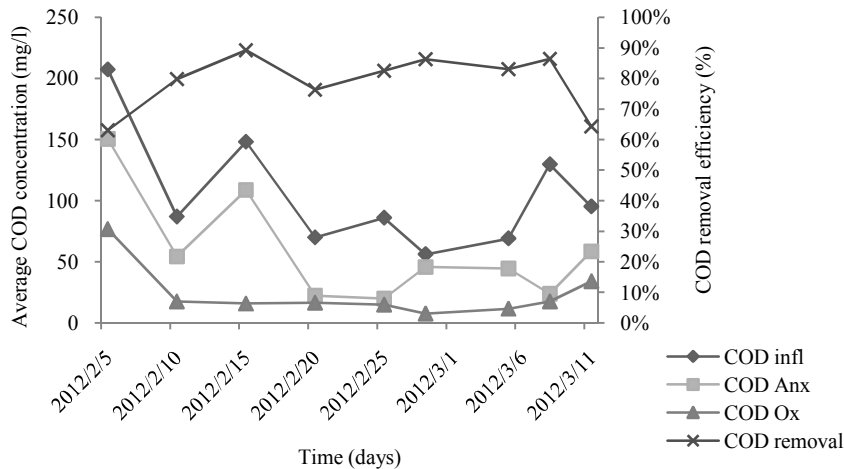


Fig. 3: COD concentrations in the influent, anoxic, oxic reactors and removal efficiency

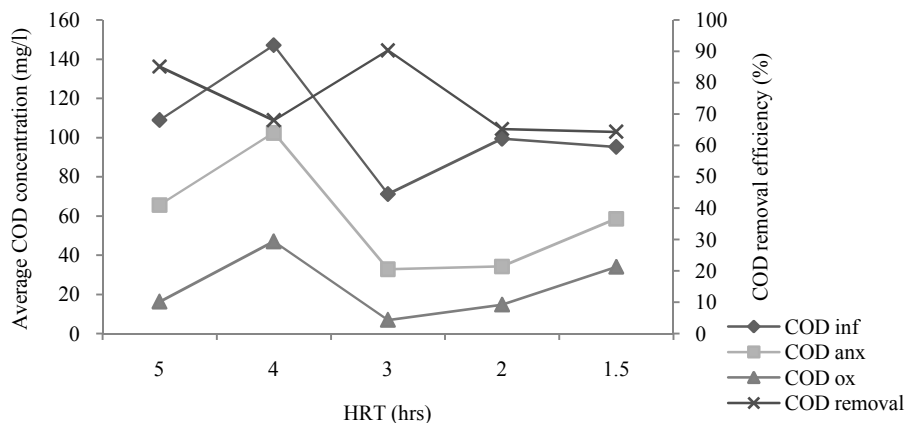


Fig. 4: Average COD removal in the influent, anoxic, oxic reactors with respect to HRT

and 23.8 mg/L, respectively. Figure 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. The overall removal efficiency of COD was 77.2%. This result obtained is quite similar to the study conducted by Gurung *et al.* (2011) who observed an average COD removal rate of 85% when the organic loading rate was 0.19 kg 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 64.3, 65.2, 68.0, 85.1 and 90.3% with effluent concentration of 34, 14.7, 47.0, 16.2 and 6.9mg/L with HRT of 1.5, 2, 4, 5 and 3 h respectively (Table 3). It can be noted that,

COD removal efficiency increases with increase in HRT (Fig. 4).

NH₄⁺-N and NO₃⁻-N Removal: In order to monitor the nitrification process in the reactor, the concentrations of NH₄⁺-N and NO₃⁻-N in the effluent of the nitrification reactor were tested. The performance of the A/O reactor and constructed wetland with respect to NH₄⁺-N removal under different recycle ratios and HRT is shown in Table 4 and Fig. 5 and 6. In the process of nitrification, the oxidation of NH₄⁺-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

Table 3: Average COD concentration in the influent, anoxic, oxic reactors, removal efficiency, HRT and recycle ratios

| HRT (h) | COD inf tank (mg/L) | COD Anoxic (mg/L) | COD Oxic (mg/L) | Removal efficiency (%) | Recycle |
|---------|---------------------|-------------------|-----------------|------------------------|---------|
| 5 | 108.9 | 65.5 | 16.2 | 85.1 | 1 |
| 4 | 147.1 | 102.4 | 47.0 | 68.0 | 2 |
| 3 | 71.1 | 32.7 | 6.9 | 90.3 | 2 |
| 2 | 99.4 | 34.1 | 14.7 | 65.2 | 3 |
| 1.5 | 95.2 | 58.5 | 34.0 | 64.3 | 3 |

Table 4: Average NH₄⁺-N concentrations in the influent, anoxic, oxic reactors, CW, removal efficiency, 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) | NH ₄ ⁺ -N CW | Removal efficiency (%) | Recycle ratio |
|---------|-------------------------------------------------|-----------------------------------------------|---------------------------------------------|------------------------------------|------------------------|---------------|
| 5 | 17.4 | 29.0 | 6.7 | 6.2 | 64.4 | 1 |
| 4 | 37.6 | 39.9 | 4.5 | 3.1 | 91.8 | 2 |
| 3 | 18.1 | 18.6 | 6.8 | 6.7 | 63.0 | 2 |
| 2 | 15.6 | 16.3 | 11.0 | 6.2 | 60.3 | 3 |
| 1.5 | 21.3 | 15.2 | 12.7 | 6.1 | 71 | 3 |

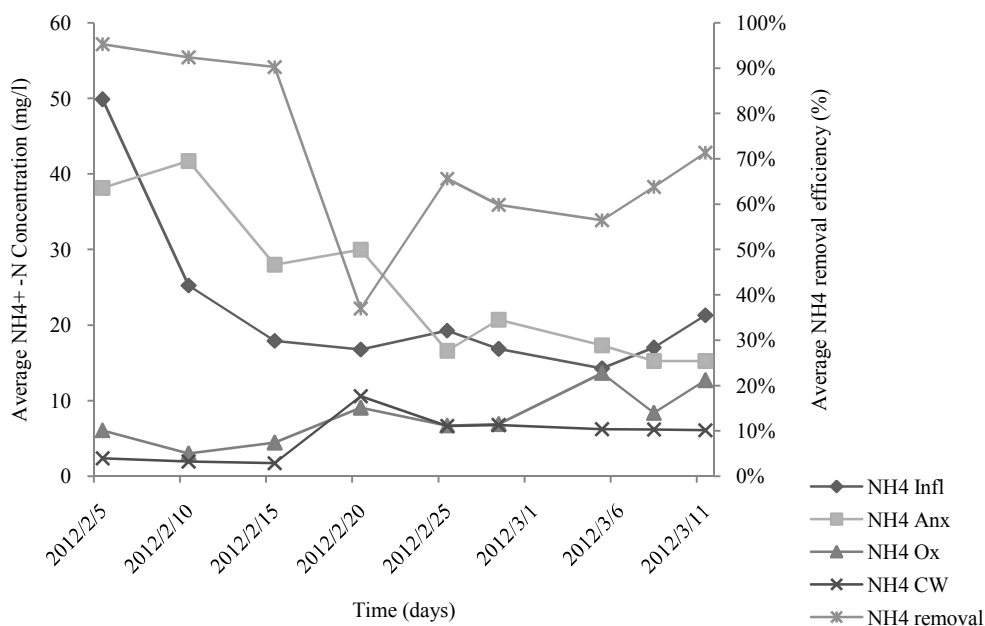


Fig. 5: NH₄⁺-N concentrations in the influent, anoxic, oxic reactors, CW and removal efficiency

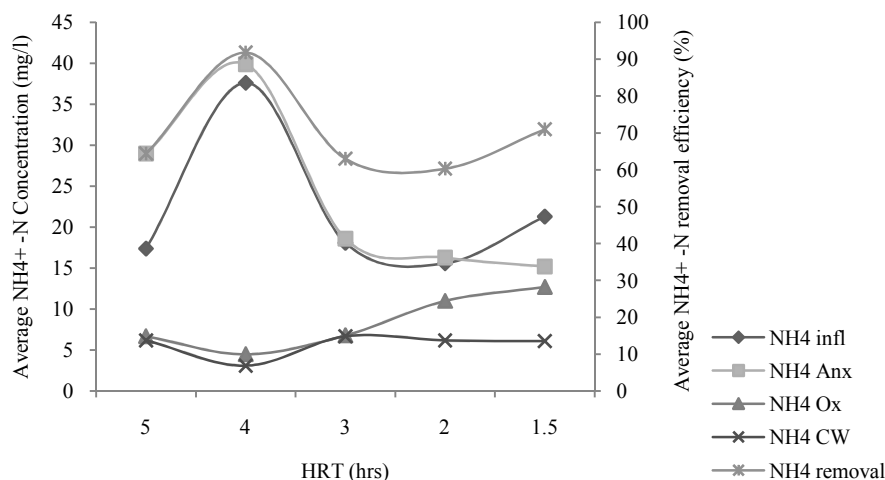


Fig. 6: Average NH₄⁺-N removal in the influent, anoxic, oxic reactors, CW with respect to HRT

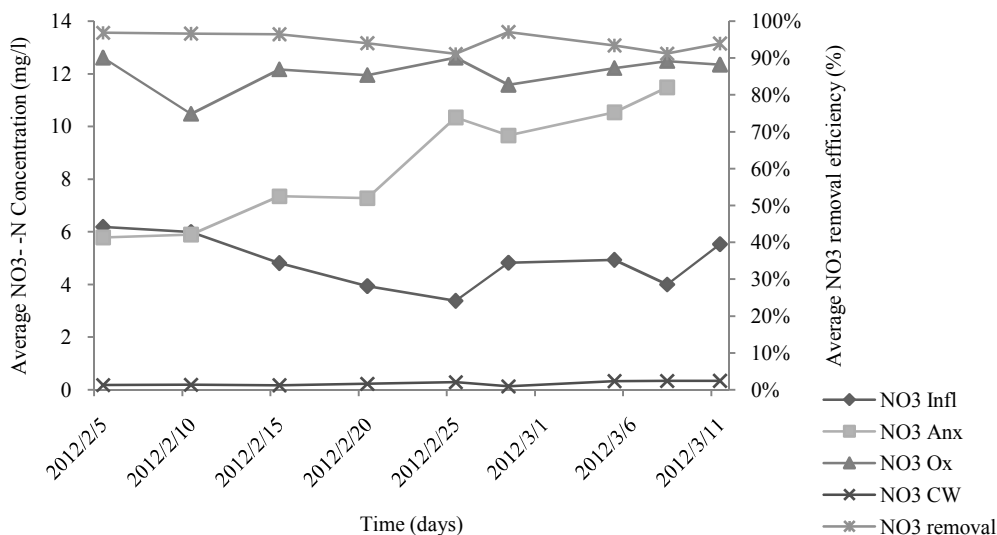


Fig. 7: NO₃⁻-N concentrations in the influent, anoxic oxic reactors and CW

Table 5: Average NO₃⁻-N concentration in the influent, anoxic, oxic reactors, CW, removal efficiency 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) | NO ₃ ⁻ -N CW (mg/L) | Removal efficiency (%) | Recycle ratio |
|---------|-------------------------------------------------|-----------------------------------------------|---------------------------------------------|-------------------------------------------|------------------------|---------------|
| 5 | 4.4 | 7.3 | 12.1 | 0.2 | 95 | 1 |
| 4 | 6.1 | 5.8 | 11.5 | 0.5 | 97 | 2 |
| 3 | 4.1 | 10 | 6.7 | 0.2 | 94 | 2 |
| 2 | 4.5 | 11 | 12.4 | 0.3 | 92 | 3 |
| 1.5 | 5.5 | 11.5 | 12.3 | 0.3 | 94 | 3 |

to poor NH₄⁺-N removal efficiency. In order to minimize such drawback, sodium bicarbonate (NaHCO₃) as an external source of alkalinity was added throughout the study period whenever necessary. Since temperature is one of the important environmental factors in biological treatment and significantly affects 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 NH₄⁺-N in the influent, anoxic oxic and constructed wetland during the experimental operations were 22, 23.8, 8.3 and 5.7 mg/L, respectively (Table 4). The average removal efficiency of total NH₄⁺-N was 74.1% almost similar to that obtained by Gurung *et al.* (2011).

The average removal of $\text{NH}_4^+\text{-N}$ was 60.3, 63.0, 64.4, 71 and 91.8 % with effluent concentration of 6.2, 6.7, 6.2, 6.1 and 3.1 mg/L operated with HRT of 2, 3, 5, 1.5 and 4 h, respectively (Table 4 and Fig. 5 and 6). 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 7.6 to 8.1 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 2.3 to 3.0 mg O_2/l , respectively.

In Fig. 7, the average concentration of $\text{NO}_3^-\text{-N}$ in the influent, anoxic, oxic and constructed wetland and the removal efficiency throughout the operation period are illustrated. During the operation, there is high concentration $\text{NO}_3^-\text{-N}$ in the effluent of the nitrification reactor (oxic). Usually, $\text{NO}_3^-\text{-N}$ 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 $\text{NO}_3^-\text{-N}$ in the integrated system was 94%. The average removal of

$\text{NO}_3^-\text{-N}$ was 92, 94, 94 and 97% with effluent concentration of 0.3, 0.2 and 0.5 mg/L operated with HRT of 2, 3, 5 and 4 h with recycle ratios of 2, 3 and 1, respectively (Table 5 and Fig. 7 and 8). Usually increase in recycle leads to high removal efficiency of $\text{NO}_3^-\text{-N}$ although other factors can influence the reactor performance. But the effluent of the oxic reactor contained relatively high concentration of $\text{NO}_3^-\text{-N}$ (11 mg/L) as compared to anoxic reactor and constructed wetland 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).

Total phosphorus removal: The removal efficiency of TP was quite stable despite the concentration of TP in the influent was ranging between 2.9 mg/L to 4.5 mg/L. The effluent TP was mostly below 0.5 mg/L (Table 6 and Fig. 9). In the constructed wetland, most of the TP removal was accomplished by medium interception, microbial transformation and plant adsorption.

Table 6: Average TP concentrations in the influent, anoxic, oxic reactors, CW removal efficiency, HRT and recycle ratios

| HRT (h) | TP inf tank (mg/L) | TP Anoxic (mg/L) | TP Oxic (mg/L) | TP CW | Removal efficiency (%) | Recycle ratio |
|---------|--------------------|------------------|----------------|-------|------------------------|---------------|
| 5 | 4.3 | 4.1 | 2.2 | 0.5 | 78 | 1 |
| 4 | 2.9 | 2.6 | 2.4 | 0.5 | 88 | 2 |
| 3 | 4.5 | 4.5 | 3.2 | 0.7 | 85 | 2 |
| 2 | 3.5 | 3.5 | 3.3 | 0.6 | 85 | 3 |
| 1.5 | 3.8 | 3.6 | 3.3 | 0.8 | 89 | 3 |

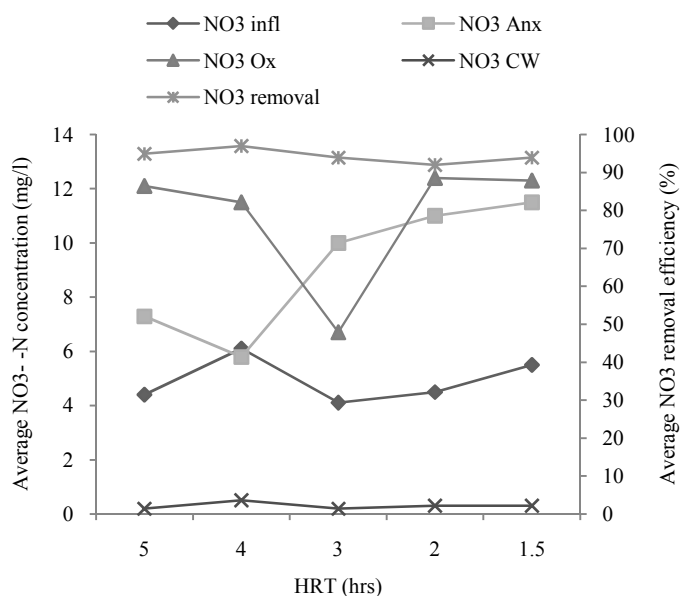


Fig. 8: Average $\text{NO}_3^-\text{-N}$ removal in the influent, anoxic, oxic reactors and CW with respect to HRT

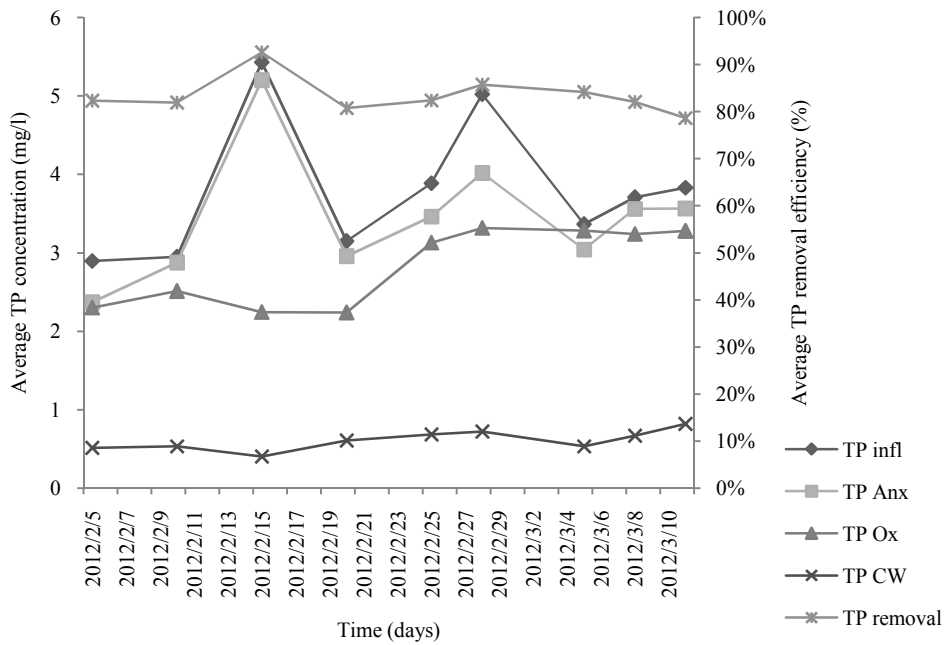


Fig. 9: TP concentrations in the influent, anoxic oxic reactors, CW and removal efficiency

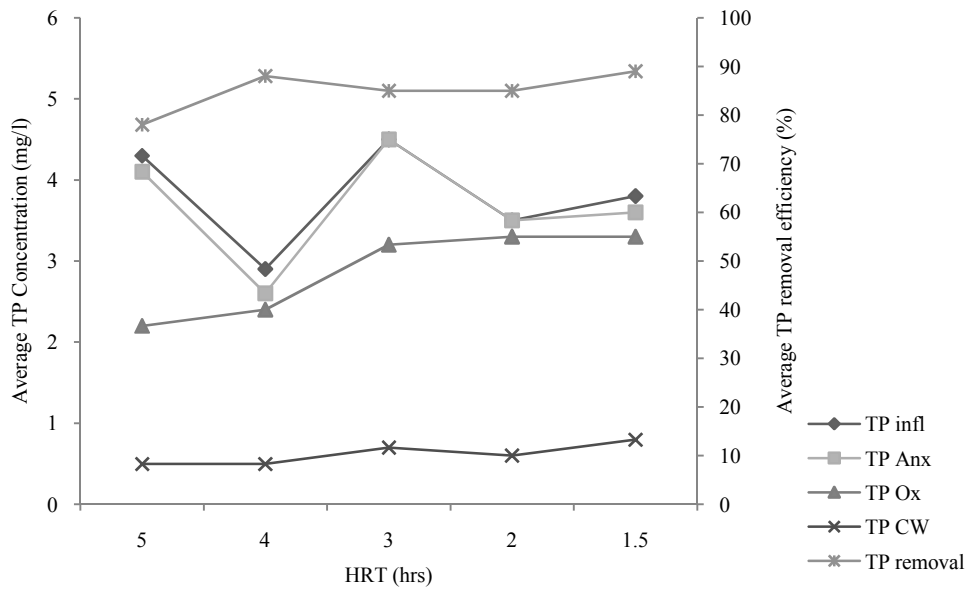


Fig. 10: Average TP removals in the influent, anoxic, oxic reactors and CW with respect to HRT

The average removal efficiency of Total Phosphorus (TP) in the integrated system was 83%. The average removal of total phosphorus (TP) was 78, 85, 88 and 89% with effluent concentration of 0.5, 0.6, 0.7 and 0.8 mg/L operated with HRT of 5, 3, 2 and 1hr with recycle ratios of 3, 2 and 1, respectively (Table 5 and Fig. 7 and 8).

Even though temperature fluctuates and reed in the constructed wetland withered steadily during the winter

season, TP removal in this system wasn't affected obviously due to the help of the scraped plaster (Fig. 10).

CONCLUSION

This study used A/O bioreactor and constructed wetland for treatment of campus (rural) domestic wastewater at different operating condition. According

to the result obtained during the whole experimental operation, the A/O bioreactor and constructed wetland emerge to be well suited to the treatment of this kind of low strength campus domestic wastewater. Since heterotroph uses organic substrates as a source of carbon, heterotrophic denitrification is responsible for COD degradation. In the constructed wetland, most of the TP removal was accomplished by medium interception, microbial transformation and plant adsorption. The result obtained revealed that, the A/O reactor and constructed wetland is suitable and efficient in upholding a reasonably high and stable organic and nutrients removal throughout the experimental period.

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