STUDY ON DECENTRALIZED DOMESTIC WASTEWATER TREATMENT BY CONSTRUCTED WETLAND VERTICAL - SUBSURFACE FLOW SYSTEM FOR SMALL COMMUNITIES

Phong Nguyen Tan[1] and Phuong Tieu Vu[1]

[1] Department of Environmental Engineering, Ho Chi Minh City University of Technology, Ho Chi Minh City, Vietnam, Tel: +84-8-38639682, e-mail: tanphong69@yahoo.com, abcphh2002@yahoo.com

Received Date: July 11, 2011

Abstract

This research investigated the feasibility of using constructed wetland system with vertical - subsurface flow (VF-SFS) for treating the decentralized domestic wastewater for household and small community. The pilot studied on three beds included three macrophytes tested parallel reed, vetiver and bulrush with four different hydraulic application rates (176, 132, 88 and 44 mm/ day).This study was tested with six different parameters such as biochemical oxygen demand (BOD), total suspended solids (TSS), orthophosphate (PO43-), ionized ammonia (NH4+) and nitrate (NO3-) nitrogen and total coliform loadings. The removal rate of characteristic parameters was obtained: BOD5 96%, TSS 96.9%, N-NH4+ 60.5%, PO43- 47.6%, total coliform 97.7%, respectively. In particular, the highest removal efficiency was obtained in the bed with the longer hydraulic retention time. Simultaneously, there was no removal difference among 03 beds constructed wetland with 03 different plant species, significantly. Through the results of research, VF-SFS can be considered an appropriate treatment method for domestic wastewater; however the additional pre-treatments were necessary to remove grit, heavy solids and floating scum.

Keywords: Constructed wetland, Domestic wastewater, Vertical subsurface

Introduction

Wetland is an area of land containing water in regularly saturated or sub-saturated form. In nature, wetlands present in hollow land where eliminate plant species dependent upon aerobic soil conditions such as flood field, marsh, pond [11].

Constructed wetlands are systems designed and constructed as natural wetlands but altered by the hydrology conditions such as hydraulic mode, saturated soil conditions as well as by plant in order to enhance capacity of control, operation and treatment [11].

Constructed wetland types can be classified into 02 main groups: Free surface flow wetland system (FWS); sub surface flow wetland system (SFS) with horizontal flow (HF) or vertical flow (VF). Design of FWS consists of bed material where plant root can hold on, grow and the wastewater flows through this material. Plants are usually of the emergent species in this system to create a plug-flow hydraulic mode. In SFS systems, the filter material consists of some layers such as stone 1x2 cm, gravel and sand where the plants root (reed, vetiver and bulrush) grows [9]. Moreover, these filling media help mechanize restrain and adsorb pollutants during treatment process.

Constructed wetlands can be considered as a method which has high applied potential for treatment of septic effluents in rural areas and small communities. This is due to its outstanding advantages compared to the conventional treatment systems such as on-site treatment, high treatment efficiency, low cost of investment, construction, operation and maintenance and environmentally friendliness. In addition, in the case of, vertical subsurface flow, this type tends to be simple, high treatment efficiency, good ventilation condition. It does not emit odour or noise, and runs stably with small fluctuation of effluent wastewater quality [5].

The basic removal processes in constructed wetland are settling, filtration, precipitation, chemical absorption, and pollutant absorption by plants. Most physical, chemical, and biological processes in constructed wetlands occur in the filter media and in the plants roots where microorganisms forms biological films and uses oxygen supplied from the plant's rhizomes, roots, and rootlets [1]. During biological decomposition, the organic matter serves as substrate for the microorganisms thereby eliminating BOD while nitrification and subsequent de-nitrification removes nitrogen and releases nitrogen gas into the atmosphere. Phosphorus is removed via absorption, settling and co-precipitation with ubiquitous materials in wetlands such as iron, aluminium, and calcium compounds [2][3].

The aim of this study is to assess the response behaviour of applying constructed wetland – vertical flow for treating decentralized domestic wastewater in rural areas and small communities which features high treatment efficiency and low capital and operating cost.

Methods

The Experimental Site

A pilot scale constructed wetland system was built in the laboratory department of Faculty of Environment, University of Technology, Ho Chi Minh City, Vietnam. Ho Chi Minh City has a tropical climate and two distinct seasons. During the rainy season, the average annual rainfall is about 1,800 millimetres (approximately 150 rainy days per year), from May to late November and the dry season begins from December to April. With an average humidity of 75%, temperatures range from 16^0C (61 °F) to 39 °C (102 °F) with an average temperature of 28 °C (82 °F).

The pilot consisted of three beds planted with three macrophytes and configured in parallel i.e., reed, vetiver and bulrush. The beds were run with different hydraulic application rates (HAR) of 44 (run 1), 88 (run 2), 132 (run 3) and 176 (run 4) mm/day and hydraulic retention times (HRT) of 8, 4, 3 and 2 days, respectively). The operating parameters are shown in Table 1. The surface area of each bed was $0.48m^2$ calculated by the formula: surface area = flow/ HAR [7], the ratio of length and width was 3:1 and the depth of each bed was 0.7m. Filter media layers of each bed were distributed equally the top layer is fine sand (1-2mm in size) having a depth of 25cm; the next layer is round gravel (5-10mm size) with a depth of 10cm; the bottom layer is stone (1x2 cm in size) with depth of 15cm (Figure 1.). Influent was distributed regularly through a distribution system (perforated PVC pipes, 21mm diameter). The wastewater was allowed to flow slowly through the filter layers and roots of treatment plants and was collected by filtered PVC pipe systems, 42mm diameter distributed at the tank bottom. The water level in the tank was maintained at 20 cm below the free water surface, to avoid flooding of the macrophytes and also facilitate oxygen supply the wetland system.

For ventilation, this wetland system used hollow pipes to collect the effluent and vented to the atmosphere. These are vertical pipes extending to 20 cm to 40 cm above the surface. This scheme supplied oxygen for the oxidation and nitrification processes, enhanced removal of nutrient and organic components, and reduces the pressure of water inside the tank. In addition, the operation of the pump distributing the wastewater is semi-continuous operating for three hours then idle for another three before the next cycle. Effecting both nitrification and de-nitrification process to occurs simultaneously and continuously. The operation mode enhances nitrogen removal in wastewater, and save energy in pump operation.

Table 1. Operating Parameters of Beds

Bed	Plant Species	Retention Time (days)	Flow (litre day $^{-1}$)	Hydraulic Application Rate (mm day $^{-1}$)
Bed 1	Vetiver	8	21	44
		4	42	88
		3	63	132
		2	84	176
Bed 2	Bulrush	8	21	44
		4	42	88
		3	63	132
		2	84	176
Bed 3	Reed	8	21	44
		4	42	88
		3	63	132
		2	84	176

Decentralized domestic wastewater from household and small community was used for the influent of each bed. The volume and flow rate of the influent was controlled daily by measuring pump and timer. Simultaneously, a flow regulating valve of the effluent was used to avoid flooding for macrophytes. Sample for analysis were taken from the effluent from each of the beds including one from the input sample common to three beds. The physical and chemical characteristics of the domestic wastewater utilized and effluent standard are shown in Table 2.

Sowing

Young macrophytes such as reed, vetiver and bulrush were collected from nursery gardens or natural marshes, and cut to a length of about 30 cm including stem and rhizome and grown in the each bed. The density of macrophytes was maintained at about 20 plants/m^2. After sowing, the plants were irrigated with fresh water to ensure their rhizome can acclimate to the new environment. After 20 – 30 days, fresh water was replaced by synthetic water, to supply nutrients to macrophytes. One month after that, the synthetic water was replaced by wastewater that was mainly used for the period of experiment. After the first two months of experiment, both reed and vetiver showed the best survival and adaptation as shown by rapid growth of their leaves and stems. On the other hand, bulrush showed less vigor and was growing poorly and at a slower rate.

Experimental Set-Up

Sampling and analysis began in December-2010, 2 months after sowing, and continued until the end of May-2011. Samples were taken from the influent and effluent from each bed thrice every week in each bed, over a 6-month period. Samples were analyzed to determine the removal efficiency of BOD, TSS, PO_4^{3-}, NH^+_4, NO_3^- and total coliform. All samples were stored and analyzed in accordance with the Standard Methods for Examination of Water and Wastewater. Schematic diagram and actual experimental set-up of a constructed wetland unit used in experiment are shown in Figure 1 and Figure 2.

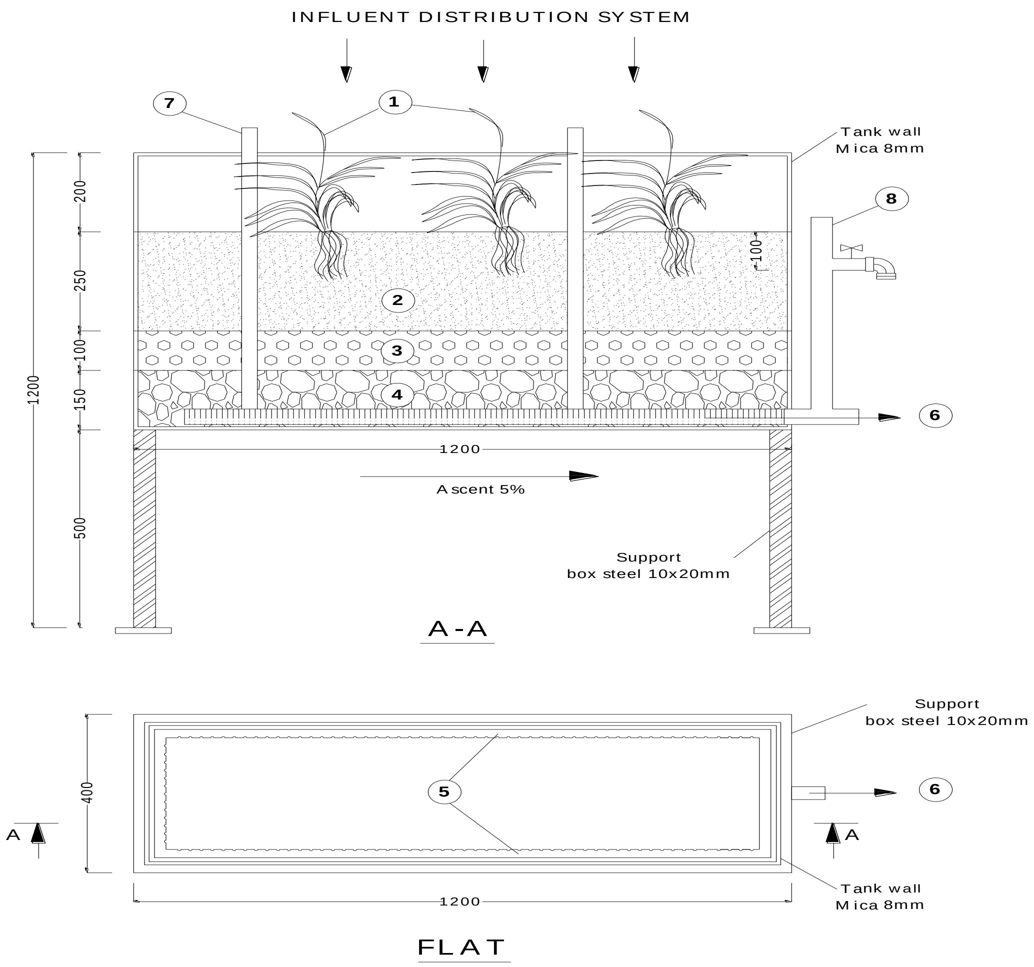

Figure 1. Schematic diagram of a typical constructed wetland unit

(1) Treatment Plant (2) Fine Sand (3) Round Gravel/ Broken Brick (4) Stone 1x2cm (5) Influent Distribution System (6) Effluent Collection System (7) Ventilation System (8) Water Level Maintaining System

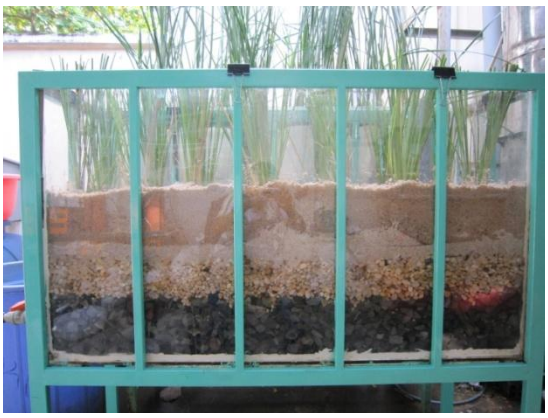

Figure 2. Actual experimental set up of constructed wetland unit

Table 2. Influent Wastewater Properties and Effluent Standard

No.	Parameters	Unit	Influent Concentrations	Effluent Standard QCVN 14-2008/BTNMT(1), Level B	Level A
1	pH	–	7.2 – 7.8	5 - 9	5 - 9
2	BOD_5 (20 ^{0}C)	mg/l	120 - 170	50	30
3	TSS	mg/l	100 - 150	100	50
4	$N\text{-}NH_4^+$	mg/l	55 - 65	10	5
5	$N\text{-}NO_3^-$	mg/l	0.15 – 1.40	50	30
6	PO_4^{3-}	mg/l	9 - 18	10	6
7	Total Coliform	MPN/100 ml	$1x10^6$ - $15\ x10^8$	5,000	3,000

(1) Effluent standard for domestic wastewater in Vietnam. Level A: Apply for water supply purpose; level B: Not apply for water supply purpose.

Results and Discussions

Removal Efficiency of BOD_5

Figure 3 showed that the BOD_5 removal efficiency of 3 plants species under different organic loading was rather high from 82.6 – 96.0%, the effluent concentration of BOD_5 was very low from 3.5 – 21.4 mg/l that lower than the permitted effluent standard - QCVN 14-2008/BTNMT – level A.

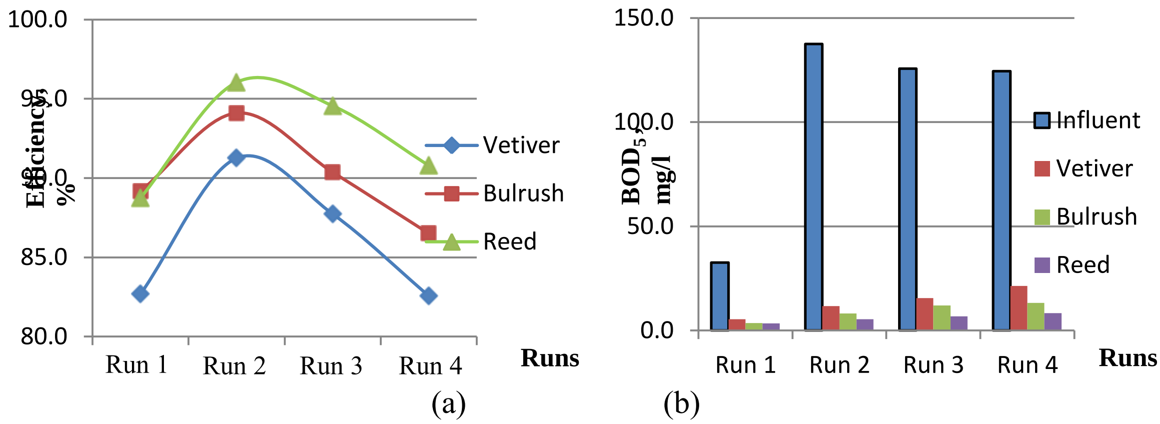

Figure 3. (a) Average BOD_5 Removal Efficiency in Different Loading (b) Average BOD_5 Influent and Effluent Concentration

The efficiency of run 2 was the highest and reed was higher than vetiver and bulrush. The reason was the capability for root – zone oxygen release of reed higher than other macrophytes [6], [12]. The removal efficiency of BOD_5 is lower at higher application rates this is due to increasing of organic loading rate, so that the biodegradable matter could not completely remove because of time constraint and microorganism density limit.

Removal Efficiency of TSS

As shown in Figure 4 the TSS efficiency was generally very high from 86.8 – 96.9% and effluent concentration was from 2.55 – 8.31 mg/l. These concentrations were much lower than QCVN 14-2008/BTNMT – level A. The removal efficiency of TSS is lower at higher application rates this is due to increasing of TSS loading rate, so that the suspended solid could clog up the filtering capacity of the layers in constructed wetland. The removal efficiency of bulrush and reed was higher than vetiver in run 2 with 96.9% and 96.8%, respectively.

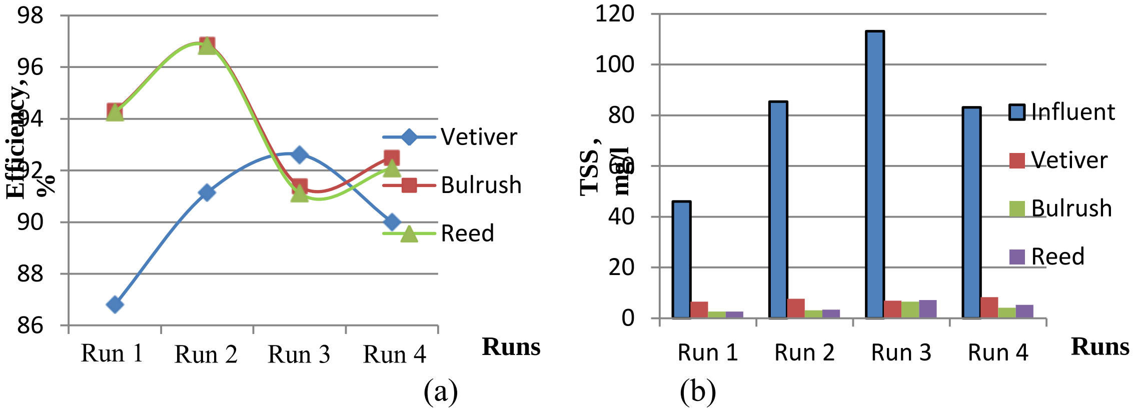

Figure 4. (a) Average TSS Removal Efficiency in Different Loading (b) Average TSSInfluent and Effluent Concentration

Removal Efficiency of NH_4^+- N

As shown in Figure 5 the NH4+ - N removal efficiency in this study was relatively low and there was no much difference among three plant species. Efficiency of reed was the highest in run 1 (60.5%) and run 2 (55.2%). The pilots show the decreasing efficiency in run 3 and run 4. This was probably because the capability of oxygen diffusion inside pilots was reduced by the accumulation of the suspended solids or strong development of biofilm [4]. Effluent concentration of NH4+ - N was rather high from 11.4 – 47.5 mg/l that exceeds QCVN 14-2008/BTNMT – level B.

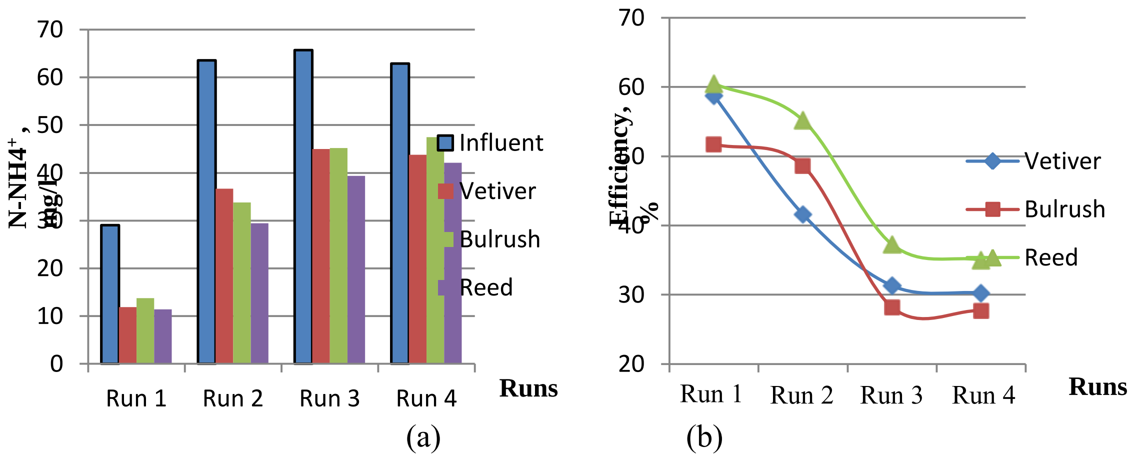

Figure 5. (a) Average Influent and Effluent Concentration of NH_4^+ - N (b) Average Removal Efficiency of NH_4^+ - N in Different Loading

Removal Efficiency of PO_4^{3-}

Figure 6 showed that as in the case of NH_4^+-N the PO_4^{3-} efficiency in the study was relatively low and there was no much difference among three wetland plants. Average efficiency was from 30.1 - 47.6%, efficiency of reed was the highest in run 2 with effluent concentration of 6.32 mg/l. Generally, effluent concentration of PO_4^{3-} was lower than QCVN 14-2008/BTNMT – level B, specially, run 1 was lower than level A. However, influent concentration of the wastewater was relatively low.

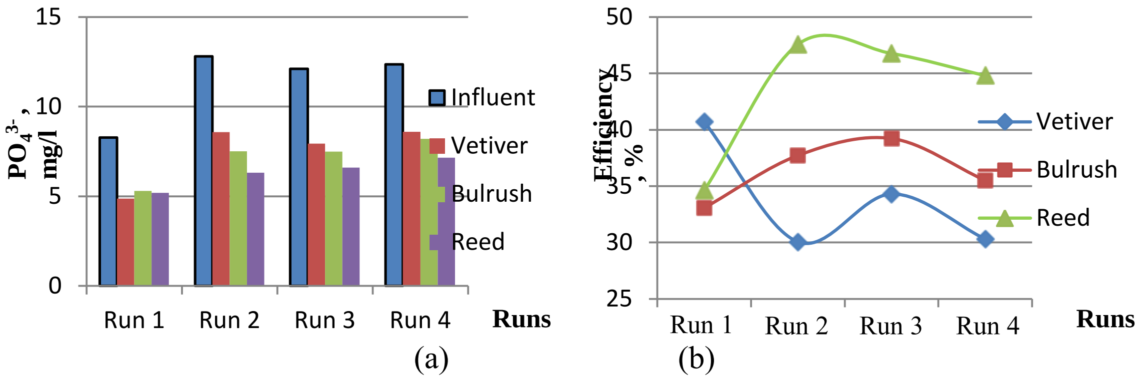

Figure 6. (a) Average Concentration of PO_4^{3-} (b) Average Removal Efficiency of PO_4^{3-} in Different Loading

Removal Efficiency of $N\text{-}NO_3^-$

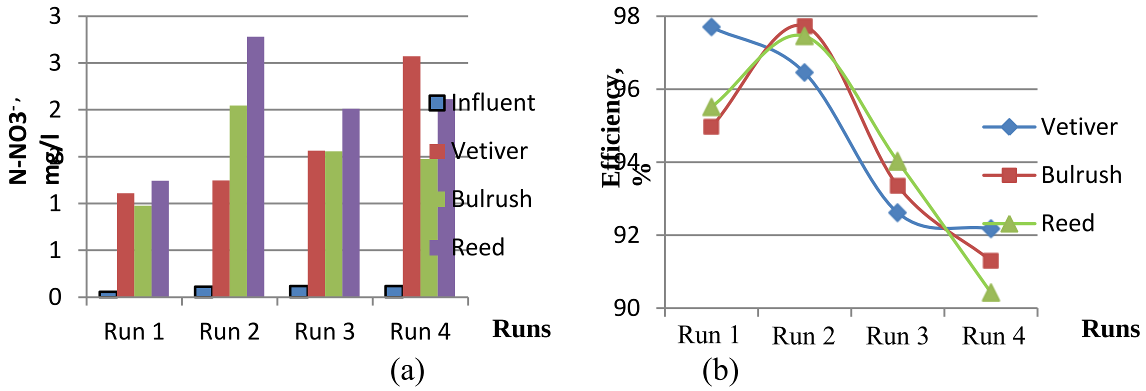

Figure 7. (a) Average Concentration of NO_3^- (b) Average Removal Efficiency of NO_3^- in Different Loading

Nitrate nitrogen concentration was much higher than the influent. This can be explained that nitrate nitrogen was produced by nitrification process. In the other hand, effluent concentration of NO_3^- in the study loading was relatively low from 0.977 – 2.572 mg/l and much lower than QCVN 14-2008/BTNMT – level A (Figure 7(a).). It is shown that de-nitrification process in pilot constructed wetland occurred completely.

Removal Efficiency of Total Coliform

Since the hydraulic retention time was long from 2 – 8 days so the removal efficiency of T. coliform was rather high from 91.3% – 97.73% (Figure 7(b).). Like the other parameters, there was not much difference among the three wetland plants, the highest efficiency being in run 1 and, run 2. However, the influent concentration of T. coliform was very high ($14.9x10^5$) so that the effluent concentration ($21.1x10^3$) still exceeded QCVN 14-2008/BTNMT – level B standard.

Conclusions

From results obtained, the following conclusions can be made:

- The highest removal efficiency was obtained in run 2 with the longer HRT (4 days) and smaller HAR ($88mmday^{-1}$). This result shows that we can be improve removal efficiency of pilot by increasing the HRT.
- High removal efficiency was attained for both physicochemical and microbiological parameters in each bed, while no significant was observed among macrophytes (vetiver, bulrush, and reed). This emphasized the special relationships between physicochemical (such as filter, settle and absorption) and microbial process (such as organic oxidation, nitrification and denitrification).
- Based on the studying results, both physicochemical and microbiological parameters are almost removed effectively within the environmental standard, except for $N\text{-}NH_4^+$ and total coliform. Therefore, it is necessary to apply additional enhanced methods for oxygen diffusion and treatment capability of coliform by direct sunlight or longer hydraulic retention time [4].
- The results have shown that VF - SFS was high potential for constructing efficient, low cost and environmental friendly wastewater treatment system in future. This system is easy to apply for treating domestic wastewater in residential areas were large lands are available.

References

[1] R. Bhamidimarri, A. Shilton, I. Armstrong, P. Jacobsen, and D. Scarlet, “Constructed wetlands for wastewater treatment: the New Zealand experience,” *Water Science and Technology*, Vol. 24, No. 5, pp. 247-253, 1991.

[2] K.H. Bowmer, “Nutrient removal from effluents by an artificial wetland: influence of rhizosphere aeration and preferential flow studied using bromide and dye tracers,” *Water Research,* Vol. 21, No. 5, pp. 591-599, 1987.

[3] D.A. Hammer, ed., “Danish experience with sewage treatment in constructed wetlands,” *Constructed Wetlands for Wastewater Treatment*, Lewis Publishers, Chelsea, Michigan, pp. 565–573, 1989.

[4] P.L.R. Diederik, A.V. Peter, and D.P. Niels, “Constructed wetlands in Flanders: a performance analysis,” *Ecological Engineering*, Vol. 23, No. 3, pp.151-163, 2004.

[5] M. Fabio, and M. Nicola, “Constructed wetlands for the Mediterranean countries: Hybrid systems for water reuse and sustainable sanitation,” *Desalination*, Vol. 215, pp. 44-55, 2007.

[6] R.M. Gersberg, B.V. Elkins, S.R. Lyon, and C.R. Goldman, “Role of aquatic plants in wastewater treatment by artificial wetlands,” *Water Research*, Vol. 20, No. 3, pp. 363-368, 1986.

[7] K.G. Gilbert, C. Shulin, E.B. Michael, and O.S. Claudio, “Combinations of horizontal and vertical flow constructed wetlands to improve nitrogen removal,” *Water Air Soil Pollution*: *Focus*, Vol. 9, No. 3-4, pp. 279-286, 2009.

[8] B. Hans, and A.A. Carlos, “The use of vertical flow constructed wetlands for on-site treatment of domestic wastewater: New Danish guidelines,” *Ecological Engineering*, Vol. 25, No. 5, pp. 491–500, 2005.

[9] United States Environmental Protection Agency (EPA), *Manual Constructed Wetlands Treatment of Municipal Wastewaters*, National Risk Management Research Laboratory Office of Research and Development, Cincinnati, Ohio, United States, 1999.
[10] M.L. Solano, P. Soriano, and M.P. Ciria, “Constructed wetlands as a sustainable solution for wastewater treatment in small villages,” *Biosystems Engineering*, Vol. 87, No. 1, pp.109-118, 2004.
[11] R.C. Smith, K.S. Baker, M.L. Byers, and S.E. Stammerjohn, “Primary productivity of the palmer long term ecological research area and the southern ocean,” *Journal of Marine System*, Vol.17, No. 1-4, pp. 245-259, 1998.
[12] C.C. Tanner, “Plants for constructed wetland treatment systems a comparison of the growth and nutrient uptake of eight emergent species,” *Ecological Engineering*, Vol.7, No. 1, pp. 59-83, 1996.