Recommendation of optimal design and operation parameters for constructed wetland for sludge treatment based on the effect of hydraulic retention time, sludge loading rate and vegetation

Nguyen Truong An, Le Thi Minh Tam*, Tran Quoc Viet, Truong Ngoc Viet, Nguyen Thanh Luan, Nguyen Van Minh, Nguyen Thi Huyen Trang, Dinh Quoc Tuc

***Abstract*—Industrial sludge is a by-product which is enormously generated in wastewater treatment plants. Constructed wetland for sludge treatment (CWST) is a low cost, effective technology. This study investigated the effect of various design and operation parameters on the efficiency of four pilot-scale CWSTs to determine the optimal parameters by using the Analytic Hierarchy Process (AHP) for Decision-Making. The wetland units were planted with Phragmites australis or Typha angustifolia, operated with four sludge loading rate (SLR) (50, 60, 70 and 80 L/m2) and monitored in six different hydraulic retention time (HRT) (2,5,7,9,12 and 14 days). AHP results provided the optimal key parameters (vegetation of P. australis, 14-day HRT, SLR of 60 L/m2) which gave the most effective sludge treatment, reducing 99.8%, 95.16% and 98.23% for COD, TKN and TP, respectively. The results also showed that HRT, SLR and vegetation remarkably affected to the efficiency of CWST. In addition, AHP is an effective method to determine the optimal design and operation parameters of CWST.**

Received: 17-8- 2017; Accepted: 13-11-2017.

This study was funded by CARE RESCIF under grant number Tc-TTC-2017-05.

Thanks, are given to members of FENR-CARE for laboratory work.

Nguyen Truong An, Le Thi Minh Tam, Tran Quoc Viet, Nguyen Thi Huyen Trang, are with the CARE, Ho Chi Minh City University of Technology - VNU-HCM, Vietnam (truongan.hcmut@gmail.com, minhtamnt2006@hcmut.eu.vn, ngthtrang@hcmut.edu.vn)

Truong Ngoc Viet, Nguyen Thanh Luan, Nguyen Van Minh, Dinh Quoc Tuc are with the Faculty of Environment and Natural Resources, Ho Chi Minh City University of Technology - VNU-HCM, Vietnam

(quoctuc@hcmut.edu.vn, truongngocviet93@gmail.com)

***Index Terms*—Sludge Treatment, Constructed Wetland, Design and operation, Phragmites australis, Typha angustifolia, AHP for Decision-Making.**

1 INTRODUCTION

INDUSTRIAL sludge management has become a matter of concern because of three reasons: (i) Sludge is a by-product with enormous volume and not expected but inevitably generated in the wastewater treatment [1]. (ii) In the composition of the industrial sludge containing hazardous substances such as heavy metals [1]. (iii) The cost of sludge treatment is tremendous to a wastewater treatment plant, accounting for 40-60% of the total cost of the wastewater treatment plant [1]. Therefore, sludge becomes one of the major challenges for many countries in the world, it is necessary to have an alternative sludge treatment technology to ensure the performance and handling costs.

Constructed wetland for sludge treatment (CWST) derived from Constructed Wetland has been applied successfully for over twenty years [2]. Advantages of CWST are the treatment efficiency and economic (investment and operation cost). In addition, it is also known as a technology-friendly environment [3]. CWST consists of two main components, are available in nature: the filter material (sand, gravel...) and the vegetation; the majority of pollutants in sludge will be retained in CWST, and gradually be transformed into minerals, gas, another part is absorbed by plants, only a small amount of pollutants are escaped CWST [4]. Some studies have demonstrated that the treatment efficiency of CWST based on the following factors: the objective factors (characteristics of sludge, climatic conditions) and subjective factors (filter material, vegetation, sludge loading rate, hydraulic retention time) [5, 6]. Therefore, it is necessary to determine the optimal parameters including vegetation, sludge loading rate (SLR), hydraulic retention time (HRT) to operate effectively according to the subjective factors.

Analytic Hierarchy Process (AHP) is one of the most widely used multiple criteria decision-making tool [7] that is also useful for selection of wastewater treatment process. AHP method combines both quantitative and qualitative information in order to convert them into a comparable value to rank the options on the basis of numerous criteria [8]. This study investigated the effect of various design and operation parameters on the efficiency of four pilot-scale CWSTs in order to determine the optimal design and operation parameters (including vegetation, SLR, HRT) by using the Analytic Hierarchy Process (AHP) for Decision-Making.

2 MATERIALS AND METHODS

2.1 System configuration

Four pilot-scale CWSTs were constructed in the open-air of the campus of Ho Chi Minh City University of Technology, VNU-HCM under the tropical climate. Each CWSTs unit consisted of the transparent acrylic (1.2 m length, 0.5 m width and 0.7 m depth), two aeration tubes, unplanted/ planted Typha latifolia or/and Phragmites australis (Fig 1). The filter layers from the bottom to the top were composed of 15 cm of the gravel layer (D=70-100 mm), 15 cm of the fine gravel layer (D=5-10 mm) and 10 cm of the sand layer (D=0.5-2mm).

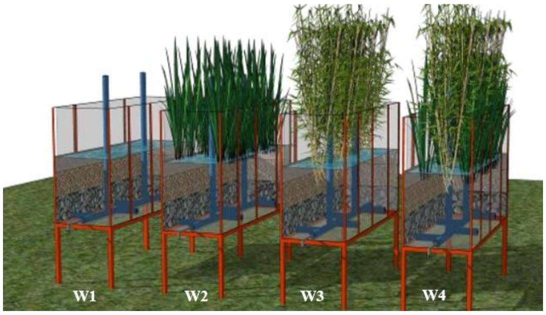

Fig 1. Schematic of the pilot-scale CWSTs (CWST1-unplanted, CWST2-Typha latifolia, CWST3-Phragmites australis, CWST4-mixture of Typha latifolia and Phragmites australis)

2.2 Characterization of the sludge influent and sludge loading rates

Four pilot-scale CWSTs were fed with the industrial sludge from WWTP in Ho Chi Minh City. The characteristics of the sludge influent are shown in Table 1. In the first 100 days, the systems were fed with tap water and low SLR (below 20 kgTS/m2/yr) for bed layer stabilization and plant adaptation. Then they were operated officially in 60 days to apply four SLR from 50 L to 80 L of industrial sludge, respectively from 37 to 64 kgTS/m2/yr, each SLR was applied for 15 days (one day of feeding followed by 14 days of retention).

TABLE 1.
INFLUENT SLUDGE CHARACTERISTICS ACCORDING TO FOUR SLR

Pollutants in sludge	***Unit***	***Concentration of pollutants in each SLR***			
		SLR1=50L	***SLR2=60L***	***SLR3=70L***	***SLR4=80L***
Total solids (TS)	g/L	17.2	18.1	17.9	18.7
	g/m^2	1433	1810	2088	2493
Chemical Oxygen Demand (COD)	mg/L	20241	21103	19862	19028
	g/m^2	1686	2110	2317	2537
Total Kjeldahl Nitrogen (TKN)	mg/L	205.2	215.4	204.3	224.0
	g/m^2	17.1	21.5	23.8	29.9
Total Phosphorus (TP)	mg/L	99.0	91.0	93.3	92.3
	g/m^2	8.3	9.1	10.9	12.3

TABLE 2.
THE SCORES OF THE POLLUTANT CONCENTRATIONS BASED ON VIETNAMESE NATIONAL TECHNICAL REGULATION ON INDUSTRIAL WASTEWATER (QCVN 40:2011/BTNMT)

Range of COD (mg/L)	***Score***	***Range of TKN* (mg/L)***	***Score***	***Range of TP (mg/L)***	***Score***
(150; +∞)	0	(20; +∞)	0	(6; +∞)	0
[100; 150]	25	[15; 20]	25	[5; 6]	25
(75; 100)	50	(10; 15)	50	(4; 5)	50
[0; 75]	100	[0; 10]	100	[0; 4]	100

Scoring rules: Based on two levels (A and B) of water quality in QCVN 40:2011/BTNMT. If the pollutant concentrations were higher level B, below level B, middle of level B and A or below level A, the score would be 0, 25, 50 or 100 respectively.
*: *TKN were adapted from TN and NH_4-N of the QCVN 40:2011/BTNMT.*
**: *"[" or "]" means that it can be equal; "(" or ")" means that it is only higher or lower than a value*

TABLE 3.
THE TOTAL SLUDGE VOLUME (V) CAN BE TREATED IN ONE YEAR BY CWSTS ACCORDING TO HRT AND SLR.
Formula V=365 × SLR/HRT (m^3/yr)

	HRT1=2d	***HRT2=5d***	***HRT3=7d***	***HRT4=9d***	***HRT5=12d***	***HRT6=14d***
SLR1=50L	9.13	3.65	2.61	2.03	1.52	1.30
SLR2=60L	10.95	4.38	3.13	2.43	1.83	1.56
SLR3=70L	12.78	5.11	3.65	2.84	2.13	1.83
SLR4=80L	14.60	5.84	4.17	3.24	2.43	2.09

This formula computed the sludge quantity (V) could be treated in a year (m^3/yr), equal to SLR (m^3) × 365 (days)/ HRT (days).

TABLE 4.
THE MATRIX WEIGHT (W) OF PAIR SLR AND HRT. FORMULA W=(100 × V)/(MAX OF V)

	HRT1=2d	***HRT2=5d***	***HRT3=7d***	***HRT4=9d***	***HRT5=12d***	***HRT6=14d***
SLR1=50L	63	25	18	14	10	9
SLR2=60L	75	30	21	17	13	11
SLR3=70L	88	35	25	19	15	13
SLR4=80L	100	40	29	22	17	14

This formula converted the sludge quantity in to the weight score, from 0 to 100, the highest sludge quantity (Max of V) was accounted for 100.

TABLE 5.
THE SCORE MATRIX (M) OF THE TREATMENT EFFICIENCY ACCORDING TO PAIRWISE SLR, HRT.
FORMULA M= (TP SCORE + TKN SCORE + COD SCORE) × WEIGHT. THE HIGHEST SCORE ACCOUNTED FOR THE OPTIMAL PAIRWISE SLR, HRT

	HRT1=2d	***HRT2=5d***	***HRT3=7d***	***HRT4=9d***	***HRT5=12d***	***HRT6=14d***
SLR1=50L	Score×63	Score×25	Score×18	Score×14	Score×10	Score×9
SLR2=60L	Score×75	Score×30	Score×21	Score×17	Score×13	Score×11
SLR3=70L	Score×88	Score×35	Score×25	Score×19	Score×15	Score×13
SLR4=80L	Score×100	Score×40	Score×29	Score×22	Score×17	Score×14

2.3 Sampling, analytical methods and statistical analyses

In 14 days retention of each SLR, samples of inlet sludge and outlet water drainage were taken and analyzed at the day 2,5,7,9,12 and 14 (These numbers accounted for HRT). Samples were collected with 500 ml polyethylene bottles and analyzed immediately in the sampling day or freezed at -18°C for later analysis. Total solids (TS), Chemical Oxygen Demand (COD), Total Kjeldahl Nitrogen (TKN) and Total Phosphorus (TP) were analyzed according to Standard Methods [9].

One-way analysis of variance (ANOVA) was used to determine whether the significant differences between the SLRs or HRTs occurred on the quality of outlet water (COD, TKN and TP). Paired t-test (95% confidence level) was performed to examine the effect of vegetation on the pollutant removal. Excel 2016 (Microsoft Corporation) was applied to achieve these purposes.

2.4 AHP method for optimal parameter decision

Based on the idea of AHP method, the pollutant concentrations (the quantitative information) of the water outlet were converted into the scores (from 0 to 100, see Table 2) and the pair of SLR, HRT (qualitative information) were calculated to determine the weights (from 1 to 100, see Table 3 and Table 4), then both quantitative and qualitative information were combined to find the highest score which accounted for the optimal SLR and HRT of each CWST (Table 5). Four CWST units would provide four pairs of SLR, HRT; and the highest score of these pairs was the optimal CWST which accounted for the optimal vegetation.

3 RESULTS AND DISCUSSION.

3.1 Effect of HRT, SLR and vegetation

3.1.1Effect of HRT and SLR

The usage of different SLRs, HRTs (low SLR to high SLR, short HRT to long HRT) allowed examining the effect of SLR and HRT on the treatment efficiency. The COD, TKN and TP concentrations of the leachate were affected by both SLR ($P < 0.01$) and HRT ($P < 0.01$) and there was a significant interaction between SLR and HRT to treatment efficiency according to the two-way ANOVA ($P < 0.01$). It is clear that the effluent concentrations of all pollutants were increased (i.e. the treatment efficiency decreased) when increasing the SLR or/and decreasing the HRT.

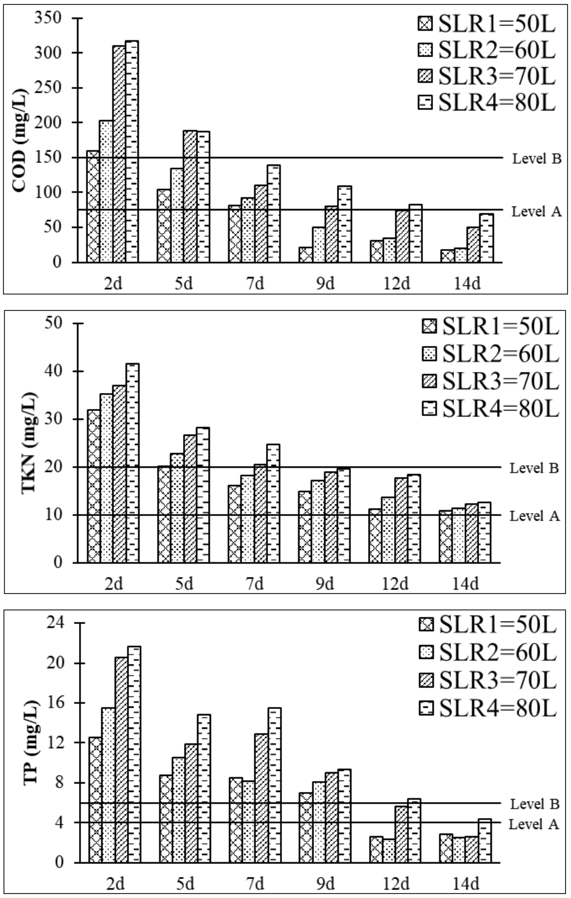

Fig 2. The pollutant concentrations of outlet water drainage according to the different SLRs and HRTs (Note: this figure only presents the data of CWST4 once the CWST4 got the same trend with other CWSTs)

The HRT and the leachate concentrations had a negative relationship. The means of influent concentrations were about 20000 mg/L, 200 mg/L and 100 mg/L for COD, TKN and TP respectively. After only two days of retention, the means of outlet concentrations were dropped dramatically, achieving the removal efficiency more than 80%, especially the COD removal was roughly 98%. However, the CWST units with plants had to undergo 12-day HRT to ensure the water quality of the leachate met the Vietnamese regulation QCVN 40:2011/BTNMT. From 2-day to 14-day HRT, the leachate quality was improved gradually and linearly with HRT (Fig 2), in another way the mass reductions of these pollutants were 1881 mgCOD/m2/day ($R2 = 0.88$, $P < 0.001$), 222 mgTKN/m2/day ($R2 = 0.88$, $P < 0.001$) and 131 mgTP/m2/day ($R2 = 0.95$, $P < 0.001$) in 12 days.

There were a positive relationship and a significant correlation between the SLR and the leachate concentrations. Four SLRs from 50L to 80L of sludge have been respectively applied in the CWST units, equivalent to 37 to 64 kgTS/m2/yr with 14-day HRT. While the SLR increased 20% after each batch (i.e. 80% at SLR4=80L), the average concentrations of the outlet in 14 days had been considerably affected, increasing 38.90% for COD ($R2 = 0.96$, $P < 0.001$), 12.83% for TKN ($R2 = 0.99$, $P = 0.01$) and 19.85% for TP ($R2 = 0.97$, $P = 0.01$). For the COD and TKN, with the low SLR=50L, the concentrations for these parameters met the QCVN 40:2011/BTNMT at level B after only 5-day HRT. However, with the high SLR=80L, the CWST units needed 9 days of retention to achieve level B (Fig 2). Moreover, the concentration of TP cannot meet the level A of this regulation even after 14-day HRT with the highest SLR (64 kgTS/m2/yr). This is consistent with previous studies, most of the authentic experience for SLR choice was general 50 and maximum at 60 kgTS/m2/yr [6, 10]. The SLR 64 kgTS/m2/yr in this study can be the limit SLR, because a load of 70 kgTS/m2/yr can block oxygen diffusion [11].

3.1.2Effect of vegetation

The paired t-test showed that the treatment performance between the unplanted unit CWST1 and the planted units CWST2, CWST3 and CWST4 (with the same SLR and HRTs) was significant differences ($P < 0.001$). The Fig 3 also showed that the output concentrations of the unplanted CWST unit was always higher than the planted CWST units and it also could not meet the Vietnamese regulation QCVN 40:2011/BTNMT after 14 days of retention while the planted CWSTs needed only 7 days. The presence of P. australis or T. angustifolia improved the treatment efficiency by about 57%, 70% and 80% for COD, TKN, TP comparing to unplanted CWST. Concerning the removal efficiency of organic matter, CWST unit planted with both P. australis and T. angustifolia gave the better performance than the CWST units with an individual plant. The CWST unit for the highest TKN removal was not the mixture plants but the T. angustifolia. It is interesting that the P. australis (CWST3) was the vegetation having the best TP removal efficiency from the day of 7 to 14 of retention (Fig 3). Although P. australis and T. angustifolia have been highly evaluated in the treatment efficiency by many researchers [4, 6, 10], the combination of both species has not been evaluated. In this study, the combination of both plants into a CWST could reduce the efficiency of TP or TKN treatment, since each plant gave a different ability to treat different pollutants. However, the treatment efficiency of the mixture plant CWST will be neutralized. Therefore, depending on the regulation of the effluent quality of each region or country, the plant selection will be modified for the regulation appropriation.

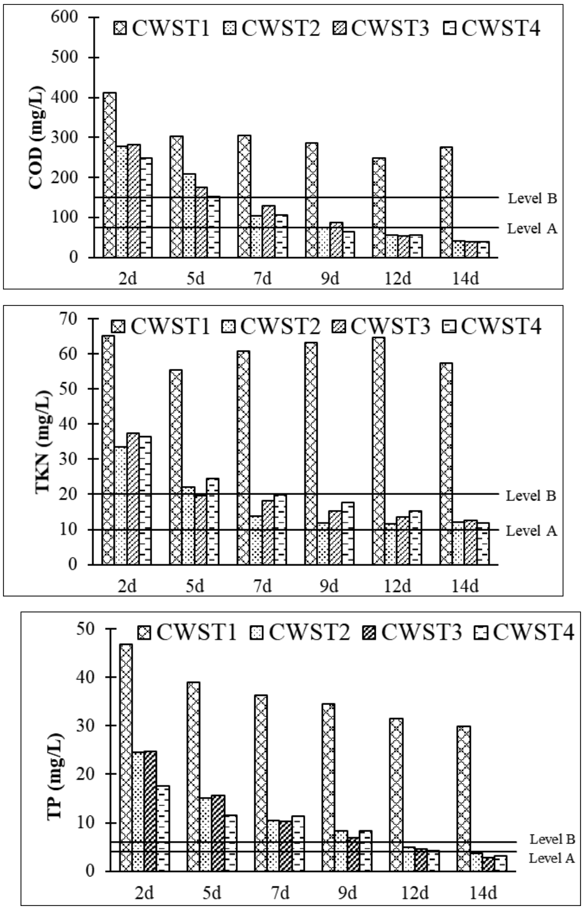

Fig 3. The pollutant concentrations of outlet water drainage according to the different vegetation (Note: this figure presents the average data of four SLRs in 14 days of retention)

3.2 Recommendation of optimal parameters

The highest score of AHP result belonged to CWST3 (Phragmites australis) with 14-day HRT and 60L of SLR (Table 6), equivalent to 44 kgTS/m2/yr, 48.67 kgCOD/m2/yr, 0.49 kgTKN/m2/yr, 0.24 kgTP/m2/yr. The outlet concentrations of COD, TKN and TP when applying the optimal parameters were respectively 22.73, 9.68 and 1.77 mg/L, they all meet the Vietnamese National Technical Regulation on Industrial Wastewater. In another way, the CWST applied with the optimal parameters could reduce 99.89% COD, 95.16% TKN and 98.23% TP. Table 6. also showed that the unplanted CWST (CWST1) were not met any regulation for COD, TKN and TP as its highest scores were 0. Besides that, APH results recommended that the HRT should be longer than 5 days because from 2-day to 5-day HRT, most of the scores were 0 (i.e. the outlet quality did not meet the regulation).

4 CONCLUSIONS.

Four pilot-scale CWSTs were operated with different four SLRs and HRTs from 2 days to 14 days and different vegetation, which provided whether SLR, HRT and vegetation significantly affected to the treatment efficiency. The results showed that the leachate quality was affected significantly and linearly with HRT and SLR ($P < 0.01$, $R^2 > 0.8$). While HRT had a positive relationship with leachate quality, the SLR was a negative relationship. If the loading increased 20%, the average concentrations of the outlet in 14 days could increase from 19.85% to 38.90% for COD, TKN and TP. After 2-day HRT, the pollutants could reduce more than 80% and in the rest of 12 days, the concentrations of the outlet could daily decrease 1881 mgCOD/m2/day, 222 mgTKN/m2/day and 131 mgTP/m2/day. Furthermore, the presence of vegetation (Typha latifolia and Phragmites australis) could improve the treatment efficiency from 57% to 80%.

In addition, AHP is an effective method to determine the optimal design and operation parameters of CWST. The results showed that the CWST planted with Phragmites australis and operated with the loading 44 kgTS/m2/yr, 48.67 kgCOD/m2/yr, 0.49 kgTKN/m2/yr, 0.24 kgTP/m2/yr in 14-day HRT were the optimal choices for Vietnamese conditions and regulation.

TABLE 6.
THE SCORE MATRIX OF THE TREATMENT EFFICIENCY OF FOUR CWST UNITS

HRT / SLR	CWST1							CWST2					
	2d	**5d**	**7d**	**9d**	**12d**	**14d**		**2d**	**5d**	**7d**	**9d**	**12d**	**14d**
SLR1=50L	0	0	0	0	0	0		0	625	2232	2083	3125	2679
SLR2=60L	0	0	0	0	0	0		0	0	2143	2500	2500	2679
SLR3=70L	0	0	0	0	0	0		0	0	1875	2917	2552	2500
SLR4=80L	0	0	0	0	0	0		0	0	1429	1667	1667	2500
	CWST3							**CWST4**					
SLR1=50L	0	625	1339	2778	2604	2679		0	625	1339	2083	2604	2232
SLR2=60L	0	750	1071	2500	3125	**3214**		0	750	1607	2083	3125	2679
SLR3=70L	0	0	1250	1458	2917	3125		0	0	625	1458	2188	3125
SLR4=80L	0	0	0	1111	2083	2500		0	0	714	1111	1250	2857

REFERENCES

[1] G. Tchobanoglous, F. L. Burton, H. D. Stensel, Metcalf, and I. Eddy, *Wastewater Engineering: Treatment and Reuse*. McGraw-Hill Education, 2003.

[2] E. Uggetti, I. Ferrer, E. Llorens, and J. García, "Sludge treatment wetlands: a review on the state of the art," *Bioresource Technology,* vol. 101, no. 9, pp. 2905-2912, 2010.

[3] J. L. De Maeseneer, "Constructed wetlands for sludge dewatering," *Water Science and Technology,* vol. 35, no. 5, pp. 279-285, 1997.

[4] V. Gagnon, F. Chazarenc, Y. Comeau, and J. Brisson, "Effect of plant species on sludge dewatering and fate of pollutants in sludge treatment wetlands," *Ecological engineering,* vol. 61, pp. 593-600, 2013.

[5] A. I. Stefanakis and V. A. Tsihrintzis, "Effects of loading, resting period, temperature, porous media, vegetation and aeration on performance of pilot-scale vertical flow constructed wetlands," *Chemical engineering journal,* vol. 181, pp. 416-430, 2012.

[6] S. Nielsen, "Sludge drying reed beds," *Water Science and Technology,* vol. 48, no. 5, pp. 101-109, 2003.

[7] O. S. Vaidya and S. Kumar, "Analytic hierarchy process: An overview of applications," *European Journal of operational research,* vol. 169, no. 1, pp. 1-29, 2006.

[8] X. Ouyang, F. Guo, D. Shan, H. Yu, and J. Wang, "Development of the integrated fuzzy analytical hierarchy process with multidimensional scaling in selection of natural wastewater treatment alternatives," *Ecological Engineering,* vol. 74, pp. 438-447, 2015.

[9] APHA., AWWA., and WEF., *Standard Methods for the Examination of Water and Wastewater*. American Public Health Association, 2012.

[10] J. Vincent, P. Molle, C. Wisniewski, and A. Liénard, "Sludge drying reed beds for septage treatment: towards design and operation recommendations," *Bioresource technology,* vol. 102, no. 17, pp. 8327-8330, 2011.

[11] J. Vincent, N. Forquet, P. Molle, and C. Wisniewski, "Mechanical and hydraulic properties of sludge deposit on sludge drying reed beds (SDRBs): Influence of sludge characteristics and loading rates," *Bioresource technology,* vol. 116, pp. 161-169, 2012.

Nguyen Truong An, are with the CARE, Ho Chi Minh City University of Technology - VNU-HCM, Vietnam (truongan.hcmut@gmail.com,)

Le Thi Minh Tam, are with the CARE, Ho Chi Minh City University of Technology - VNU-HCM, Vietnam (minhtamnt@hcmut.eu.vn)

Tran Quoc Viet, are with the CARE, Ho Chi Minh City University of Technology - VNU-HCM, Vietnam

Truong Ngoc Viet, are with the Faculty of Environment and Natural Resources, Ho Chi Minh City University of Technology - VNU-HCM, Vietnam (truongngocviet93@gmail.com)

Nguyen Thanh Luan, are with the Faculty of Environment and Natural Resources, Ho Chi Minh City University of Technology - VNU-HCM, Vietnam

Nguyen Van Minh, are with the Faculty of Environment and Natural Resources, Ho Chi Minh City University of Technology - VNU-HCM, Vietnam

Nguyễn Thị Huyền Trang are with the CARE, Ho Chi Minh City University of Technology - VNU-HCM, Vietnam (ngthtrang@hcmut.edu.vn)

Dinh Quoc Tuc, are with the Faculty of Environment and Natural Resources, Ho Chi Minh City University of Technology - VNU-HCM, Vietnam (quoctuc@hcmut.edu.vn)

Đề xuất thông số thiết kế và vận hành tối ưu cho hệ thống xử lý bùn bằng đất ngập nước kiến tạo dựa trên tác động của thời gian lưu thủy lực, tải lượng bùn và thực vật

Nguyễn Trường An, Lê Thị Minh Tâm, Trần Quốc Việt, Trương Ngọc Việt, Nguyễn Thành Luân, Nguyễn Văn Minh, Nguyễn Thị Huyền Trang, Đinh Quốc Túc
Trường Đại học Bách Khoa, ĐHQG-HCM
Tác giả liên hệ: minhtamnt2006@hcmut.edu.vn

Ngày nhận bản thảo: 17-8-2017, ngày chấp nhận đăng: 13-11-2017

***Tóm tắt*—Bùn thải công nghiệp là một sản phẩm phụ hình thành trong quá trình xử lý nước thải. Xử lý bùn thải bằng đất ngập nước kiến tạo (CWST) là một giải pháp thân thiện với môi trường và hiệu quả về kinh tế. Nghiên cứu này đánh giá tác động của các thông số thiết kế và vận hành đến hiệu quả xử lý của CWST nhằm đề xuất các thông số tối ưu dựa trên phương pháp phân tích thứ bậc (AHP). Mô hình trồng Phragmites australis hoặc Typha angustifolia, vận hành với các tải lượng bùn (SLR) (50, 60, 70 và 80 L/m2) và giám sát trong thời gian lưu thủy lực (HRT) (2,5,7,9,12 và 14 ngày). Mẫu bùn đầu vào và mẫu nước đầu ra được phân tích chỉ tiêu COD, TKN và TP. Kết quả AHP cho thấy các thông số gồm P. australis, 14 ngày, SLR là 60 L/m2 cho hiệu quả xử lý tốt nhất, lần lượt là 99.8%, 95.16% and 98.23% cho COD, TKN và TP. Kết quả nghiên cứu còn cho thấy HRT, SLR và thực vật tác động mạnh đến hiệu quả xử lý của CWST. Bên cạnh đó AHP là một phương pháp hiệu quả trong xác định các thông số tối ưu cho hệ thống CWST.**

***Từ khóa*—Đất ngập nước kiến tạo, Thông số thiết kế và vận hành, Phragmites australis, Typha angustifolia, Phương pháp phân tích thứ bậc.**