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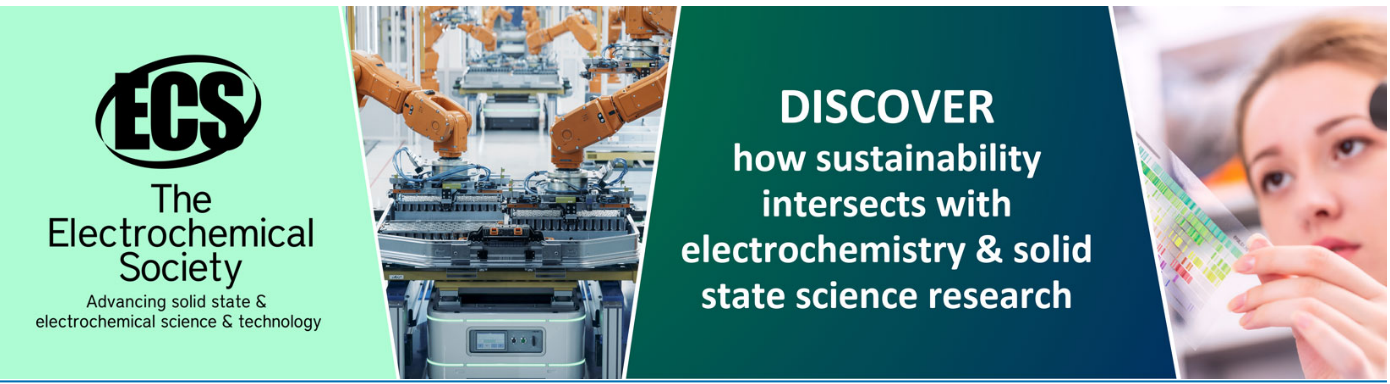

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Evaluating the efficiency of *Cyperus alternifolius* on constructed wetland for the domestic wastewater treatment in the peri-urban area of Northern Vietnam

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Abstract. Constructed wetland (CW) is an ecological work that can treat wastewater in natural condition. Combining CW with other ecological wastewater treatment works can create a suitable low-cost treatment system for peri- urban areas. The climatic conditions in the Northern region are favorable for the growth of *Cyperus alternifolius*, one of the commonly planted tree in HFCW worldwide. Our study focuses on the growth of *Cyperus alternifolius* on HFCW to evaluate the removal efficiency of organic substances and nutrients (BOD_5, $N\text{-}NH_4$, $N\text{-}NO_3$, $P\text{-}PO_4$). The dynamical coefficients of decomposition of those matters were also identified. This research employed a wastewater treatment pilot with HFCW planted *Cyperus alternifolius* and other ecological facilities in a peri-urban area in the North of Vietnam. It was found out that *Cyperus alternifolius* grew well with a high growth rate. The growth of *Cyperus alternifolius* enhanced the conversion of organic substances (BOD_5) and nutrients (NH_4, NO_3, PO_4) with high decomposition kinetic coefficients. The kinetic coefficient (k_{BOD}) of HFCW in this research was $0.214 m\cdot d^{-1}$ which is much higher than the recommendation of Design Standard TCVN 7957:2008. Domestic wastewater after being treated through CW satisfied level A of National technical regulation on domestic wastewater QCVN 14:2008/BTNMT.

1. Introduction

The North of Vietnam has a tropical monsoon climate around the year and is influenced by the Northeast monsoon and Southeast monsoon. The temperature increase gradually from north to south with the average temperature is around 25°C. Summer (April- October) is hot, humid and rainy until the monsoon comes. Winter (November- March) is colder than summer, dry and has drizzle; the temperature is 15-26°C. The average annual rainfall ranges from 1700 to 2400 mm but distributes unevenly between dry and rainy seasons [1]. Natural condition of Northern region is favorable for the application of ecological facilities for wastewater treatment. In recent years, the speed of socio-economic development in the northern mountainous region of Vietnam has increased significantly. These impacts create pressure on the environment as well as the technical infrastructure of urban areas in the region. The drainage system and centralized wastewater treatment cannot keep up with the urbanization process. Therefore, decentralized wastewater treatment for peri-urban areas is appropriate and necessary [2]. Ecological constructions such as constructed wetlands, stabilization pond, etc. are very suitable for suburban areas in the Northern region. Among frequently used CWs, horizontal submerged surface flow constructed wetlands (HF) are suitable for application in the densely

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populated areas [3], [4]. In HF, plants grow on the surface and wastewater is distributed in the planting substrate, creating underground flow, thus, reducing the potential of secondary pollution, such as odor, flies, etc.

Many kinds of plants that can treat water environment and possess strong viability were found frequently in nature in Vietnam [5]. Loc et al. (2015) found that *Pistia stratiotes L., Eichhornia crassipes*, and *Cyperus alternifolius* are suitable for growing on submerged constructed wetland in Mekong Delta region [6]. *Cyperus alternifolius* is a sun-loving, shade-tolerant perennial shrub with fibrous roots, forming large bush due to fast growing rate. *Cyperus alternifolius* can be easily propagated with seeds or from a part of the plant. *Cyperus alternifolius* is widely planted to create landscapes, fences, paper, hats, and bags and prevent soil erosion [7]. *Cyperus alternifolius* is studied as a plant species in CWs that treat pollutants in wastewater, especially N, P nutrients and heavy metals in many countries around the world as in Europe (Italy, Germany), Asia (China, Japan, Vietnam ...) [8], [9]. Moreover, *Cyperus alternifolius* is capable of highly converting organic matters and nutrients, suitable for cultivating in water environment, and can create ecological landscape for cities, particularly peri-urban areas of tropical and subtropical regions [10].

To assess the possibility of using *Cyperus alternifolius* in HF for domestic wastewater treatment, this study focuses on:

- Studying the growth of *Cyperus alternifolius* and determining the kinetic factors of decomposing organic matters and nutrients (BOD_5, $N\text{-}NH_4$, $N\text{-}NO_3$, $P\text{-}PO_4$) on HF combined with other ecological facilities in the pilot system in the field;
- Evaluating the pollutant removal efficiency of HF pilot system that is used to treat domestic wastewater for a peri-urban area in the Northern region.

2. Materials and Methods

2.1. Research on domestic wastewater treatment efficiency of CWs with Cyperus alternifolius

The subjects of this study were CWs used to treat domestic wastewater from setptic tanks in general drainage system of residential areas along Bach Quang ward, Song Cong town, Thai Nguyen province. Experimental diagram of CWs with *Cyperus alternifolius* was illustrated in Figure 1.

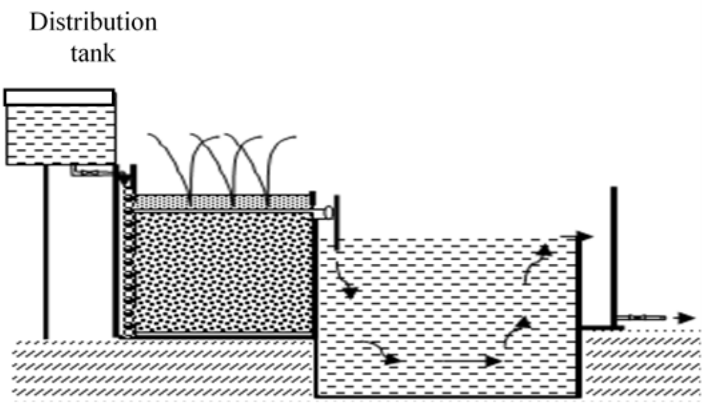

Figure 1. Experimental diagram of CWs with *Cyperus alternifolius* for domestic wastewater treatment in suburban residential area of Song Cong town

According to Figure 1, after running to distribution tank, wastewater passed through HF and stabilization pond. Criteria of experimental model was based on [11], [12] và [13] and illustrated in Table 1.

Table 1. Characteristics of studied HF

Criteria	Unit	Value
Hydraulic load rate, HLR[11]	$m^3 \cdot m^{-2} \cdot d^{-1}$	5
Wastewater flow Q	$m^3 \cdot d^{-1}$	0.048
Surface area As (As = 100Q/HLR) [12]	m^2	0.96
Length of HF	m	1.2
Width of HF	m	0.8
Depth of HF	m	0.75
Depth of surface water layer	m	0
Depth of sand filter (sand ϕ= 1÷2 mm) [12]	m	0.15
Depth of filter material (gravel ϕ = 2 ÷ 3 cm)[12]	m	0.6
Depth of supporting material (gravel ϕ = 4 ÷ 6 cm) [12]	m	-
HRT in HF (t = V/Q = As × y × n/Q [12])	d	4.57

2.2. Wastewater treatment efficiency of HF with Cyperus alternifolius

The subject of this study was HF used to treat domestic wastewater from student dormitory of Vietnam Agricultural Academy (VAA) in Trau Quy town (Gia Lam district, Hanoi). The location of HF with *Cyperus alternifolius* on the diagram of wastewater treatment process was shown in Figure 2.

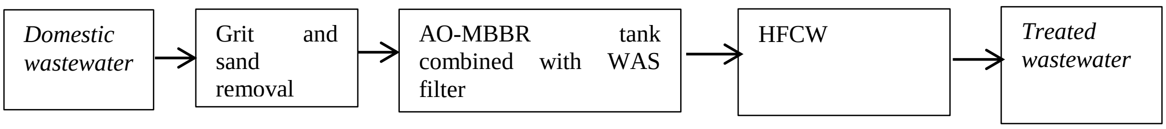

Figure 2. Wastewater treatment process in Vietnam Agricultural Academy

Domestic wastewater went through septic tanks and was pretreated in combined grit removal and sand filter tank. After that, wastewater was treated through biological process in AO-MBBR tank before returned to HF with the flow of 25-30 $m^3 \cdot d^{-1}$. Dimension of HF was calculated according to Clause 8.11.8 of Design Standard TCVN 7957:2008 [14] with the following parameters: L×B×H = 10.6×3.8×1.2m, slope i=0.5%. Material used in HF included gravel ϕ30 ÷ 50mm used to distribute wastewater at the inlet and collect wastewater at the effluent, supporting gravel ϕ8÷10mm in the middle of the facilities.

2.3. Plant on HF

Plant used on HF was *Cyperus alternifolius* belonging to the family of *Cyperaceae*, herbaceous, fibrous root with thick horizontal rhizomes, growing into clusters. The tree is usually 0.5-1.5m in height. Basal leaves reduce to sheaths at the base. *Cyperus alternifolius* has light green or light brown bracts similar to leaves, flat, and 10-30cm in length. Trunk grows on the ground with hollow core structure and unbranched.

The bushes of *Cyperus alternifolius* were divided into smaller cluster, approximately 10 trees per cluster, and planted on the pilot. Each tree was cut on the trunk, 40cm above the base and located separately 20cm in both vertical and horizontal directions. *Cyperus alternifolius* was let adapted gradually to wastewater environment, from low concentration until it grew well and buds appeared.

2.4. Analysis and calculation

Determination of dry biomass weight: After harvested, *Cyperus alternifolius* was transported to the laboratory, weighed, cut into pieces about 20-30 cm in length. *Cyperus alternifolius* was dried at 103°C - 105°C until unchanged weight, cooled down in desiccator, and weighed again. The difference between biomass weight before and after drying step was moisture content of the biomass. The difference between dry biomass weight before planting and after harvesting was the increase of plant biomass on CWs.

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Analysis of water quality parameters: BOD_5, TN, NH_4^+-N, NO_3^--N, PO_4^{3-}-P, …were analyzed in laboratory of National University of Civil Engineering and Thai Nguyen Environmental Monitoring Center. Those parameters were analyzed according to standard methods, including TCVN 6001-1995 (ISO 5815-1989) - Water quality - Determination of biochemical oxygen demand after 5 days (BOD5) - inoculation and dilution method [14], TCVN 5988-1995 (ISO 5664-1984) - Water quality - Determination of ammonium - Method of distillation and titration [15], TCVN 6180-1996 (ISO 7890-3-1988) - Water quality - Determination of nitrate - Spectroscopy method by using sulfuric acid [16], TCVN 6494-1999 - Water quality - Determine ions of orthophosphate by ion liquid chromatography [17], ...

Determination of kinetic coefficients: To determine the decomposition kinetic coefficients in CWs with *Cyperus alternifolius*, we consider CWs as biofilter reactor with a first-order reactive flow models for all pollutants, including BOD_5, TN, NH_4^+-N, NO_3^--N, PO_4^{3-}P, … First-order reaction rates are less sensitive to variable climate condition and independent of temperature [18].

$$ln\left(\frac{X_e-X^*}{X_i-X^*}\right)=\frac{-k}{q} \quad (1)$$

$$ln\left(\frac{X_i-X^*}{X_e-X^*}\right)=\frac{k}{q} \quad (2)$$

$$q=Q/A_s \quad (3)$$

in which A_s : treatment area of CWs (m^2);

X_e: pollutant concentration in the effluent ($mg\cdot L^{-1}$),

X_i: pollutant concentration in the inlet ($mg\cdot L^{-1}$);

X*: background concentration of pollutant ($mg\cdot L^{-1}$), can be identified as in Clause 8.11.8, Standard TCVN 7957:2008 [14]:

$$X^*=3.5+0.053X_i \quad (4)$$

K: first-order rate ($m\cdot d^{-1}$);

q: hydraulic load ($m^3\cdot m^2\cdot d^{-1}$ or $m\cdot d^{-1}$);

Q: average flow running to CWs ($m^3\cdot d^{-1}$).

3. Results and Discussion

3.1. Development of Cyperus alternifolius and wastewater treatment efficiency on experimental models

Cyperus alternifolius was planted on HF since Oct 4, 2015. *Cyperus alternifolius* began to grow fast around Dec 2015 with the appearance of new buds. During experimental period from Oct 2015 to May 2016, plant biomass was harvested twice in Feb 28, 2016 and Mar 20, 2016. Table 2 shows the results of development of *Cyperus alternifolius* on experimental models

Table 2. Development of *Cyperus alternifolius* in experimental period

No	Harvesting date	Total fresh biomass(g)	Total dry biomass (g)	Plant height (m)	
				Average	Maximum
1	Feb 28, 2016	4,400	867.68	1.28	1.45
2	Mar 20, 2016	7,250	1,429.70	1.60	1.80
Total		11,650	2,297.38		

Cyperus alternifolius in the experiment had a fast growth rate, high humidity (80.28%). The total obtained dry biomass was 2297.38 g. The average plant height was 1.28 and 1.60 m while the highest was 1.45 and 1.80 m in two harvesting times. Thus, *Cyperus alternifolius* adapted and developed well in HF.

3.2. Decomposition coefficients of domestic wastewater pollutants in experimented CW

Based on the obtained data from the experiments, applied equation (1) and (2), and used interpolation method, kinetic equations and decomposition coefficients of pollutants, including BOD_5, TN, NH_4^+-N, NO_3^--N, PO_4^{3-}-P,… were developed.

- Organic decomposition coefficient (k_{BOD})

The results of organic decomposition coefficient (BOD_5) was summarized in Table 3. Coefficient of organic decomposition in HF (k_{BOD}) tends to increase as the HLR increase, ranging from 0.084-0.150 $m{\cdot}d^{-1}$, reaching the highest when HLR is 0.10 $m^3{\cdot}m^{-2}{\cdot}d^{-1}$. Those values is consistent with k_{BOD} as 0.101, 0.123, 0.060-0.260 $m{\cdot}d^{-1}$ (or 37, 45, 22-95 m·y-1) published by Kadlec R.H. (2009), Vymazal J. (2008), and Trang et al. (2010), respectively [19], [20], [21].

Table 3. Coefficient of organic decomposition in domestic wastewater in experimented HF

HLR, $m^3{\cdot}m^{-2}{\cdot}d^{-1}$	Pollutant load, $kg{\cdot}ha^{-1}{\cdot}d^{-1}$	k_{BOD} $m{\cdot}y^{-1}$	k_{BOD} $m{\cdot}d^{-1}$
0.050	42.42	31	0.084
0.075	62.54	35	0.095
0.088	72.86	47	0.127
0.100	81.95	55	0.150

- Decomposition coefficients of ammonium, nitrate (k_{NH4+-N} , k_{NO3-N})

The results of decomposition coefficients of NH_4^+-N, NO_3^--N in experimented HF were illustrated in Table 4 and 5.

Coefficient k_{NH4-N} tends to decrease, ranging from 0.019-0.046 $m{\cdot}d^{-1}$, while HLR increase from 0.05 to 0.10 $m^3{\cdot}m^{-2}{\cdot}d^{-1}$. Those values are consistent with the results as 0.024 and 0.031 $m{\cdot}d^{-1}$ published by Vymazal and Kröpfelová (2008), Kadlec R.H. (2009), respectively [18], [20]. However, observed results are lower than values reported by Kadlec and Knight (1996), as k_{NH4-N} = 0.093 $m{\cdot}d^{-1}$ [22].

Coefficient k_{NO3^--N} tends to decrease, ranging from 0.029-0.093 $m{\cdot}d^{-1}$, while HLR increase from 0.05 to 0.10 $m^3{\cdot}m^{-2}{\cdot}d^{-1}$. Those values are consistent with the results as 0.039 $m{\cdot}d^{-1}$ published by Vymazal and Kröpfelová (2008) [20]. However, those results are lower than the value of 0.137 and 0.115 $m{\cdot}d^{-1}$ reported by Kadlec and Knight (1996), and Kadlec (2009), respectively [18], [22].

Table 4. Decomposition coefficients of ammonium in domestic wastewater in experimented HF

HLR, $m^3{\cdot}m^{-2}{\cdot}d^{-1}$	Pollutant load, $gN{\cdot}m^{-2}{\cdot}d^{-1}$	k_{NH4^+-N} $m{\cdot}y^{-1}$	k_{NH4^+-N} $m{\cdot}d^{-1}$
0.050	15.98	17	0.046
0.075	26.85	11	0.029
0.088	29.65	8	0.022
0.100	43.67	7	0.019

Table 5. Decomposition coefficients of nitrate in domestic wastewater in experimented HF

HLR, $m^3{\cdot}m^{-2}{\cdot}d^{-1}$	Pollutant load, $gN{\cdot}m^{-2}{\cdot}d^{-1}$	k_{NO3--N} $m{\cdot}y^{-1}$	k_{NO3--N} $m{\cdot}d^{-1}$
0.050	6.35	20	0.093
0.075	11.03	21	0.087
0.088	19.69	11	0.039
0.100	24.30	12	0.029

- Conversion coefficient of phosphate in HF ($k_{PO4^{3-}-P}$):

Table 6 illustrated conversion coefficient of phosphate in experimented HF. Coefficient $k_{PO4^{3-}-P}$ tends to decrease, ranging from 0.011-0.081 m·d^{-1}, while HLR increase from 0.05 to 0.10 m^3·m^{-2}·d^{-1}. Those values are consistent with the results as 0.033, 0.0247, 0.026, and 0.0164 m·d^{-1} published by Kadlec and Knight (1996), Brix (1998), Vymazal and Kröpfelová (2008), and Kadlec (2009), respectively [18], [20], [22], [23]. However, obtained coefficient $k_{PO4^{3-}-P}$ are lower than conversion coefficient of total phosphorus (TP) reported by Trang (2010) for domestic wastewater treated by HF (41-84 m·y^{-1} or 0.112-0.230 m·d^{-1}) [19]. Our results are also lower than coefficients for TP mentioned by Vymazal (2008) for wastewater in general (0.065 m·d^{-1}) and municipal wastewater (0.035 m·d^{-1}) [21].

Table 6. Conversion coefficient of phosphate in HF

HLR, m^3·m^{-2}·d^{-1}	Pollutant load, gN·m^{-2}·d^{-1}	$k_{PO4^{3-}-P}$	
		m·y^{-1}	m·d^{-1}
0.050	5.75	11	0.030
0.075	11.63	5	0.012
0.088	21.18	5	0.014
0.100	28.40	4	0.011
0.175	33.08	30	0.081
0.200	35.40	21	0.056

3.3. Domestic wastewater treatment efficiency of CW with Cyperus alternifolius in Vietnam Agricultural Academy

Horizontal submerged surface flow constructed wetland was used to treat domestic wastewater for Vietnam Agricultural Academy since Dec 2018. Wastewater flow in HF was 20 m^3·d^{-1}, ensuring hydraulic load (HRL) of 0.625 m^3·m^2·d^{-1}. After biological treatment process on MBBR system, organic loading rate of HF ranged around 300-315 kgBOD$_5$·ha^{-1}·d^{-1}. By observing the growth of *Cyperus alternifolius* and the variation of pollutants in the effluent, it was found that the operation of HF was divided into two distinguished phases. The former lasted one and half month, from Dec 10, 2018 to Jan 25, 2019 when *Cyperus alternifolius* adapted to HF. The latter was from Jan 25, 2019 to Mar 25, 2019 when HF operated stably. Treatment efficiency according to BOD$_5$, N-NH$_4$, TN, and P-PO$_4$ were illustrated from Figure 3 to 6.

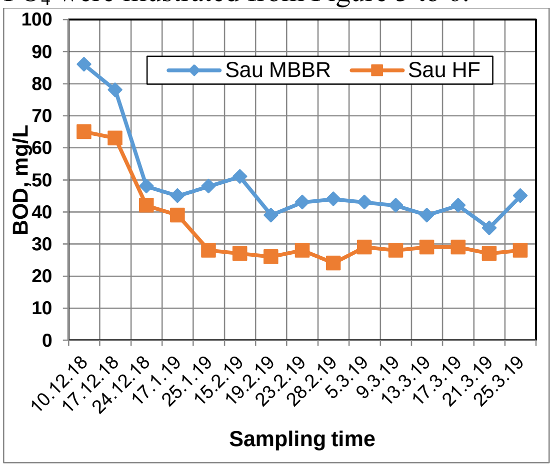

Figure 3. BOD removal efficiency of HF

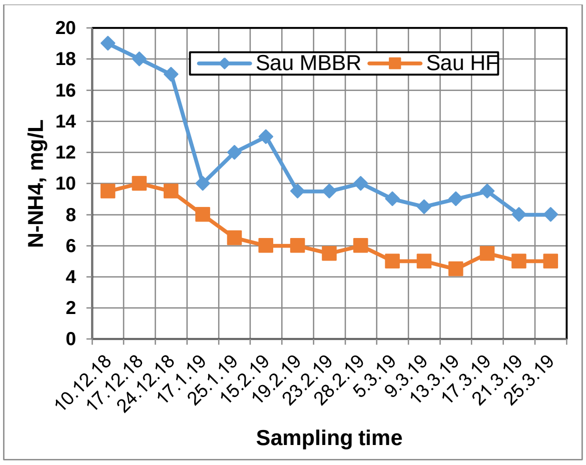

Figure 4. Ammonium removal efficiency of HF

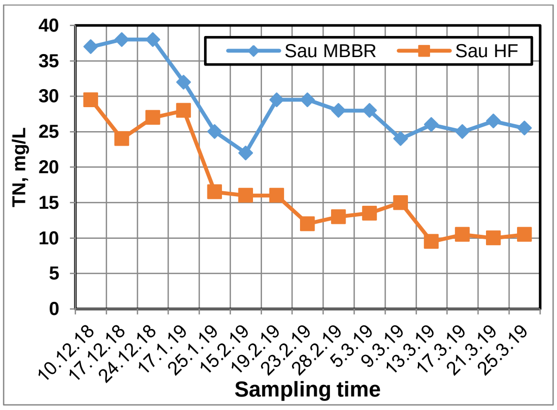

Figure 5. Total nitrogen removal of HF

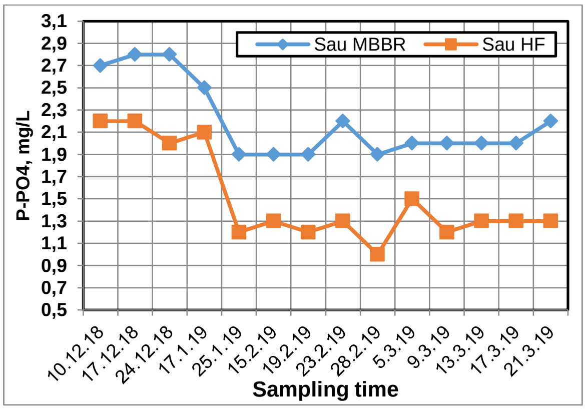

Figure 6. Phosphate removal of HF

After HF operated stably, BOD_5 concentration in the effluent of AO-MBBR and HF ranged 38-42 and 28-30 $mg \cdot L^{-1}$, respectively. Kinetic coefficient k_{BOD} calculated according to equation (2) and (4) was 0.214 $m \cdot d^{-1}$. That coefficient is similar to the obtained value from HF model in Bach Quang ward (k_{BOD} was 0.150 $m \cdot d^{-1}$, corresponding with HLR 0.100 $m^3 \cdot m^{-2} \cdot d^{-1}$) and higher than that recommended by TCVN 7957:2008 (0.095 $m \cdot d^{-1}$) [24]. Thus, *Cyperus alternifolius* on HF accelerated the process of organic decomposition in wastewater.

Similar to the decomposition of organic matters, conversion process of nitrogen and phosphorus happened strongly in HF with *Cyperus alternifolius*. After the plants adapted fully, wastewater treatment system operated stably, ammonium concentration in the effluent reduced significantly from 8-10 $mg \cdot L^{-1}$ to 4.2-5.8 $mg \cdot L^{-1}$. Total nitrogen concentration reduced from 25-28 $mg \cdot L^{-1}$ to 10-14.5 $mg \cdot L^{-1}$ while phosphorus concentration decreased from 1.9-2.2 $mg \cdot L^{-1}$ to 1.1-1.4 $mg \cdot L^{-1}$.

In addition to concentration of BOD_5, $N\text{-}NH_4$, TN, and $P\text{-}PO_4$, the results of monitoring activities for HF in VAA showed that other pollutant parameters in effluents met the thredshold for permission to discharge to surface water resource according to QCVN 14:2008/BTNMT- National technical regulation on domestic wastewater [25].

4. Conclusions

Constructed wetland is the ecological facility combining with others can create a low-cost treatment system, suitable for wastewater treatment in peri-urban area. The climate in Northern region of Vietnam is favorable for the growth of *Cyperus alternifolius*. When planted on CW, *Cyperus alternifolius* develop strongly and participate in the conversion of pollutants in wastewater.

The results from experimented CW showed that kinetic coefficients for the conversion of organic matters (k_{BOD}), nutrients ($k_{NH4\text{-}N}$, $k_{NO3\text{-}N}$, $k_{PO4^{3-}\text{-}P}$) reached high value. Research on domestic wastewater treatment system in VAA indicated that kinetic coefficient for organic matter kBOD was much higher than the value recommended by TCVN 7957:2008 [24]. Among the plants grown on CW, Cyperus alternifolius is appropriate for wastewater treatment. Therefore, after meeting level B of QCVN 14:2008/BTNMT- National standard on domestic wastewater, pollutants in wastewater can be treated in HF with *Cyperus alternifolius* to satisfy level A [25].

Acknowledgements

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