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# Reduction of Nitrogen by the Difference of Media Depths in the Vertical Subsurface Flow Constructed Wetland

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**Abstract**

The pilot scale experiment was conducted by comparing the efficiency of nitrogen removal by the difference of media depths in the vertical subsurface flow constructed wetland: (the VSF CW). In the VSF CW, there were 3 layers using 3 different types of media from the bottom layer filled with gravel (3-6 cm in diameter), the middle layer filled with small gravel (1-2 cm in diameter) and at the top layer filled with coarse sand (0.1-0.2 cm in diameter). Three different types of media were arranged in factorial form into 27 treatments with various bed depths of 10, 20 and 30 cm. The results showed that the most effective TKN and $NH_3$-N removal were found in 90 cm. of bed depth at 77.35% and 76.46%, respectively. When the hydraulic retention time increases, the efficiency of nitrogen removal also increases. The media depths in the VSF CW, the mount of nitrifying bacteria and denitrifying bacteria were positively related to the efficiency of nitrogen removal. The VSF CW that has media depths of 70, 80 and 90 cm. could remove the total nitrogen in the effluent standards. The findings will be served as a method to select appropriate media in the VSF CW for treating domestic waste water.


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*Keywords:* The Vertical Subsurface Flow Constructed Wetland, Synthetic Domestic Wastewater

## 1. Introduction

Constructed wetlands are engineering systems that have been designed to treat wastewater by the natural processes with low operation and maintenance requirements [1]. Due to this fact, they have been widely used to treat many kinds of wastewater such as domestic wastewater, industrial wastewater, tannery wastewater, acid mine drainage and landfill leachate [2-6]. The constructed wetlands are divided into 2 types; surface flow constructed wetland and subsurface flow constructed wetland. The subsurface flow constructed wetland is divided into 2 types which are the horizontal subsurface flow constructed wetland (the HF CW), and the vertical subsurface flow constructed wetland (the VSF CW).

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The VSF CW has an efficiency of nitrogen removal because of nitrification, denitrification, biological degradation, sedimentation and filtration. Generally, nitrogen removal in the VSF CW involves nitrification and denitrification processes. The majority of the nitrification and denitrification has been found to occur within the media of the VSF CW [7]. Nitrification is the biological oxidation of ammonia to nitrate in two steps. The first involves ammonia-oxidization bacteria that oxidatize ammonia to nitrite. Then nitrite-oxidizing bacteria oxidize nitrite to nitrate. Denitrification is the conversion of nitrate into nitrogen gas under anoxic conditions by denitrifying bacteria [8]. From previous studies, 3 layers of media are often used [9-12] but there are no studies on the relationship among the difference of media depths in the VSF CW, among the nitrifying bacteria and denitrifying bacteria, and the efficiency of nitrogen removal.

The objectives of this study were 1) to study the efficiency of nitrogen removal by the difference of media depths in the VSF CW 2) to study the amount of nitrifying bacteria and denitrifying bacteria with the difference of media depth 3) to study the relationship among the different of media depth in the VSF CW, nitrifying bacteria and denitrifying bacteria, and the efficiency of nitrogen removal. 4) to study the efficiency of nitrogen removal by the difference of hydraulic retention time.

## 2. Materials and Methods

This experiment was conducted at the water purification plant of Laemchabang City Municipality, Sriracha district, Chonburi, Thailand, on January 1 to February 10, 2012. The materials and methods were as follows.

### *2.1 Description of the VSF CW*

The VSF CW was constructed from poly vinyl chloride pipes with a diameter of 15.5 cm. Inside the pipes, there were 3 types of media; gravel (3-6 cm. in diameter) at the bottom; small gravel (1-2 cm. in diameter) at the middle layer and at the top layer filled with coarse sand (0.1-0.2 cm. in diameter) as shown in Fig. 1.

Three different types of media were arranged in factorial form into 27 treatments with various bed depths of 10, 20 and 30 cm. The experiment had 3 hydraulic retention times (HRT) that were 4, 6 and 8 days as shown in Fig. 2. The VSF CW was arranged using media depths of seven groups as shown in Table 1.

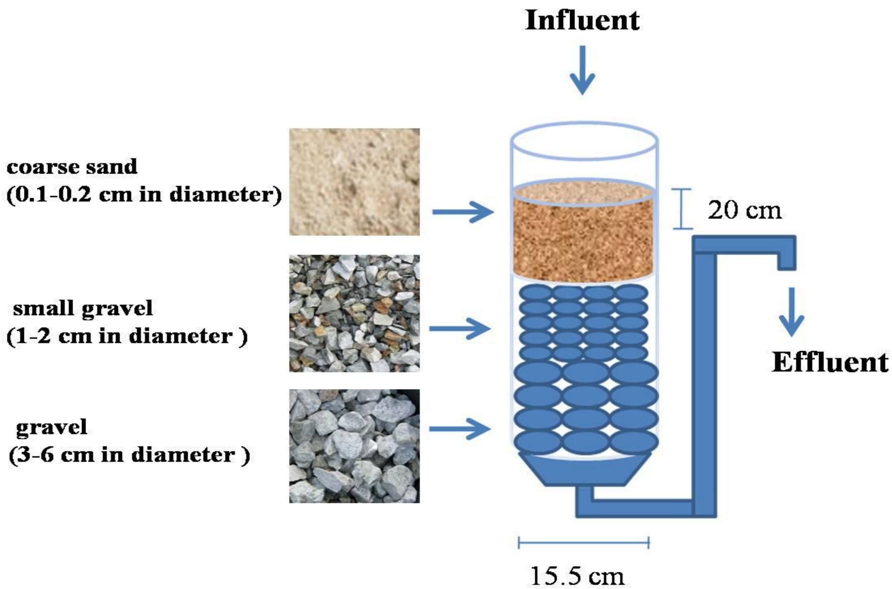


Fig. 1. the VSF CW filled with 3 types of media

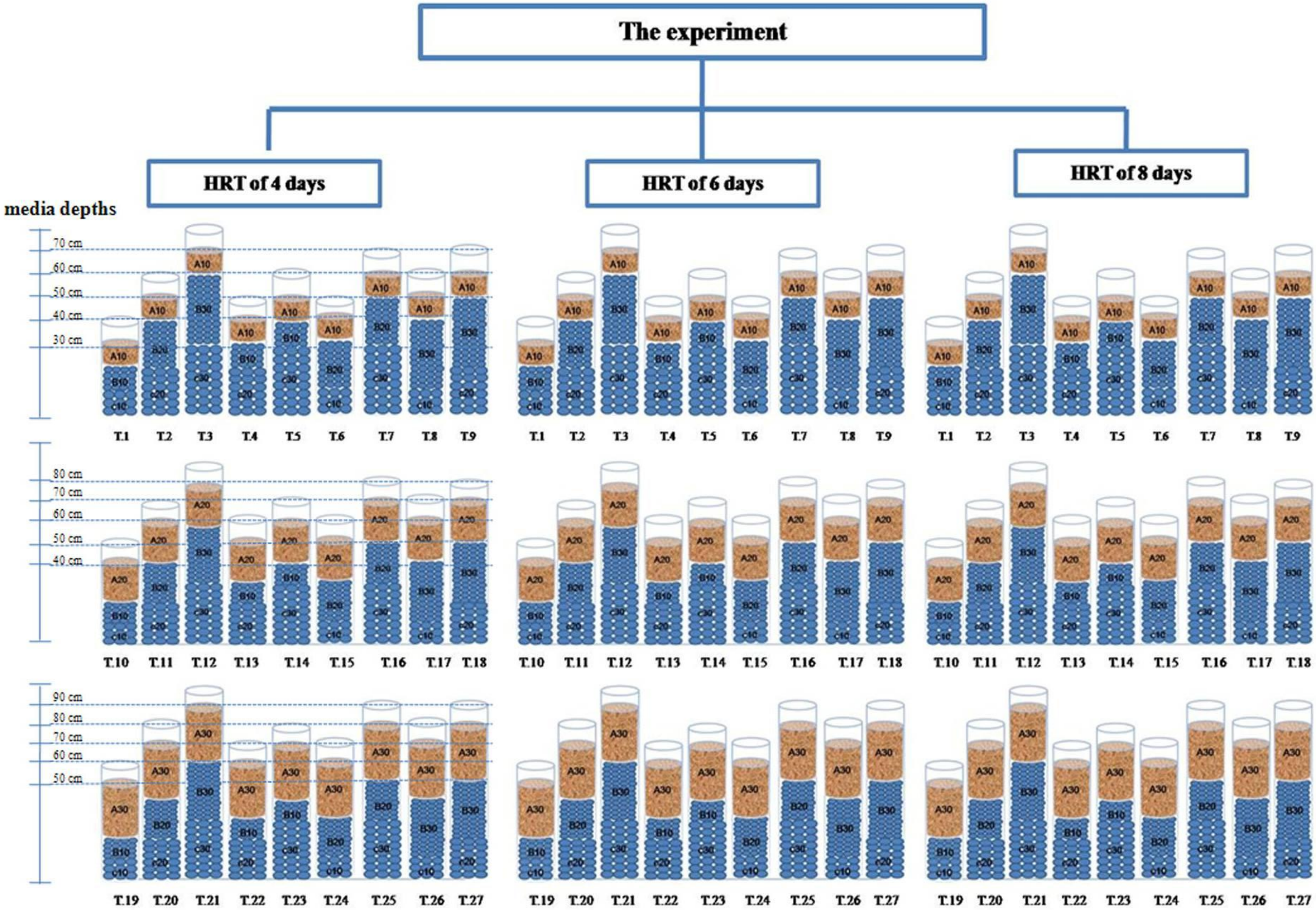


Fig.2 . There are 27 treatments with 3 hydraulic retention time, 4, 6 and 8 days total all 81 treatments.
[A: gravel (3-6 cm in diameter), B: small gravel (1-2 cm in diameter), C: coarse sand (0.1-0.2 cm in diameter) and number 10, 20 and 30 are media depths.]

Table 1. The VSF CW (T.1-T.27) was arranged into media depths of seven groups

| Groups | Media depths | Treatments |
|---|---|---|
| 1 | 30 | T.1 |
| 2 | 40 | T.4, T.6, T.10 |
| 3 | 50 | T.2, T.5, T.8, T.13, T.15, T.18 |
| 4 | 60 | T.7, T.9, T.11, T.14, T.17, T.22, T.24 |
| 5 | 70 | T.3, T.16, T.18, T.20, T.23, T.26 |
| 6 | 80 | T.12, T.25, T.27 |
| 7 | 90 | T.21 |

*2.2 synthetic domestic wastewater*

The composition of synthetic domestic wastewater per liter was $CH_3COONH_3$ 240.88 g $KH_2PO_4$ 43.94 g, $Na_2HCO_3$ 125 g, $CaCl_2$ 10 g, $FeCl_2$ 0.375 g, $MnSO_4$ 0.038 g, $ZnSO_4$ 0.035 g, $MgSO_4$ 25.00 g, and yeast extract of 50 g [13]. The synthetic wastewater showed that temperature, pH, suspended solids, chemical oxygen demand (COD), biochemical oxygen demand (BOD), total kjeldahl nitrogen (TKN), ammonia nitrogen($NH_3$-N), nitrite nitrogen ($NO_2$-N), nitrate nitrogen ($NO_3$-N) and phosphate ($PO_4^-$) were 25-27ºC, 7.21 ± 0.06, 0.0052 ± 0.0008 mg/l, 213 ± 13.06 mg/l, 131.71 ± 3.39 mg/l, 46.6511±0.4129 mg/l, 35.0844 ± 0.2789 mg/l, 0.0426 ± 0.0061 mg/l, 1.2831 ± 0.0310 mg/l, and 5.47 ± 0.0769 mg/l, respectively . The synthetic domestic wastewater was fed to each treatment and calculated from:

$$\text{Influent of synthetic domestic wastewater (liter) [14]} = \frac{\text{Volume of space in the media (each treatment)}}{\text{Hydraulic retention time (days)}}$$

*2.3 experimental methods*

To begin an experiment, synthetic domestic wastewater was diluted to 10% with tap water, and increased daily by 10% of synthetic domestic wastewater until it reached 100% on day 10. Thereafter, influent and effluent samples were collected every 5 days and analyzed for: temperature, pH , suspended solids, BOD, COD, TKN, $NH_3$-N, $NO_2$-N, $NO_3$-N and $PO_4^-$, amounts of ammonia-oxidizing bacteria, nitrite-oxidizing bacteria, and denitrifying bacteria in influent and effluent wastewater were analyzed at the beginning and end of an experiment [15]. All parameter had 3 replicate.

*2.4 Statistical analysis*

Percentage, means and standard deviation were determined for all parameters for the entire study period. Simple linear regression analysis was applied to investigate factors media depths, nitrifying bacteria and denitrifying bacteria, and the efficiency of nitrogen removal.

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## 3. Results and Discussion

*3.1 Efficiency of nitrogen removal with difference of media depths*

The average influent nitrogen concentration in the form of $NH_4$–N and TKN were 35.0844 ± 0.2789 mg/l and 46.6511±0.4129 mg/l. At HRT of 4days, 30cm of media depth (T.1) showed the lowest $NH_3$-N and TKN removal efficiency of 51.91% and 53.32%. 40cm of media depth (T.4, T.6 and T.10) $NH_3$-N and TKN removal efficiency were (58.52, 60.25%), (58.38, 60.45%) and (60.99, 62.21%), respectively. 50 cm. of media depth (T.2, T.5, T.8, T.13, T.15 and T.19) $NH_3$-N and TKN removal efficiency were (62.11, 63.00%), (62.69, 64.44%), (63.56, 63.97%), (64.39, 64.98%) and (64.96, 65.38%), respectively. The highest efficiency of $NH_3$-N and TKN removal efficiency was 90 cm. of media depth (T.21) were 76.46 and 77.35%. Treatment performances of the VSF CW were summarized in Fig. 3.

From the experiment, we can conclude that efficiency of nitrogen removal is related directly to the media depths. The deeper media depths show higher efficiency of nitrogen removal. This is consistent with the study on the removal of swine wastewater by the VSF CW that have 4 different media depths of 40, 60, 80 and 100 cm., which was found that when increasing the depth of the media in the VSF CW, the efficiency in swine wastewater was also increased [16].

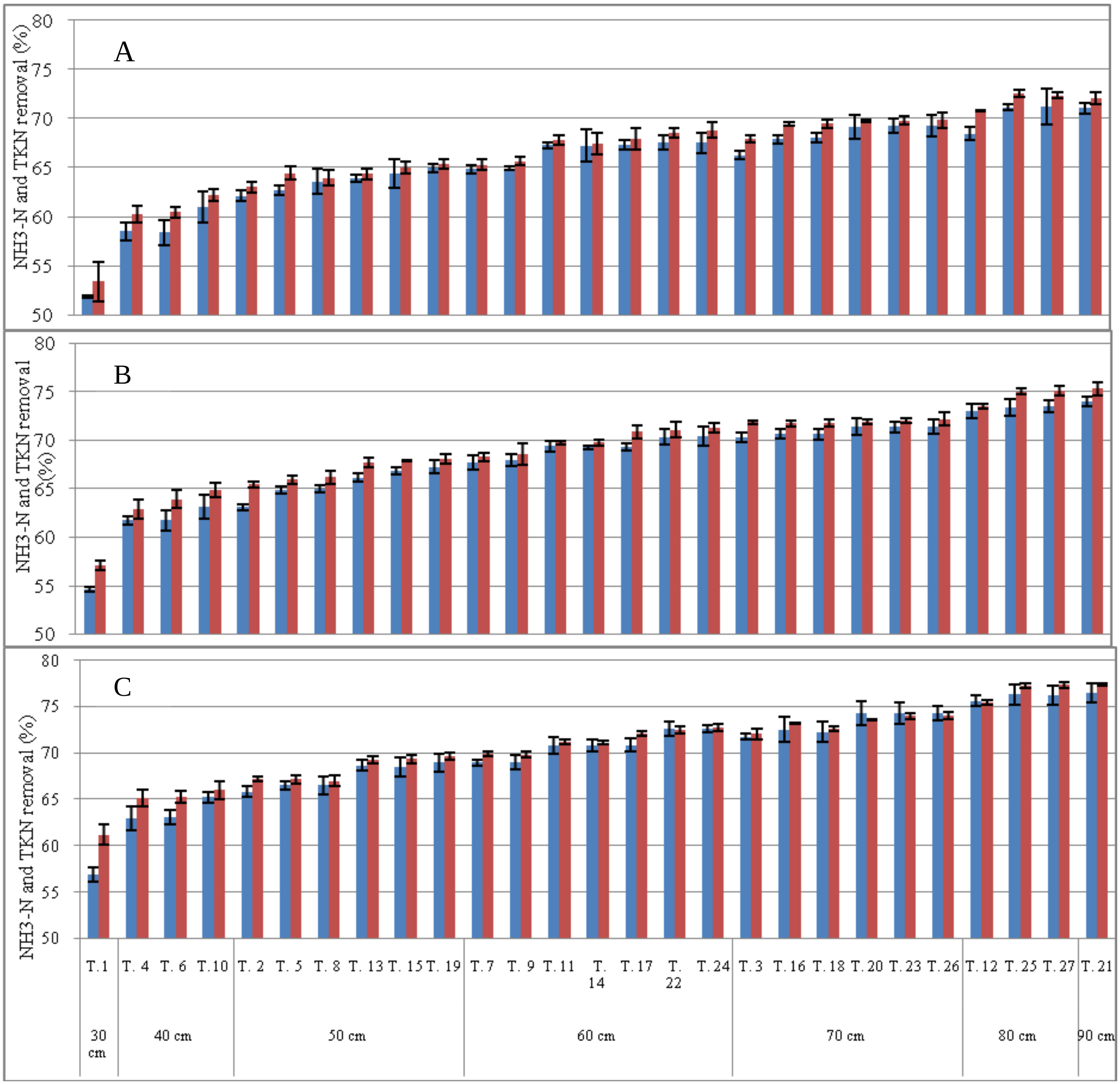


Fig. 3. Efficiency of $NH_3$-N and TKN removal in the treatments with 3 HRT: A = HRT of 4 days, B = HRT of 6 days,

C = HRT of 8 days. , were $NH_3$N and TKN Removal (%), respectively and 30 cm,40 cm, 50 cm, 60 cm, 70 cm, 80 cm and 90 cm were bed depth.

*3.2 amount of nitrifying bacteria and denitrifying bacteria with media depths*

The average of ammonia-oxidizing bacteria, nitrite-oxidizing bacteria, and denitrifying bacteria with 3 HRT at the beginning of experiment were $3.17x10^3 \pm 803$ CFU, $2.65x10^3 \pm 573$ CFU and $1.83x10^3 \pm 258$ CFU, respectively. At the end of experiment, the result showed that the HRT of 4days, 30 cm. of media depth (T.1) showed the lowest amount of ammonia-oxidizing bacteria, nitrite-oxidizing bacteria, and

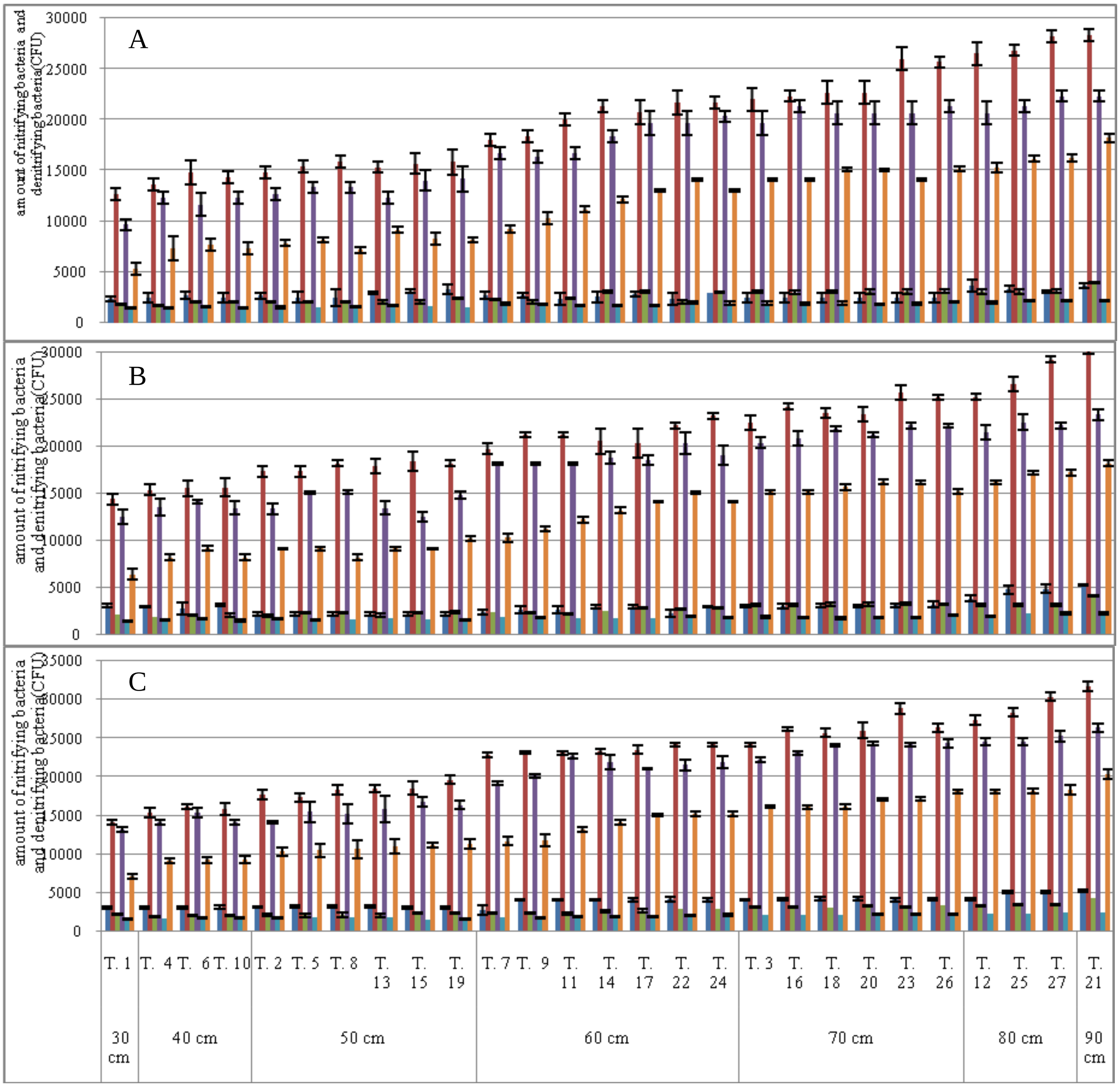


Fig. 4. The amount of ammonia-oxidizing bacteria, nitrite-oxidizing bacteria and denitrifying bacteria with 3 HRT:

A = HRT of 4 days, B = HRT of 6 days, C = HRT of 8 days and 30 cm,40 cm, 50 cm, 60 cm, 70 cm, 80 cm and 90 cm were bed depths. ■, ■ were ammonia-oxidizing bacteria at the first day and the last day. ■, ■ were nitrite-oxidizing bacteria at the first day and the last day. ■, ■ were ammonia-oxidizing bacteria at the first day and the last day.

denitrifying bacteria were $1.26x10^4 \pm$ 289 CFU, $9.66x10^4 \pm$ 577 CFU and 5.33 $x10^4 \pm$ 577 CFU, respectively. 40 cm. of media depth (T.4, T.6 and T.10) showed the amount of ammonia-oxidizing bacteria, nitrite-oxidizing bacteria and denitrifying bacteria were ($1.36x10^4 \pm$ 577 CFU, $1.23x10^4 \pm$ 577 CFU and 7.33 $x10^3 \pm$ 1154 CFU), ($1.48x10^4 \pm$ 289 CFU, $1.16x10^4 \pm$ 577 CFU and 7.66 $x10^4 \pm$ 577 CFU), ($1.43x10^4 \pm$ 577 CFU, $1.23x10^4 \pm$ 577 CFU and 7.33 $x10^4 \pm$ 577 CFU), respectively. The highest amount of ammonia-oxidizing bacteria, nitrite-oxidizing bacteria and denitrifying bacteria was 90 cm., and the media depth (T.21) were $2.83x10^4 \pm$ 577 CFU, $2.23x10^4 \pm$ 543CFU and 1.82 $x10^4 \pm$104 CFU, respectively. The amount of ammonia-oxidizing bacteria, nitrite-oxidizing bacteria and denitrifying bacteria were summarized in Fig. 4

The results showed that ammonia-oxidizing bacteria, nitrite-oxidizing bacteria and denitrifying bacteria related directly with media depths. The deeper media depths show higher amount of ammonia-oxidizing bacteria, nitrite-oxidizing bacteria and denitrifying bacteria. Some references recommend that nitrifying bacteria and denitrifying bacteria increased because the appropriate conditions for nitrifying and denitrifying bacterial growth such as 25-35 °C of temperature, 7.0 - 8.6 of pH, oxygen demand >1 mg/l for nitrification[17-20]. For this experiment, the conditions were 25-33 °C of temperature, 7.0 - 80 of pH, oxygen demand of influent (synthetic domestic wastewater) >1 mg/l was in rang of the nitrifying bacteria and denitrifying bacteria growth.

*3.3 relationships among the difference of media depth in the VSF CW, nitrifying bacteria and denitrifying bacteria, and efficiency of nitrogen removal*

The media depth has an important role in the VSF CW of nitrogen removal. The deeper media depths promote more surface area available where nitrifying bacteria and denitrifying bacteria attach themselves to the surfaces [21]. When nitrogen becomes trapped in the pores of the media, chemical treatment also takes place as a reaction in the media. From the data, media depths, nitrifying bacteria and denitrifying bacteria were positively related to the efficiency of nitrogen removal ($p < 0.05$).

*3.4 efficiency of nitrogen removal at the difference of hydraulic retention time*

When the hydraulic retention time increases, the efficiency of nitrogen removal was increased. For example, at hydraulic retention time of 4 Days, T.21 has the efficiency of TKN removal of 73.38%, and at hydraulic retention time of 6 Days and 8 days, the efficiency of TKN removal increases to 76.25 and 77.35%, respectively. The increasing of hydraulic retention time helps increasing the time and completing of the nitrification and denitrification, hydraulic retention time, which also plays a critical role in nitrogen removal efficiency. Nitrogen removal in constructed wetlands requires a long HRT. Accordingly, the VSF CW with HRT of 8 days is required being recommended as optimal [22].

## 4. Conclusions

The VSF CW with 90 cm. of bed depth showed the most effective TKN and $NH_3$-N removal at 77.35% and 76.46%, respectively. When the hydraulic retention time increases, the efficiency of nitrogen removal increases. The media depths in the VSF CW, the mount of nitrifying bacteria and denitrifying bacteria were positively related to the efficiency of nitrogen removal. The VSF CW that has media depths of 70, 80 and 90 cm. (T.3, T.16, T.18, T.20, T.23, T.26, T.12, T.25, T.27 and T.21) can remove total nitrogen in the effluent standards [23].

## Acknowledgements

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