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Comparison of Experimental Measurement and Simulated Model of Ammonia Nitrogen Removal by the Vertical Subsurface Flow Constructed Wetland

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Abstract:*The pilot scale experiment was conducted to study the efficiency of ammonia nitrogen removal by the Vertical Subsurface Flow Constructed Wetlands (VSF CW) and model of the ammonia nitrogen removal by using computer software. There were three media layers inside VSF CW: 1) the bottom layer was filled with gravel (3-6 cm in diameter), 2) the middle layer was filled with small gravel (1-2 cm in diameter) and 3) the top layer was filled with coarse sand (0.1-0.2 cm in diameter). Three types of media were arranged into three treatments: VSF CW1 contained bed depths of 10, 10 and 10 cm; VSF CW2 contained bed depths of 20, 20 and 20 cm; and VSF CW3 contained bed depths of 30, 30 and 30 cm. The synthetic domestic wastewater was loaded into VSF CW1, 2 and 3 every 24 hours at 0.28 l/day, 0.59 l/day and 0.915 l/day, respectively (Hydraulic Retention Times of 8 days). The HYDRUS-2D software was applied to model the effluent of flow rate, while CW2D module was used to model the removal processes of ammonia nitrogen in VSF CW1, 2 and 3. The results showed VSF CW3 had a high efficiency for ammonia nitrogen removal. The simulation model results also showed a good match with the experimental measured result of ammonia nitrogen removal processes.*
Keywords:*HYDRUS-2D, CW2D module, Media depth, Vertical Subsurface Flow Constructed Wetlands*.

I. Introduction

Constructed wetlands are an integration of Science and Engineering systems that are designed to treat wastewater by using natural processes [1]. They have been widely used to treat many types of wastewater such as domestic wastewater [2], industrial wastewater [3], tannery wastewater [4], acid mine drainage [5] and landfill leachate [6]. Generally, constructed wetlands are divided into two types: surface flow constructed wetlands and subsurface flow constructed wetlands. The subsurface flow constructed wetland is further divided into two sub-types, which include the Horizontal Subsurface Flow Constructed Wetland (HSF CW) and the Vertical Subsurface Flow Constructed Wetland (VSF CW) [7].

According to the literature reviewed, VSF CW is widely used due to there are high efficiency of ammonium nitrogen removal. The composition of VSF CW consists of four major components including media, microorganisms, plants and hydraulic retention times (HRT). The media plays an important role in the efficiencies of ammonia nitrogen removal [8]. It is provide supportive base for microorganisms to attach, especially Ammonia-Oxidizing Bacteria (AOB), Nitrite-Oxidizing Bacteria (NOB) and Denitrifying Bacteria (DN), which can removal ammonia nitrogen by nitrification and denitrification processes [7].

However, ammonia nitrogen removal processes in media bed depths in VSF CW are often described as black boxes [9], where the interactions between media and microorganisms are not well known. The most widely used approaches and optimizations for VSF CW designs are based on empirical rules outlined from the experience of designers [10]. During the last few years, several numerical models have been developed as tools to get better understand of the ammonia nitrogen removal processes in VSF CW. HYDRUS-2D software and CW2D module were developed to model the degradation processes in VSF CW [11]. HYDRUS-2D was applied to describe the wastewater flow rate, while the CW2D was used to model the transformation and elimination processes of ammonia nitrogen removal [10]. In addition, CW2D was used to simulate of 12 parameters as dissolved oxygen (DO), readily biodegradable soluble COD (CR), slowly biodegradable soluble COD (CS), inert soluble COD (CI), ammonia nitrogen (NH_4-N), nitrite nitrogen (NO_2-N), nitrate nitrogen (NO_3-N), nitrogen gas (N_2), inorganic phosphorus, heterotrophic bacteria and ammonia-oxidizing bacteria (AOB), nitrite-oxidizing bacteria (NOB) [11].

As mentioned earlier, the usage of HYDRUS-2D software and the CW2D module can be used to design VSF CW easily. However, only a few research studies have been conducted to identify ammonia nitrogen removal by VSF CW with the different of media depths by using software computer.

Thus, the objectives of this experiment were 1) to comparethe experimental measurement and simulated model of ammonia nitrogen removal by VSF CW with the different of bed depth 2) to study the interactions between media depth with ammonia-oxidizing bacteria (AOB) and nitrite-oxidizing bacteria (NOB) in VSF CW by using HYDRUS-2D software and the CW2D module. This study will be useful for media bed depth usage selection in VSF CW, which can reduce construction cost and media cost as well as achieving high treatment efficiency. Moreover, the HYDRUS-2D software and CW2D module have been designed to predict the effluent concentration of ammonia nitrogen, which should not exceed the effluent standard of the domestic waste water treatment plant [12].

II. Materials and Methods

2.1. The VSF CW design

The experiment was conducted at a domestic wastewater treatment plant in Laemchabang City Municipality, Sriracha district, Chonburi, Thailand, on January 1 to February 10, 2012. The pilot-scale of VSF CW was constructed from poly vinyl chloride pipes with a diameter of 15.5 cm, as shown in Figure 1A. Inside the pipes contained three types of media: gravel (3-6 cm in diameter) at the bottom; small gravel (1-2 cm in diameter) in the middle layer and coarse sand (0.1-0.2 cm in diameter) in the top layer. Three types of media were arranged into three treatments: VSF CW1 contained bed depths of 10, 10 and 10 cm; VSF CW2 contained bed depths of 20, 20 and 20 cm; and VSF CW3 contained bed depths of 30, 30 and 30 cm [13], as shown in Figure 1B.

2.2. Synthetic domestic wastewater

This experiment used Synthetic Domestic Wastewater (SDWW) [14], due to the properties of real domestic wastewater samples that are often highly variable and very dynamic. These properties depends on the conditions of sample area and it may be change over time [15].

The characteristics of SDWW of 12 parameters were temperature, pH, suspended solids, chemical oxygen demand (COD), biochemical oxygen demand (BOD), total kjeldahl nitrogen (TKN), ammonia nitrogen(NH_4-N), nitrite nitrogen (NO_2-N), nitrate nitrogen (NO_3-N) and phosphate (PO_4-P) were 25-27ºC, 7.21 $\pm$ 0.01, 0.0052 ± 0.0008 mg/l, 213.15 ± 13.06 mg/l, 131.71 ± 3.39 mg/l, 46.65±0.41 mg/l, 35.08 ± 0.27 mg/l, 0.04 ± 0.61 mg/l, 1.28 ± 0.03 mg/l, and 5.47 ± 0.0769 mg/l, respectively [16].

The SDWW was loaded into VSF CW1, 2 and 3 that can calculated from: Influent of SDWW (litre) = volume of space area in the VSF CW (litre) / hydraulic retention time (days). Then SDWW was loaded into VSF CW1, 2 and 3 were 0.28 l/d, 0.59 l/d and 0.915 l/d, respectively (calculated from hydraulic retention times of 8 days) [13], [17].

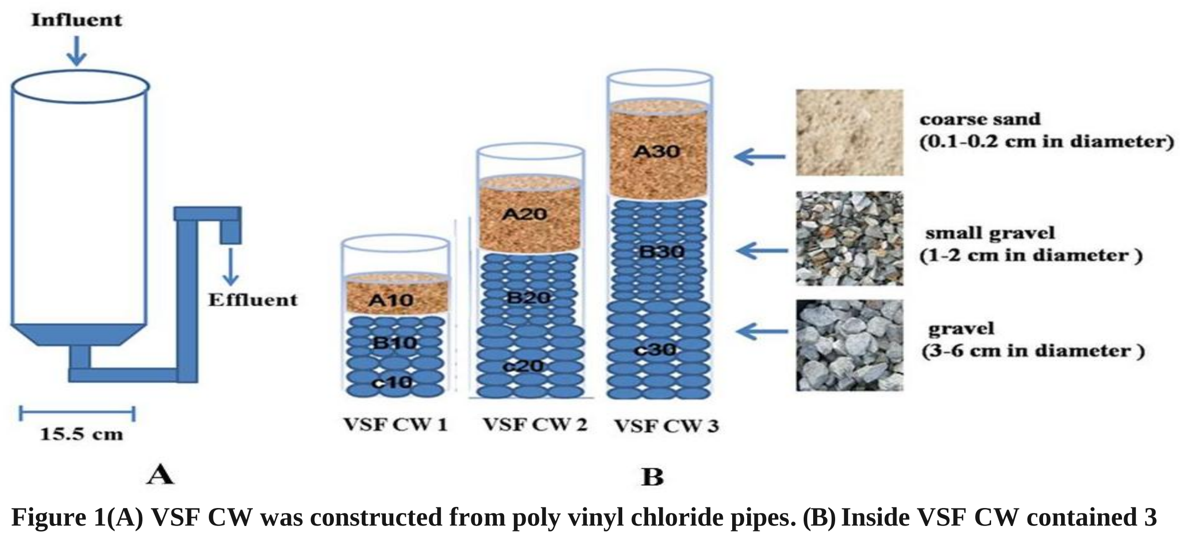

Figure 1(A) VSF CW was constructed from poly vinyl chloride pipes. (B) Inside VSF CW contained 3 types of media. A: coarse sand (0.1-0.2 cm in diameter), B: small gravel (1-2 cm in diameter), C: gravel (3-6 cm in diameter), and number 10, 20 and 30 are media depths (cm).

2.3 Measured of effluent flow rate

SDWW was loaded into VSF CW1, 2 and 3 (0.28 l/d, 0.59 l/d and 0.915 l/d, respectively). Then, collected the effluent of SDWW every minute and measured the volume by cylinder for 30 minutes.

2.4 Parameter and frequency in analyzing

The influent and effluent samples were collected every five days and analyzed for wastewater temperature, volume of influent wastewater, volume of effluent wastewater, suspended solid, pH, BOD, COD, TKN, NH_4-N, NO_2-N, NO_3-N and PO_4-P.

Amounts of ammonia-oxidizing bacteria (AOB)and nitrite-oxidizing bacteria (NOB) in influent and effluent wastewater were analyzed at the beginning and end of an experiment. The experiment period of this study was 30 days.

2.5 The model setup

The used of HYDRUS-2D software and the CW2D module have three steps as follow;

2.5.1 Step I: The 2D finite element meshes were generated for the calibration and simulations processes in this program [11], [18].

The 2D finite element of VSF CW1, 2 and 3 was generated into 30 rows and 15 columns (450 nodes), 60 rows and 15 columns (900 nodes) and 90 rows and 15 columns (1,350 nodes), respectively. On the top of all 2D finite element of VSF CW were set of an atmospheric boundary condition and at the bottom set of manually controlled by a throttle, as shown in Figure 2.

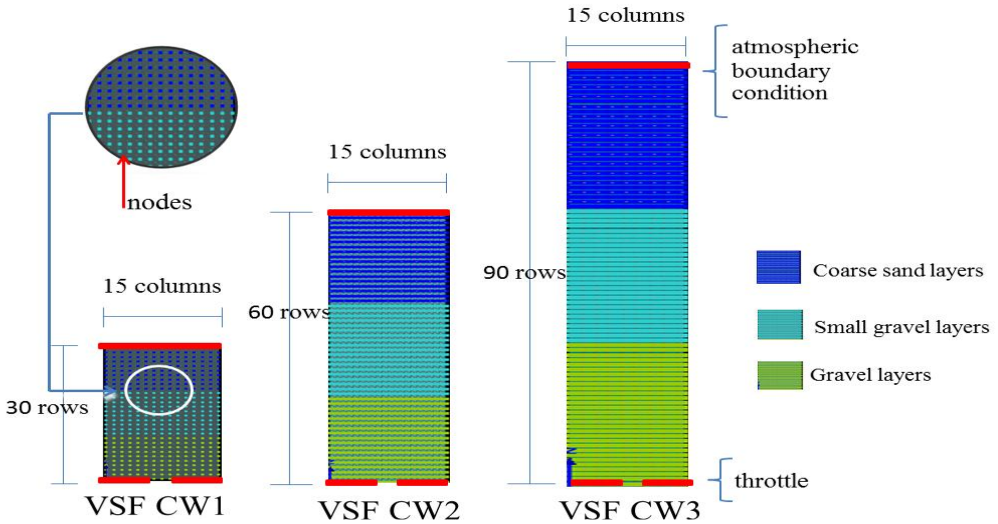

Figure 2 The 2D finite element mesh of VSFCW1,2 and 3were generated by HYDRUS-2D.

2.5.2 Step II: Calibration of effluent flow rate

The calibration of effluent flow rate model was used to set up a reactive transport simulation. This procedure was calibrated by comparing (1) the simulated effluent flow rate and (2) measured of effluent flow rate with hydrograph.

(1) The simulated effluent flow rate wasusing the van Genuchten–Mualem equations [19] implemented in HYDRUS-2D. The Soil hydraulic parameters for the van Genuchten–Mualem equations according to Carsel and Parrish (1988) [20], as show in Table 1.

(2) Measured of effluent flow rate (2.3 in Materials and Methods)

Table 1 Soil hydraulic parameters used in this experiment

Media in VSF CW	Soil hydraulic parameters				
	Residual water content (dm_w^3/dm_s^3)	Saturated water content (dm_w^3/dm_s^3)	Saturated hydraulic conductivity (m/h)	Empirical parameters	
				a (m_s^{-1})	N
Sand	0.045	0.43	712	0.145	2
Small gravel	0.050	0.23	3000	0.145	2.8
Gravel	0.056	0.15	6000	0.145	2.8

Source: Carsel and Parrish (1988)

From this step, (1) simulatedeffluent flow rate and (2) measured effluent flow rate were plotted to hydrograph. The soil hydraulic parameters for effluent flow were altered in an iterative process until a good match between simulated and measured effluent concentrations was archived. This procedure proposed for the evaluation of the quality of a model fit [21].The hydrograph of this experimental as shown in Figure 3.

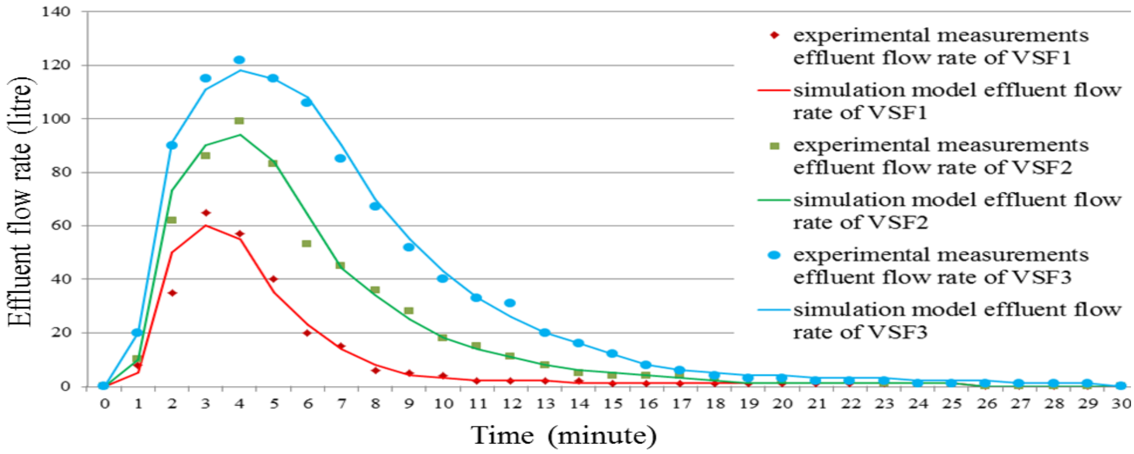

Figure 3 Hydrograph of experimental measurement and simulation model of effluent flow rates of VSF CW 1, 2 and 3.

Figure 3 shows the calibration of effluent flow rate model graph. It is shown that simulation and measurements of flow rate of SDWW were good matched. Then calibration of the effluent flow rate model acceptable results was achieved, the model can be used for simulating varying parameters as dissolved oxygen (DO), readily biodegradable soluble COD (CR), slowly biodegradable soluble COD (CS), inert soluble COD (CI), ammonia nitrogen (NH_4-N), nitrite nitrogen (NO_2-N), nitrate nitrogen (NO_3-N), nitrogen gas (N_2), inorganic phosphorus(PO_4-P), and ammonia-oxidization bacteria (AOB), nitrite-oxidizing bacteria (NOB) [22].

2.5.3 Step III: Simulated process; after calibrating effluent flow rate, the influent concentrations of ammonia nitrogen were input in CW2D for running program.

III. Results

3.1 Comparison of experimental measurement and simulated model of ammonia nitrogen removal by VSF CW with the different of bed depth.

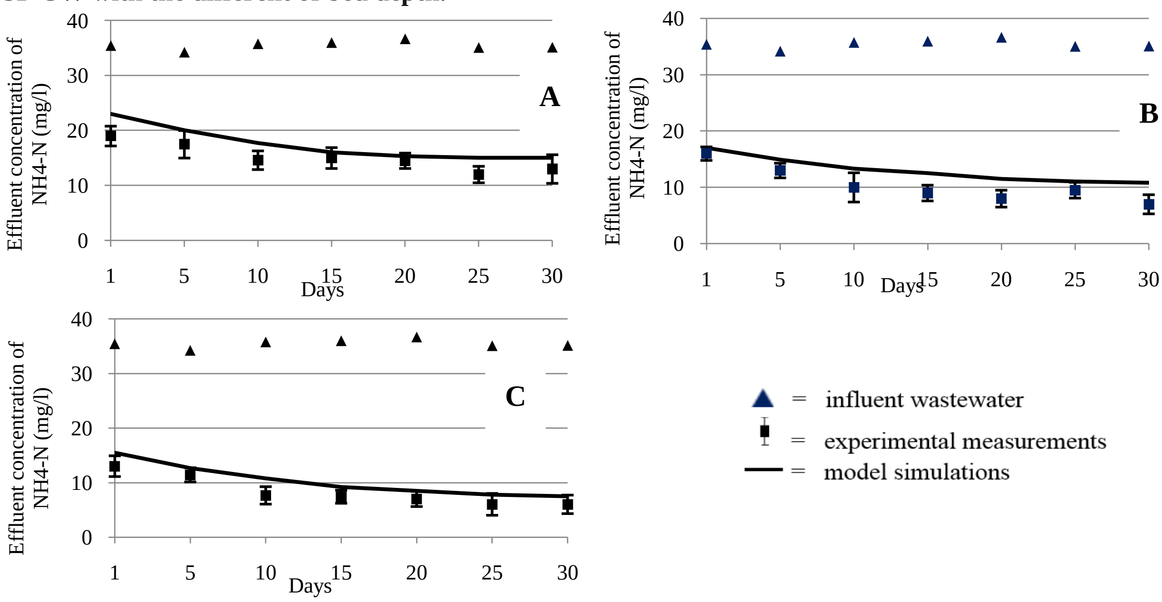

Figure 4 Effluent concentrations of ammonia nitrogen removal by VSF CW1 (A), VSF CW 2 (B) and VSF CW3 (C).

In Figure4, the average influent concentration of ammonia nitrogen in SDWW was 35.08 ± 0.27 mg/l. After loading SDWW into VSF CW1, 2 and 3, found that the effluent concentration of ammonia nitrogen was decreases over time. The concentrations of ammonia nitrogen removal by VSF CW1, 2 and 3 were in the range of 19.12±2.31 to 12.22±2.23 mg/l,16.20 ±1.65 to 7.15± 2.88 mg/l and11.50±1.22 to 6.12 ±0.35 mg/l respectively. While the simulation model showed that the concentrations of ammonia nitrogen removal by VSF CW1, 2 and 3 were in the range of 24.25-15.04 mg/l, 17.09-11.20 mg/l and 15.50-7.52 mg/l, respectively.

Comparison of the experimental measurements and the model simulations of ammonia nitrogen removal efficiencies by VSF CW 1, 2, and 3 were presented in Figure 5. The results showed the average ammonia nitrogen removal efficiency of VSF CW1, 2, and 3 were 57.46±2.43%, 70.80±2.74%, and 76.46±4.69%, respectively. The model simulation efficiencies of VSF CW1, 2, and 3 were 50.86±5.75%, 63.34±2.12%, and 71.00±2.49%, respectively.

In the experimental measured, the highest efficiency of ammonia nitrogen removal and the model simulations were observed in VSF CW3 were 76.46%±4.69%, and 71.00±2.49%. The lowest efficiency of ammonia nitrogen removal was observed in VSF CW1 were 57.46±2.43% and 50.86±5.75%. The experimental measurements and the model simulations were consistent with approximately7% different from each other. From the observation, the values obtained from experimental measurement and model simulations were good match.

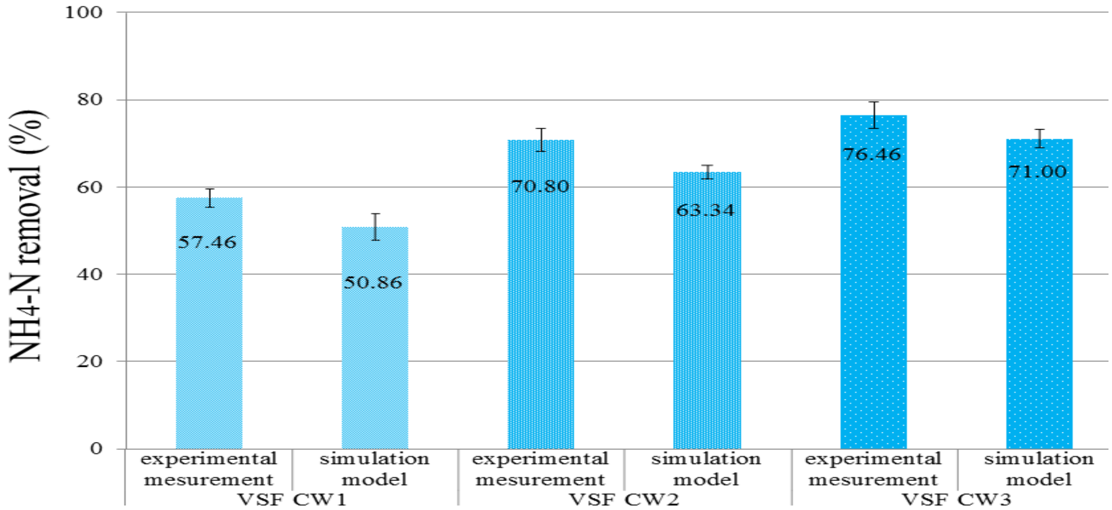

Figure 5 Experimental measurements and the model simulations of average ammonia nitrogen removal efficiencies by VSF CW 1, 2, and 3.

3.2 Interactions between media depth with ammonia-oxidizing bacteria (AOB) and nitrite-oxidizing bacteria (NOB.)

In Figure 6, CW2D module used to simulate the distribution of AOB and NOB in VSF CW1, 2 and 3. This simulation clarified the interaction between media depth and quantities of AOB and NOB. From the simulation result, we can observed that the quantities of high density distribution of AOB and NOB bacteria was observed in VSF CW3 from top of media surface 1 to 45 cm depth are presented. VSF CW2 showed quit good distribution of AOB and NOB from 1 to 30 cm depth. VSF CW1 had a low density and distribution of AOB and NOB (1-15 cm).According to the experimental measured, amounts of ammonia-oxidizing bacteria (AOB) and nitrite-oxidizing bacteria (NOB) in effluent wastewater were analyzed at end of an experiment. The results showed that, the quantities of AOB and NOB were mostly found in VSF CW3 (AOB, $2.83x10^4$±377 CFU and NOB, $2.23x10^4$±443 CFU), followed by VSF CW2 (AOB, $2.00x10^4$±720 CFU and NOB, $1.66x10^4$±544 CFU), and VSF CW1 (AOB, $1.26x10^4$±507 CFU and NOB, $9.66x10^3$±377 CFU), respectively.

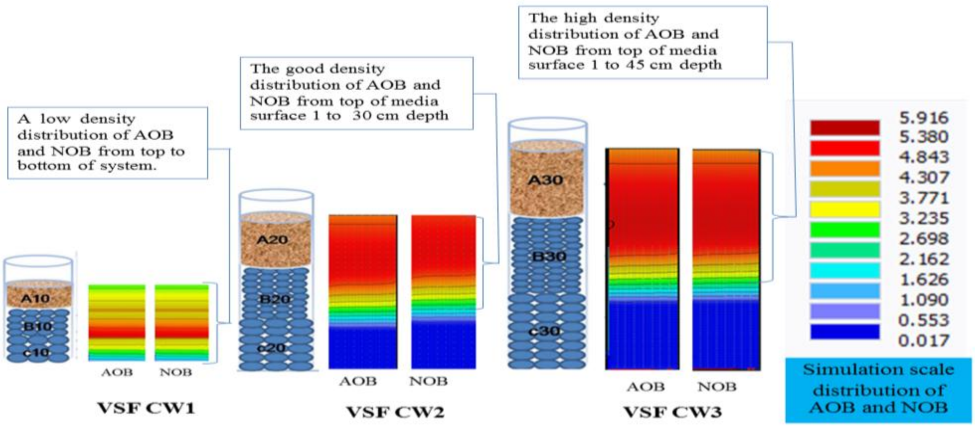

Figure 6 Simulation scale of distribution of ammonia-oxidizing bacteria (AOB) and nitrite-oxidizing bacteria (NOB) in the VSF CW1, 2 and 3 at day 30.

IV. Discussion

In comparison, the experimental measurement and model simulation of ammonia nitrogen removal by VSF CW by different bed depth found that VSF CW3 had highest of ammonia nitrogen removal efficiency (experimental measurements, 76.46% and model simulations, 71.00 %.) The experimental measurement and the model simulation were approximately 7% difference. These findings agreed with the 5% different from the experimental measurements and the model simulations of ammonia nitrogen removal in a pilot-scale two-stage subsurface flow constructed wetlands [23], which used HYDRUS-2D software and CW2D module. In addition, Günter Langergraber and JirkaŠimůnek (2006) study on modeling variably saturated water flow and multicomponent reactive transport in constructed wetlands indicated that the successful calibration of the effluent flow model could be increased the correlations between the experimental measurements and the model simulations [24]. Nevertheless, theaccuracy of CW2D modules were depended on the assumptions of constant value of pH, constant coefficients in rate equations, and variations of experimental temperatures [25].

The major ammonia nitrogen removal mechanism in VSF CW is nitrification and denitrification processes, amount of ammonia-oxidizing bacteria (AOB), nitrite-oxidizing bacteria (NOB) and denitrifying bacteria (DB) plays an important role in removal efficiencies [26],[27]. Hence, the VSF CW3 has a high efficiency of NH_4–N removal because it showed high distribution of ammonia-oxidizing bacteria (AOB), nitrite-oxidizing bacteria (NOB) where ammonia nitrogen reduction reaction took place. VSF CW2 was good with high density distribution of AOB and NOB at 1-30 cm depth. For VSF CW1, had poor ammonia nitrogen removal efficiency because there was low density distribution of AOB and NOB. The finding was supported that the biological active layer has a height of approximate 40 cm from the top of media layer [28].

V. Conclusion

Ammonia nitrogen removal by VSF CW with the different of bed depth was compare simulation model by HYDRUS-2D software and the CW2D module. The results show a good match between simulation model and experimental measured data. Our findings confirm that the hydraulic behavior of the VSF CWmust be correctly described to obtain a good match between simulation models and experimental measured effluent parameters. The VSF CW3 has a high efficiency of ammonia nitrogen removal because it showed high distribution of ammonia-oxidization bacteria (AOB), nitrite-oxidizing bacteria (NOB) where ammonia nitrogen reduction reaction took place. In particular, simulated effluent ammonia nitrogen concentrations were similar to measured data.

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Reference

[1]. J. Vymazal, Removal of nutrients in various types of constructed wetlands, Science of the Total Environment, 380, 2006, 48–65.

[2]. D. Konnerup, T. Koottatep, and H. Brix, Treatment of domestic wastewater in tropical subsurface flow constructed wetlands planted with Canna and Heliconia, Ecological engineering, 35, 2009, 248–257.

[3]. S. Khan, I. Ahmad, M.T. Shah, S. Rehman, and A. Khaliq, Use of constructed wetland for the removal of heavy metals from industrial wastewater, Journal of Environmental Management, 90, 2009, 3451–3457.

[4]. S. C. C. Cristina, O. S. S. R. Anto´nio, and M. L. C. Paula, Constructed Wetland Systems vegetated with different plants applied to the treatment of tannery wastewater, Water Research, 41, 2007, 1790–1798.

[5]. A. S. Sheoran and V. Sheoran, Heavy metal removal mechanism of acid mine drainage in wetlands: A critical review, Minerals Engineering, 19, 2006, 105–116.

[6]. R. H. Kadleca, and L. A. Zmarthieb, Wetland treatment of leachate from a closed landfill, Ecological Engineering, 36, 2010, 946–957.

[7]. J. Vymazal, Constructed Wetlands for Wastewater Treatment, Water, 2, 2010, 530-549.

[8]. S. A. Christos, and A. T. Vassilios, Effect of temperature, HRT, vegetation and porous media on removal efficiency of pilot-scale horizontal subsurface flow constructed wetlands, Ecological Engineering, 29, 2007, 173–191.

[9]. G. Langergraber, D. Giraldi, J. Mena, D. Meyer, M. Peña, A. Toscano, A. Brovelli, and E.A. Korkusuz, Recent developments in numerical modelling of subsurface flow constructed wetlands, Science of the Total Environment, 407, 2009, 3931–3943.

[10]. G. Langergraber, and J. šimůnek, The multi-component reactive transport module CW2D, (PC-Progress, Czech Republic. Prague, Czech Republic, 2006).

[11]. G. Langergraber, and J. šimůnek, HYDRUS wetland module manual. (PC-Progress, Czech Republic. Prague, Czech Republic, 2011).

[12]. The Ministry of Natural Resource and Environment of the Kingdom of Thailand. Effluent standards of domestic waste water treatment plant, 2011.

[13]. C. Sameanram, N. Jungphiboonpan, R. Rattanakate, and N. Chaiyanate, Reduction of Nitrogen by the Different of Media Depths in the Vertical Subsurface Flow Constructed Wetland. International Science, Social Science, Engineering and Energy Conference, 11th-14th December, 2012,Golden Beach Cha-Am Hotel, Petchburi, Thailand

[14]. H. Yoo, K. Ahn, H. Lee, K. Lee, Y. Kwak, and K. Song, Nitrogen removal from synthetic wastewater by simultaneous

Nitrification and denitrification (SND)via nitrite in an intermittently aerated reactor, Water resource, 3, 1999. 145–154.

[15]. D. Fitria, M. Scholz, G. M. Swift, and S. M. Hutchinson, Impact of Sludge Floc Size and Water Composition on Dewater ability, Chemical engineering technology, 37, 2014, 471–477.

[16]. APHA, AWWA,WPCF, Standard Methods for Examination of water and Wastewater (20th edition), (Wasnington D.C., American Public Health Associate Inc, 1995).

[17]. S. Sirianuntapiboon, A. Kongchum, and W. Jitmaikasem, Effects of hydraulic retention time and media of constructed wetland for treatment of domestic wastewater, African Journal of Agriculture Research, 1(2), 2006, 27-37.

[18]. G. Langergraber, and J. šimůnek, HYDRUS user manual version 2. (PC-Progress, Prague, Czech Republic, 2011).

[19]. M. Th. Van Genuchten, A closed-form equation for predicting the hydraulic conductivity of unsaturated soils, Soil Sci. Soc, 1980, 892-898.

[20]. R. F. Carsel, and R. S. Parrish, Developing joint probability distributions of soil water retention characteristics,Water Resource Research, 24, 1988, 755-769.

[21]. U. Dittmer, D. Meyer, and G. Langergraber, Simulation of a subsurface vertical flow constructed wetland for CSO treatment, Water Science & Technology, 51, 2005, 225–232.

[22]. J. Simunek, M. Senja, and M.Th. van Genuchten, The HYDRUS-2D software package for simulating the two-dimensional version 2.0 manual.(U.S. Salinity Laboratory, USDA, Riverside, California, USA, 1999).

[23]. A. Toscano, G. Langergraber, S. Consoli, G. L. Cirelli, Modelling pollutant removal in pilot-scale two-stage subsurface flow constructed wetlands, Ecological Engineering, 35, 2009, 281-289.

[24]. G. Langergraber, and J. Simunek, Modeling variably saturated water flow and multicomponent reactive transport in constructed wetlands, Vadose Zone Journal, 4 , 2005, 924–938.

[25]. C. G. Lee, T. D. Fletcher, and G. Sun, Nitrogen removal in constructed wetland systems, Eng. Life Sci, 9(1), 2009, 11–22.

[26]. P. Noophan, C. Wantawin, S. Sripiboon, S. Sirivitayapakorn, and M. Damrongsri, Nitrogen removal by autotrophic ammonium oxidizing bacteria enrichment under anaerobic conditions, Songklanakarin journal Science and Technol, 30(5), 2008, 659-665.

[27]. J. Vymazal, Nutrient removal in gravel and soil-based wetland microcosms with and without vegetation, Ecological Engineering, 18, 2001, 91–105.

[28]. M. Henrichs, A. Welker, and M. Uhl, Modelling of biofilters for ammonium reduction in combined sewer overflow, Water Science & Technology, 2009, 825-831.