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Application of constructed wetland for advanced treatment of industrial wastewater

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Abstract:

An experimental study to use a pilot vegetated submerged bed (VSB) wetland for the advanced treatment of effluent from the central wastewater treatment plant (CWWTP) of an industrial zone was carried out. The pilot VSB wetland included reeds (*Phragmites australis*), cattail (*Typha orientalis*), and blank cells in parallel. The constructed wetland was observed to be a suitable measure for wastewater reuse via the high performance of organic matter, turbidity removal, and detoxification. At loading rates of up to 250 kg chemical oxygen demand (COD) ha^{-1}d^{-1}, both cells with emergent plants obtained high efficiency of contaminant removal. Suspended solids (SS) and turbidity removal reached 67-86% and 69-82%, respectively. The COD removal efficiencies of the reed and cattail cells at a loading rate of 130 kg COD ha^{-1}d^{-1} were 47 and 55%, respectively. At a high loading of 400 kg COD ha^{-1}d^{-1}, the toxicity unit (TU) reduced from 32-42 to 4.9 and 4.2 in the effluent of the cattail and reed cells, respectively. Especially at loadings of 70, 130, and 185 kg COD ha^{-1}d^{-1}, the effluent TU was less than 3.0, corresponding to a non-toxic level to the ecosystem. The effluent quality met industrial or landscaped wastewater reuse at these loading rates.

Keywords: **constructed wetland, wastewater polishing, wastewater reclamation and detoxification.**

Classification number: **5.1**

Introduction

Until 2009, there were 16 industrial zones in Ho Chi Minh city, Vietnam. All of them are located in the suburbs of Ho Chi Minh city. Now, all industrial zones have a CWWTP with capacities ranging from 2,000 to 6,000 m^{3}d^{-1} [1]. Preliminary treatment, followed by secondary treatment with activated sludge, was used widely in these CWWTPs. However, degradation of the quality of receiving water canals in the suburbs has led the Ministry of Natural Resources and Environment [1] to report poor operation and control of effluent discharge in CWWTPs .

On the other hand, industrial zones have also been faced with the challenge of freshwater scarcity due to factors contributing to the degradation of groundwater quality such as high salinity, high iron, and manganese concentration, resulting in a decrease of groundwater supply and increase of the price of piped water by the Water Supply Company. Therefore, wastewater reclamation is a good option to solve these problems. In order to use polished and reclaimed effluent from the CWWTPs in for industrial applications or as irrigation for landscaped areas in the industrial zones, advanced treatment is necessary to remove any remaining SS, biochemical oxygen demand (BOD), and nutrients.

Constructed wetlands are an environmentally friendly technology for wastewater treatment or polishing of effluent, and it is becoming increasingly popular in many countries all over the world [2-4]. The mechanism of pollutant removal by a constructed wetland is well known. It is based on biological filtration processes that occur in the medium layer dense with aquatic plants [5]. In developing countries, the application of constructed wetlands for decentralized

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*Corresponding author: Email: minhtamnt2006@hcmut.edu.vn wastewater treatment is being promoted because of low construction requirements and low operation costs compared with other conventional wastewater treatment systems [6-8].

Therefore, this study aims to (1) investigate the treatment efficiency of a VSB wetland for advanced industrial wastewater treatment and (2) assess the detoxification of the VSB wetland in terms of the reduction of acute toxicity.

Materials and methods

The pilot VSB wetland

The pilot horizontal VSB wetland was located on the campus of the CWWTP of Le Minh Xuan industrial zone located in the Binh Chanh district, a sub-urban area of Ho Chi Minh city. The Le Minh Xuan industrial zone generates 4,000 m^3d^{-1} of wastewater. The Le Minh Xuan industrial zone contains polluting industries such as chemical manufacturing, tanning, pesticide, textile, and dyeing companies, which were required to relocate from the inner city by the city government. Therefore, the wastewater of the industrial zone may contain toxic compounds. The pilot VSB wetland included three cells, each with the size of 12×3.5×1.2 m, and the empty working volume of each cell was 42 m^3 (Fig. 1). *Phragmites australis* and *Typha orientalis* were transplanted at a density of 20 plants m^{-2} and 25 plants m^{-2}, respectively. These emergent plants were taken from natural low-lying land next to the Le Minh Xuan industrial zone. Both of these plants were studied because they could tolerate high loading of industrial wastewater [9, 10]. All of the selected plants that were over 2.0 m in height were cut from the top part into a stem section of 0.3 m height with the root. The pilot size and structure of the media are presented in Table 1.

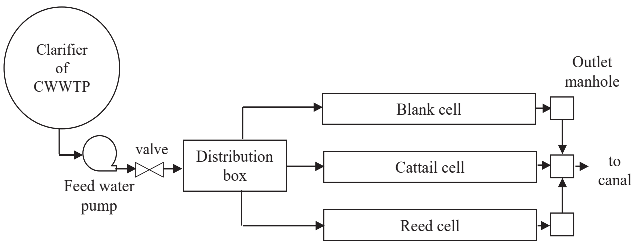

Fig. 1. Layout of the pilot VSB wetland.

Table 1. Size and structure of the pilot VSB wetland cell.

No	Parameter	Unit	Size
1	Length	m	12
2	Width	m	3.5
3	Bottom slope	%	0.01
4	The number of layers:	-	3
	Height of gravel (20×4 mm) layer	mm	250
	Height of gravel (10×20 mm) layer	mm	100
	Height of sand layer (0.1-0.5 mm)	mm	250

Feed wastewater

The feed wastewater was the effluent from a secondary clarifier of the CWWTP in the Le Minh Xuan industrial zone. Table 2 shows the characteristics of the effluent during the experiment of the pilot VSB wetland, which started from January in 2008 and ended on August 2009.

Table 2. Quality of effluent from the CWWTP during the run of the pilot VSB wetland.

Parameter	Unit	Range	Average value (n=40)	Effluent quality standards [(*)]
pH	-	6.91-7.69	7.4±0.3	6-9
Turbidity	FAU	14-140	35±29	NA
Colour	Pt-Co	132-500	259±198	70
TSS	mgl^{-1}	10-34	39±31	100
COD	mgl^{-1}	62-540	189±141	100
N-ammonia	mgl^{-1}	0.4-1.2	0.68±0.2	10
N-nitrite	mgl^{-1}	0.02-0.04	0.03±0.01	NA
N-nitrate	mgl^{-1}	27-72	55±14.6	30
BOD_5	mgl^{-1}	36-250	61±13	50

Note: [(*)] Vietnamese industrial effluent quality standards for secondary treatment (QCVN40:2011/BTNMT); NA: non-available.

Table 2 shows that the effluent of the CWWTP had much variation during the experimental run of the pilot VSB wetland. The high variation of the effluent quality was due to (i) poor control of discharge from industries inside the industrial zone and (ii) poor operation of the CWWTP. Therefore, the quality of the CWWTP effluent used did not to meet the Vietnamese industrial effluent standards in terms of COD, BOD_5 and colour.

Operation conditions

The pilot VSB wetland was run at loading rates of 70, 130, 185, 250, and 400 kg COD $ha^{-1}d^{-1}$. The COD loading rates were controlled by the adjustment of the feed wastewater flowrate using a pump discharge valve and weirs in the distribution box. The adjusted flow rate of the fed wastewater was in the range of 2.7 to 12 m^3d^{-1}. The influent COD to the VSB wetland was the real COD effluent of the CWWTP. The influent COD values at loading rates greater than and equal to 185 kg COD $ha^{-1}d^{-1}$ occurred during poor operation or overload of the CWWTP (Table 3).

Table 3. The operation conditions of pilot VSB wetland.

Loading rate (kg COD $ha^{-1}d^{-1}$)	Duration (days)	HRT$^{(*)}$ (day)	Influent COD to VSB wetland (mgl^{-1})
70	12	9.0	72±11 (n=5)
130	22	5.4	90±10 (n=12)
185	14	4.0	129±60 (n=7)
250	31	2.0	250±90 (n=8)
400	31	2.0	416±75 (n=8)

Note: $^{(*)}$ HRT = V_bQ^{-1}. Where: V_b - the empty bed volume (24 m^3 of material bed), and Q - flow rate (m^3d^{-1}).

Analysis methods

All parameters including COD, SS, turbidity, colour, ammonia, nitrite, and nitrate were analysed according to the Standard Methods for the Examination of Water and Wastewater [11].

The acute toxicity tests of *Vibrio fischeri* and *Daphnia magna* were used in this study to assess the detoxification of the VSB wetland. The freeze-dried marine bacteria *V. fischeri* was obtained from AZUR Environmental (standardized protocols from US EPA) using the Microtox analyzer 500 ISO, 1998 [12]. The concentration causing 50% inhibition of light emitted by the bacteria (EC50) was determined after 5, 15, and 30 min. The maximum dimethyl sulfoxide (DMSO) concentration used for testing was 2%.

D. magna or waterflea is a common microcrustacean found in fresh water. The culture of the *D. magna* Straus clone 1829 was maintained in an M4 medium [13]. The immobilization of the *D. magna* was recorded after 24 h and 48 h. An ISO medium [14] was used for the dilution of the sample and as the control. The maximum DMSO concentration used for testing was 0.1%.

Results and discussion

Turbidity and SS removal

Turbidity is an aesthetic parameter widely used in regulations of reclaimed water quality. Limits on turbidity for agricultural or for industrial reuse range from 2 to 5 FAU [15]. Fig. 2 shows the variation of influent and effluent turbidity during the operation time.

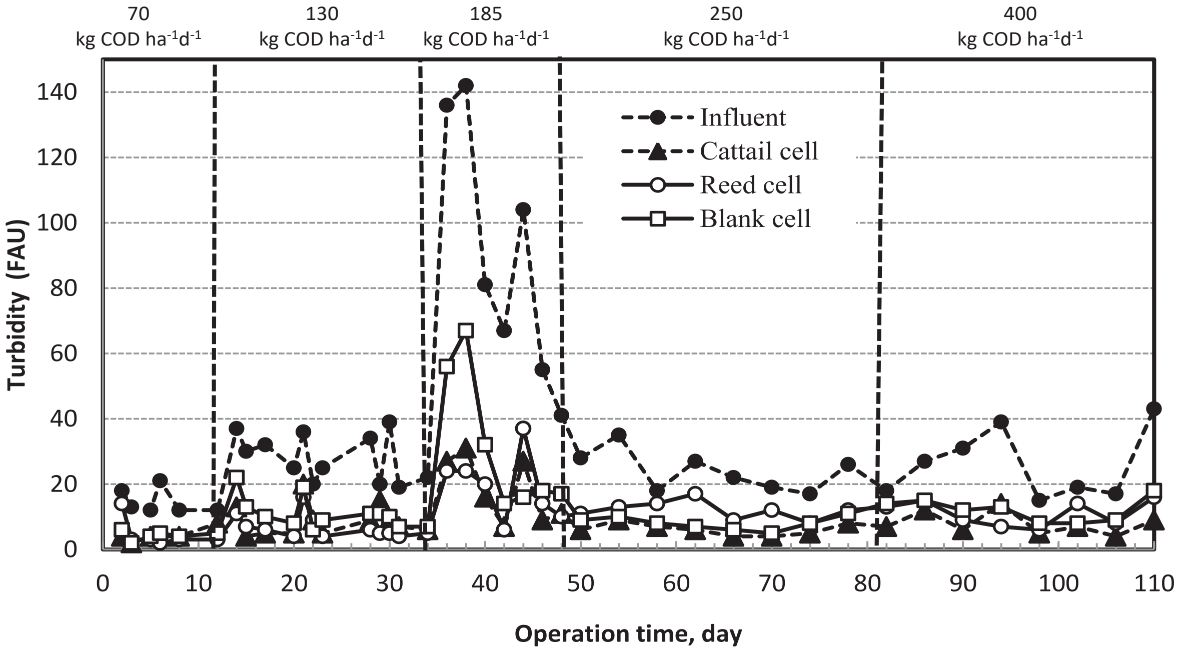

Fig. 2. Course of influent and effluent turbidity versus operation time.

Turbidity is used as a surrogate measure of suspended solids [15]. A high performance of turbidity removal was observed. The VSB wetland with dense root zone may provide a transport-attachment trap for turbidity that escaped the CWWTP. At all the tested COD loading rates, the removal efficiencies of the reed and cattail cells were higher than that of the blank cell. In the cattail and reed cell, 68 and 73% of influent turbidity were removed, respectively, while a turbidity removal of 64% was found in the blank cell at loading rates of 70 and 130 kg COD ha^{-1}d^{-1}.

The average removal efficiencies were 65 and 68% in the cattail and reed cell, respectively, at loading rates equal to and greater than 185 kg COD ha^{-1}d^{-1}. The performance of the reed cell was a little higher than that of the cattail cell at most of the loading rates. This trend may be attributed to the superior growth of the local reed to that of the cattail in terms of density of roots, rhizomes, and leaves.

It is noteworthy the mean of the effluent turbidity of the cattail and reed cells at loading rates less than 185 kg COD ha^{-1}d^{-1} were 7.4±4.6 FAU and 6.1±4.0 FAU, respectively, which meets the limit on turbidity for agricultural reuse (10 FAU). However, in order to satisfy the allowable turbidity for industrial reuse (3 FAU), additional treatment such as adsorption, flocculation, or filtration for VSB wetland effluent is needed.

The effluent suspended solids of the cattail and reed cells at low COD loading rates were 5.9±2.5 and 4.5±1.8 mgl^{-1}, respectively. These values met the SS threshold for industrial reuse (20 mgl^{-1}). The average effluent suspended solids of all cells at the high loading rate of 400 kg COD ha^{-1}d^{-1} were less than 26 mgl^{-1}. Thus, a wash-out of the bio-solids of the VSB wetland had not occurred after 110 days of runs at short hydraulic retention times (HRTs).

Colour removal

The influent for the VSB wetland was the effluent of secondary treatment at the CWWTP. Then, the colour was mainly caused by non-biodegradable soluble organic matter. This resulted in low colour removal by the VSB wetland at low COD loading rates (70 and 130 kg COD ha^{-1}d^{-1}). The average colour removal of the reed, cattail, and blank cells at low COD loading rates were 16, 21, and 12%, respectively. The average effluent colour values were 145, 155, and 160 Pt-Co for the reed, cattail, and blank cells, respectively (Fig. 3).

At higher loading rates, in which overload of the CWWTP occurred, higher colour removal of all cells were obtained. Discharge to the CWWTP comes mainly from 16 textile and dyeing companies in the industrial zones that lead to high influent colour values into the pilot VSB wetland [16]. At the loading rate of 185 kg COD ha^{-1}d^{-1}, the average colour removal efficiency of the reed, cattail, and blank cells were 51, 48 and 45%, respectively. High colour removal at this loading rate was significantly attributed to the attached bacteria living in the bed media and rhizomes. The bacteria living in the wetland continuously degraded the organic dyes, which could not be completely removed by the CWWTP.

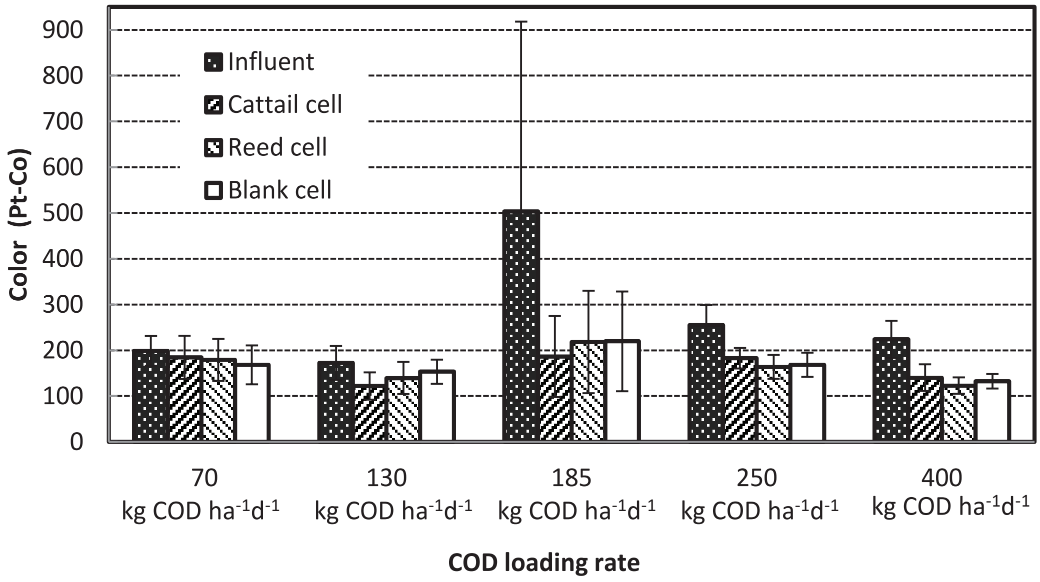

Fig. 3. Colour profile versus COD loading rates.

COD removal

At COD loading rates of 70 kg COD $ha^{-1}d^{-1}$ (HRT of 5 d) and 130 kg COD $ha^{-1}d^{-1}$ (HRT of 3 d) when the mean influent COD to the VSB wetland was 84±14 mgl^{-1} (n=18), the average COD removal of the reed, cattail, and blank cells were 48, 41, and 31%, respectively. The remaining COD after the secondary treatment of the CWWTP was mainly non-biodegradable and slow-degradable organic matter that resulted in low COD removal efficiencies at low COD loading rates. The average effluent COD concentration of the reed, cattail, and blank cells were 49, 43, and 57 mgl^{-1}, respectively, while the average effluent BOD_5 concentration of all cells were less than 15 mgl^{-1}, which met allowable BOD_5 concentrations for agricultural, industrial, or environmental reuses (20 mgl^{-1}).

Figure 4 shows that at higher loading rates, namely 185 kg COD $ha^{-1}d^{-1}$ (HRT of 2 d) and 250 kg COD $ha^{-1}d^{-1}$ (HRT of 1 d), the average effluent COD removal of the reed, cattail, and blank cells were 51, 51, and 41%, respectively. The average effluent COD values of both the reed and cattail cells were 78 mgl^{-1}, which was lower than the allowable COD value set by the Vietnamese industrial effluent quality standards (100 mgl^{-1}). This indicates that the application of a VSB wetland can be a suitable measure to mitigate organic

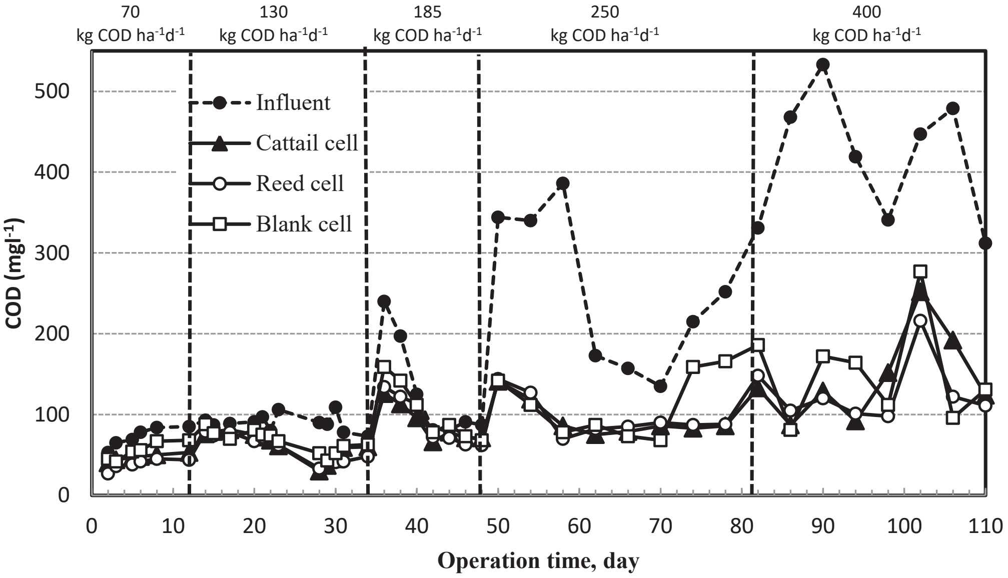

Fig. 4. Course of influent and effluent COD concentrations versus operation time.

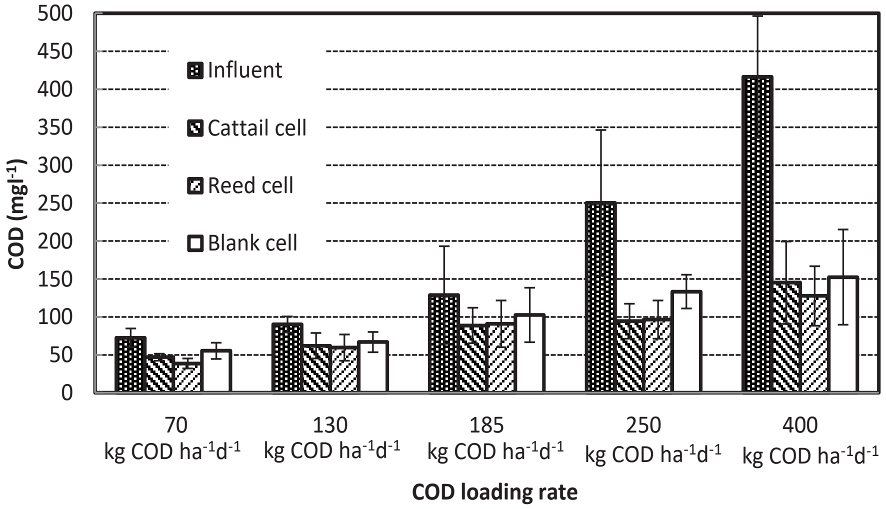

Fig. 5. COD concentration profile versus COD loading rates.

loading shock or overload of wastewater from a treatment plant.

Figure 5 presents high influent COD values at the loading rate of 400 kg COD ha^{-1}d^{-1} (HRT of 1 d) due to the overload of the CWWTP. High performance of both the cattail and reed cells in terms of COD removal was observed. The COD removals of the reed and cattail cells were about 69 and 64%, respectively. These results were similar to those of previous studies [17, 18]. The biodegradable organic matter that remained in the effluent from the secondary treatment of the CWWTP were broken down completely by attached bacteria in the VSB wetland. However, the average effluent COD concentration did not meet the COD threshold given by the Vietnamese industrial effluent quality standards.

Nitrogen removal

The feed wastewater quality of the pilot VSB was characterized by low ammonia concentration and high nitrate concentration (Table 2). The average total nitrogen removal of the reed, cattail, and blank cells at a COD loading rate of 70 kg COD ha^{-1}d^{-1} (HRT of 5 days) were 40, 37, and 29%, respectively. Fig. 6 shows that a lower total nitrogen removal was obtained at short HRTs.

There was no remarkable difference between the cattail and reed cells in terms of total nitrogen removal. The performance of the emergent plant cells was higher by 10% of the total nitrogen than that of the blank cell, which had the same support media but without the emergent plant. The uptake of nitrates by the emergent plants may have led to this difference [19]. Because of low ammonia concentration in the influent, attached denitrifying bacteria living in the bed media, along with rhizomes, played the main role in total nitrogen removal. However, the average effluent nitrate-N concentration at low loading rates and high loading rates (higher than 130 kg COD ha^{-1}d^{-1}) were 35 and 45 mgl^{-1}, respectively. Those values were higher than the allowable nitrate concentration set by the Vietnamese industrial effluent quality standards. In order to meet the standards, an anaerobic-aerobic (A-O) process should be done in the CWWTP.

Toxicity assessment

L.C.D. Hong, et al. (2000) [12] reported that wastewater with a TU_a higher than 10 could cause a medium toxic effect on the ecological system, and a TU_a higher than 50 is considered very toxic. The effluent of the CWWTP at low COD loading rates when the average COD concentration was around 78 mgl^{-1} had an average TU of 32, corresponding to medium toxicity level.

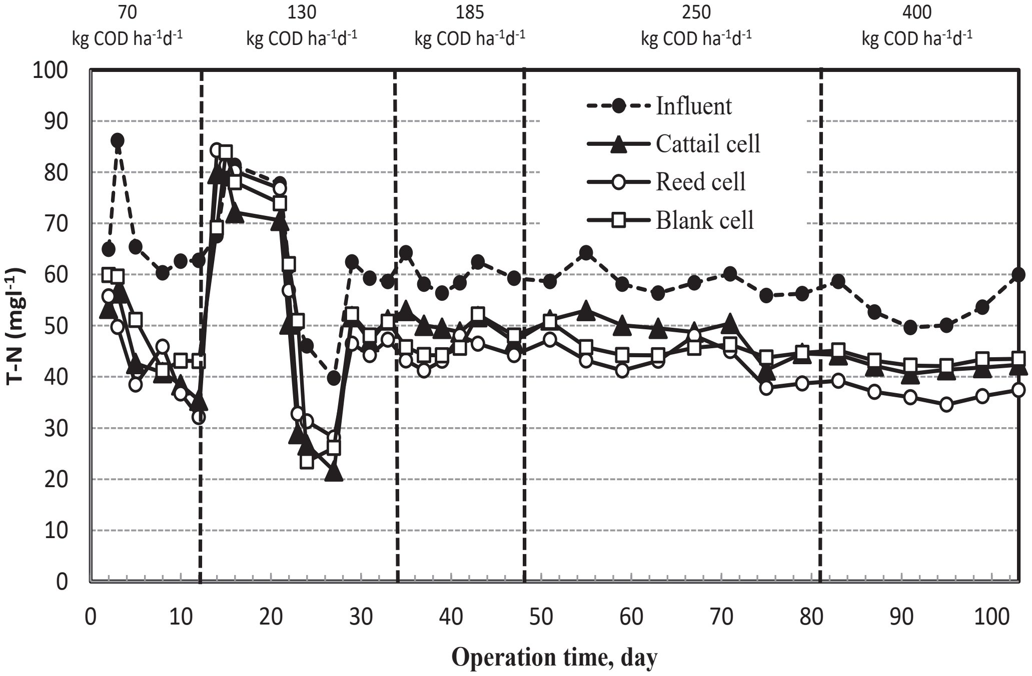

Fig. 6. Course of influent and effluent total nitrogen concentrations versus operation time.

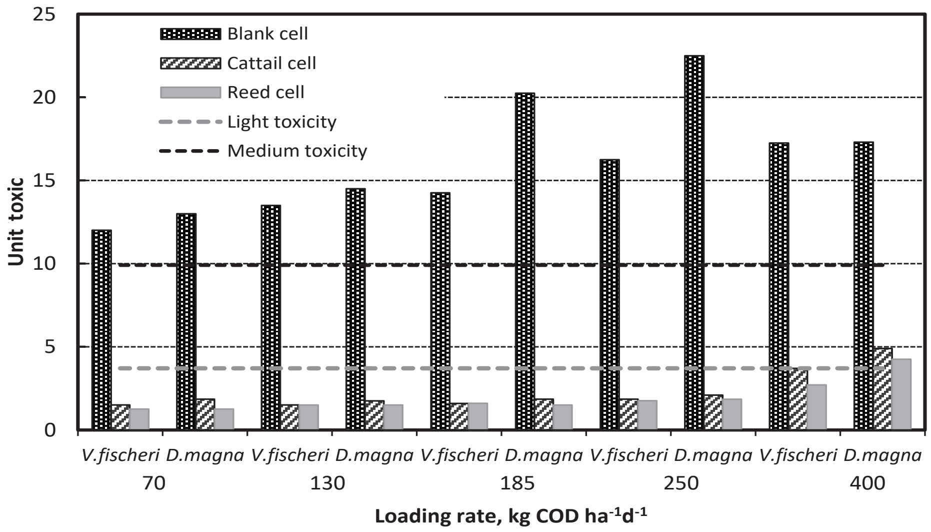

Fig. 7. The reduction of acute toxicity at various COD loading rates.

It was noticeable that the VSB wetland remarkably reduced TU_a of at all COD loading rates (Fig. 7). A high TU reduction efficiency was observed for both reed and cattail cells. At loading rates equal to and less than 250 kg COD $ha^{-1}d^{-1}$, the TUs of the effluent of the emergent plant cells were less than 3.0, while those of the blank cell was around 12. At a COD loading rate of 400 kg COD $ha^{-1}d^{-1}$, the TUs of the VSB wetland was approximately 5.0, corresponding to a light toxicity level. A significant difference in TU_a between the emergent plant cells and the blank one may be attributed to plant uptake of toxicants remaining in the influent. The effluent from the CWWTP may contain metals such as zinc, cadmium, and chromium and pesticide/herbicide residuals that originated from the 24 plating industries and a few pesticide industries in the industrial zone. Dan and Thanh (2010) [16] reported that the effluent from the CWWTP of the Le Minh Xuan industrial zone contained heavy metals, such as 0.5-2.7 mgl^{-1} of zinc, 0.27-0.45 mgl^{-1} of nickel, and 0.02-0.90 mgl^{-1} of chromium. Compared to the soil media, the plants do not take up as much metal or organic toxicants, but they are involved in oxygenation and microbiological processes that contribute to the ability of the wetland to remove metals and organic toxicants [19].

Conclusions

The VSB wetland was a good option for wastewater reuse and to enhance the performance of the industrial wastewater treatment plant. The pilot VSB wetland obtained high turbidity, SS, and COD removal at loading rates equal to and less than 250 kg COD $ha^{-1}d^{-1}$. The colour removal performance of the VSB wetland was low, even at low COD loading rates, due to the nonbiodegradable soluble substances contributing to the colour of the IZ wastewater treatment plant effluent. The highest total nitrogen removal efficiency, 40%, was obtained with the reed cell. The effluent quality at these loading rates met the limits for agricultural and industrial reuses.

The VSB wetland was a proper measure to mitigate overload or loading shock from industrial wastewater treatment plants. The results of this study show that the VSB wetland obtained a high efficiency of acute toxicity reduction due to the contributions of plant uptake of toxicants, biodegradation by attached bacteria, and other related physical-chemical processes.

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The authors declare that there is no conflict of interest regarding the publication of this article.

REFERENCES

[1] Ministry of Natural Resource and Environment (2010), *Annual Report on National Environment*.

[2] J. Vymazal (2009), "The use constructed wetlands with horizontal sub-surface flow for various types of wastewater", *Ecological Engineering*, **35**, pp.1-17.

[3] H. Wu, J. Zhang, H.H. Ngo, W. Guo, Z. Hu, S. Liang, et al. (2015), "A review on the sustainability of constructed wetlands for wastewater treatment: design and operation", *Bioresource Technology*, **175**, pp.594-601.

[4] X. Wang, Y. Tian, X. Zhao, S. Peng, Q. Wu, and L. Yan (2015), "Effects of aeration position on organics, nitrogen and phosphorus removal in combined oxidation pond-constructed wetland systems", *Bioresource Technology*, **198**, pp.7-15.

[5] R. Kadlec, R. Knight, J. Vymazal, H. Brix, P. Cooper, and R. Haberl (2000), *Constructed Wetlands for Pollution Control: Processes, Performance, Design and Operation*, IWA Publishing.

[6] J. Lloyd, D. Klessa, D. Parry, P. Buck, and N. Brown (2004), "Stimulation of microbial sulphate reduction in a constructed wetland: microbiological and geochemical analysis", *Water Research*, **38**, pp.1822-1830.

[7] A. Machado, M. Beretta, R. Fragoso, and E. Duarte (2017), "Overview of the state of the art of constructed wetlands for decentralized wastewater management in Brazil", *Journal of Environmental Management*, **187**, pp.560-570.

[8] W. Park (2009), "Integrated constructed wetland systems employing alum sludge and oyster shells as filter media for P removal", *Ecological Engineering*, **35**, pp.1275-1282.

[9] C.S. Calheiros, A.O. Rangel, and P.M. Castro (2008), "The effects of tannery wastewater on the development of different plant species and chromium accumulation in Phragmites australis", *Archives of Environmental Contamination and Toxicology*, **55**, pp.404-414.

[10] C.S. Calheiros, A.O. Rangel, and P.M. Castro (2009), "Treatment of industrial wastewater with two-stage constructed wetlands planted with *Typha latifolia* and *Phragmites australis"*, *Bioresource Technology*, **100**, pp.3205-3213.

[11] American Public Health Association, American Water Works Association, Water Environment Federation (2005), *Standard Methods for the Examination of Water and Wastewater, 21st*, USA.

[12] L.C.D. Hong, K. Becker-van Slooten, J.J. Sauvain, T.L. Minh, and J. Tarradellas (2000), "Toxicity of sediments from the Ho Chi Minh city canals and Saigon river, Viet Nam", *Environmental Toxicology: An International Journal*, **15**, pp.469-475.

[13] B.P. Elendt (1990), "Selenium deficiency in Crustacea", *Protoplasma*, **154**, pp.25-33.

[14] E. ISO (2012), "Water quality-determination of the inhibition of the mobility of Daphnia magna Straus (Cladocera, Crustacea) - acute toxicity test", *EN ISO*, **6341**, p.1996.

[15] Metcalf & Eddy, Inc. an AECOM Company, T. Asano, F.L. Burton, H. Leverenz, R. Tsuchihashi, et al. (2007), *Water Reuse: Issues, Technologies, and Applications*, McGraw-Hill Education.

[16] N.P. Dan and B.X. Thanh (2010), *Surveying wastewater system of Le Minh Xuan Industrial Zone and proposing the improvement measures*.

[17] T. Chen, C. Kao, T. Yeh, H. Chien, and A. Chao (2006), "Application of a constructed wetland for industrial wastewater treatment: a pilot-scale study", *Chemosphere*, **64**, pp.497-502.

[18] H. Hadad, M. Maine, and C. Bonetto (2006), "Macrophyte growth in a pilot-scale constructed wetland for industrial wastewater treatment", *Chemosphere*, **63**, pp.1744-1753.

[19] R. Lorion (2001), *Constructed Wetlands: Passive Systems for Wastewater Treatment*, US EPA Technology Innovation Office.