CHEMISTRY JOURNAL OF MOLDOVA. General, Industrial and Ecological Chemistry, 2017, 12(1), 45-52
ISSN (p) 1857-1727 ISSN (e) 2345-1688
http://cjm.asm.md
http://dx.doi.org/10.19261/cjm.2017.403

REMOVAL EFFICIENCY OF CONSTRUCTED WETLAND FOR TREATMENT OF AGRICULTURAL WASTEWATERS

Michal Šereš [a,b*], Tereza Hnátková [a,c], Jan Vymazal [c], Tomáš Vaněk [d]

[a]*Dekonta, A.S., 109, Dřetovice str., 273 42 Stehelčeves, Czech Republic*
[b]*University of Chemistry and Technology Prague, 5, Technická str., 166 28 Prague 6, Czech Republic*
[c]*Czech University of Life Sciences in Prague, 129, Kamýcká str., 165 21 Prague 6, Czech Republic*
[d]*Institute of Experimental Botany, Academy of Sciences of the Czech Republic, 313, Rozvojová str., 165 02 Prague 6-Lysolaje, Czech Republic*
[*]*e-mail: michal.seres@dekonta.cz; phone: (+420) 312 292 964*

Abstract. Constructed wetlands were proven to be the efficient method for treatment of agricultural wastewaters in last two decades. In this study, the performance of a constructed wetland for treating wastewater from small farm was tested. The constructed wetland for 75 PE with horizontal subsurface flow at Chrámce, Central Bohemian Uplands, Czech Republic, was built in 2011. A hybrid constructed wetland combining the horizontal (HF), vertical filter (VF) and horizontal (HF) filter stages has been designed to treat wastewater from the agriculture production (processing of fruits, sheep, pigs, production of jams, spirits and wine, etc.). The mechanical pretreatment consists of two accumulation tanks (for different wastewater types) from which the wastewater is intermittently pumped into a settling tank. The treatment system consists of two horizontal flow beds and one vertical flow bed with intermittent feeding. The filters are planted with *Phragmites australis*, *Phalaris arundinacea*, *Iris pseudacorus*, *Iris sibirica*, *Glyceria maxima* and *Lythrum salicaria*. For tertiary treatment, three shallow ponds with littoral vegetation were designed. During the feed batch operation the inflow values up to 25.400 mg/L COD and 2.640 mg/L BOD_5 were reduced by up to 99%. The volume of each feed batch was applied at one to five day intervals. Also, the effect of discharged water on the littoral zone of aquatic biotopes has been evaluated. This knowledge is necessary for the design of a stable, artificial water system.

Keywords: constructed wetland, agriculture wastewater, hybrid systems, horizontal filter, vertical filter.

Received: 31 March 2017/ Revised final: 4 April 2017/ Accepted: 17 May 2017

Introduction

Constructed wetlands (CWs) have been used for a long time for treatment of domestic sewage [1-4]; recently, being used for treatment of agricultural and industrial wastewaters [5-8]. Constructed wetlands are often used as tertiary treatment; however, their use as a secondary stage for small municipalities is quite common as well [9]. According to the Czech legislation, constructed wetlands are included among BAT technologies for municipalities < 500 PE. Since 1989, about 250 constructed wetlands have been built in the Czech Republic [10,11].

There are several types of constructed wetlands, which differ in absence/presence of water (free water surface CWs, subsurface flow CWs), vegetation (submerged, emergent, free floating) and flow direction (horizontal, vertical) [4]. The most commonly used CWs in Europe are those with horizontal subsurface flow (HF CWs) [12], but constructed wetlands with vertical flow (VF CWs) are getting more attention at present [1,3]. Hybrid constructed wetlands usually combine HF and VF wetlands in a staged manner in order to exploit advantages of each wetland. The major reason for the use of hybrid CWs are the more stringent requirements for discharged water quality and especially nitrogen [13,14]. In hybrid CWs, both units are used to eliminate the organic matter and suspended solids, VF and HF units are supposed to perform nitrification and denitrification, respectively [13]. The removal of total nitrogen in hybrid CWs may amount to 85% or even more [13,15]. The hybrid CWs are based on the concept developed by Käthe Seidel in Max Planck Institute in Krefeld, Germany [16]. Such systems consisted of several parallel VF beds followed by 2-3 HF beds. Brix, H. *et al.* [1] described a hybrid system consisting of a large HF bed followed by a small VF bed. Vymazal and

Kröpfelová described an experimental hybrid constructed wetland with saturated VF bed, free-drain VF bed and HF bed [18]. The combined system exhibited 78% removal of ammonium with no buildup of nitrates at the outflow. Another hybrid CW in the Czech Republic was built in 2011 at Kotenčice in Central Bohemia. The system replaced the original CW, which was built in 1994. The original system consisted of one HF bed with surface area of 1800 m^2. The removal efficiency of the original system was enough to meet the discharge limits set by the legislation; however, severe clogging occurred at several locations of the bed. The newly built system is designed for 300 PE and consists of three parallel streams in which HF beds (total area 911 m^2) and VF beds (total area 300 m^2) are alternately connected. The fourth stream consists of four independent beds (2 HF and 2 VF). The hybrid CW has been designed to test optimum combination of HF and VF beds and the results are intended to be used as guidelines for future hybrid constructed wetlands [19].

The use of constructed wetlands for elimination of pollution from agricultural wastewaters is getting more common, especially for wastewaters from animal feedlots [6] and drainage waters [20,21]. Feedlot wastewaters are characterized by high content of organic matter, with BOD_5 concentrations usually one order of magnitude higher than in domestic sewage [5]. Healy *et al.* [22] reported the inflow BOD_5, total nitrogen (TN) and $N\text{-}NH_4$ concentrations in seven constructed wetlands treating concentrated animal wastewaters in the range of 220 – 7130 mg L^{-1}, 64 - 103 mg L^{-1} and 22 – 350 mg L^{-1}, respectively. The total organic loading varied between 1.9 and 60 g m^{-2}. According to the Livestock Wastewater Treatment Database [6] summarizing data from 48 constructed wetlands with 1390 samplings from animal feedlots, dairies, pig farms and poultries, the highest BOD_5 concentrations were measured in dairies (up to 442 mg L^{-1}), while at other facilities BOD_5 varied between 104 and 153 mg L^{-1}. Dairy wastewaters also exhibited the highest total suspended solids (TSS) concentrations (up to 1111 mg L^{-1}), while TSS concentrations from the pig farms and cattle feedlots amounted to about 128 mg L^{-1} and 291 mg L^{-1}, respectively. Total nitrogen concentrations from pig farms, poultry farms and dairies averaged 407 mg L^{-1}, 89 mg L^{-1} and 103 mg L^{-1}, respectively.

Wastewaters from food processing facilities, namely from wine-making facilities, are characterized by high concentrations of organic matter, high acidity and high fluctuation in quantity [23]. COD in wastewater from wine production process and rest seasons may amount to 7406 mg L^{-1} and 1721 mg L^{-1} [24] or 15400 mg L^{-1} and 3700 mg L^{-1}, respectively [25]. Masi *et al.* reported BOD_5 concentrations from three wine-making facilities in the range of 354 - 1793 mg L^{-1} [23]. Grismer *et al.* reported the off-season elimination of COD, TSS and TN of 79%, 85% and 66%, respectively [24]. On the other hand, during the wine-making season the elimination substantially decreased with sharp increase of the inflow concentrations and amounted to only 49, 30 and 25%, respectively. Also, constructed wetlands have shown to effectively removed pesticides [26] and therefore, constructed wetlands seem to be appropriate treatment technology for such agricultural waters.

As constructed wetlands are efficient and have low capital and operation and maintenance costs, they seem to be a suitable solution for wastewater treatment, especially in developing countries [27]. So called “Integrated” constructed wetland are also used in Europe [8,28] and are suitable alternative to conventional treatment systems. Due to high concentrations of nutrients in agricultural wastewaters and drainage waters, agriculture contributes significantly to the global pollution of surface and ground waters [29], and therefore, it is necessary to continue the development of effective, simple and cheap methods for the treatment of this type of wastewater. This article presents a high cleaning efficiency of the hybrid constructed wetland system for different loadings of agricultural wastewaters produced by the farm.

Methods

Description of constructed wetland Chrámce

Constructed wetland Chrámce in North Bohemia, Czech Republic is owned by “Caste Orchards Chrámce” and it receives sewage from the castle (negligible part of the total flow), wastewaters from fruit, fruit juice and wine processing (total area of orchards and vineyards is 195 ha and 1.9 ha, respectively) and from 150 sheep. The constructed wetland was put in full operation in 2012. The system is located at the altitude of 355 m and the area is characterized by low precipitation (*cca.* 500 mm per year) and high average annual air temperature (8.4-8.8°C).

Hybrid constructed wetland Chrámce consists of pretreatment, series of three constructed wetlands (HF1-VF-HF2, Table 1), and tertiary treatment is achieved in three small ponds with littoral zones connected with a meandering stream.

Table 1

Main design parameters of constructed wetlands.

Parameter	*Unit*	*HF1*	*VF*	*HF2*
Length	m	19	7	10
Effective area	m^2	133	49	70
Depth	m	0.7	1.3	0.9
Filtration material*		a, b, c	a, b, c, d	a, b, c, e
Effective volume	m^3	97.2	50.4	48.6
Hydraulic loading rate	cm d^{-1}	3.8	10.2	7.1

**a - washed gravel 2–4 mm (protective material);*
b - washed gravel 4–8 mm, porosity 45%, hydraulic conductivity 16 cm s^{-1};
c - washed gravel 8–16 mm, porosity 44%, hydraulic conductivity 94 cm s^{-1};
d - washed gravel 32–64 mm, porosity 46%, hydraulic conductivity 350 cm s^{-1};
e - slag 8–16 mm, porosity 51%, hydraulic conductivity 47 cm s^{-1}.

The treated water is discharged into the existing pond (Figure 1). Pretreatment stage consists of two accumulation tanks (10 m^3 and 16 m^3) and a three-chamber septic tank (effective volume -14.1 m^3). Outflow from the pretreatment stage feeds HF1 CW, where reduction of TSS, BOD_5, COD and nitrate is achieved. The next stage, VF CW, is designed to achieve nitrification and final stage and HF2 CW is designed to denitrify. The discharged water flows into a sealed meandering stream overgrown by wetland plants to a series of there shallow ponds. Wetland beds are planted with Reed canarygrass (*Phalaris arundinacea*) and Common reed (*Phragmites australis*). Meandring stream and littoral zones are planted with Sweet mannagrass (*Glyceria maxima*), Purple loosestrife (*Lythrum salicaria*), Yellow iris (*Iris pseudacorus*), Siberian iris (*Iris sibirica*), Sweet flag (*Acorus calamus*), Beaked sedge (*Care xrostrata*) and Broadleaf cattail (*Typha latifolia*). The design flow is 5 m^3 d^{-1} and theoretical retention time is 15.7 days. The tracer tests with KBr [2] indicated the retention time of 10 days. Wastewater is fed into accumulation tanks once a week.

For treatment efficiency evaluation, parameters limited by the Czech legislation were monitored: COD, BOD_5, total phosphorus (TP), TN, NH_4^+, TSS (Table 2). Also, for more detailed evaluation of nitrogen removal, concentration of nitrate and nitrite were monitored. Samples of raw wastewater were taken on a weekly basis from accumulation tank during feeding (n = 11) during the period September-November 2013 after one year of operation during the high season and during the period April – July 2014 after two years of operation, off-season. Other sampling points (1-7) are shown in Figure 1. The samples were analyzed according to the Standard Methods [30]. For the final evaluation, results from the second sampling campaign were used as after two years of operation the systems usually become mature and treatment performance is usually stable [31].

Results and discussion

The evaluation of treatment performance was carried out first after one year of operation, during the period September – November 2013 (Table 3). The results indicate that water discharged from the constructed wetland has met the limits set by the Czech legislation. However, the composition of agricultural wastewaters is very variable during the year and this fact is documented in Table 3. The difference between season and off-season wastewater characteristics quality is particularly obvious for TSS (season mean 65x higher than off-season mean) and organics - COD (23x higher) and BOD_5 (7x higher).

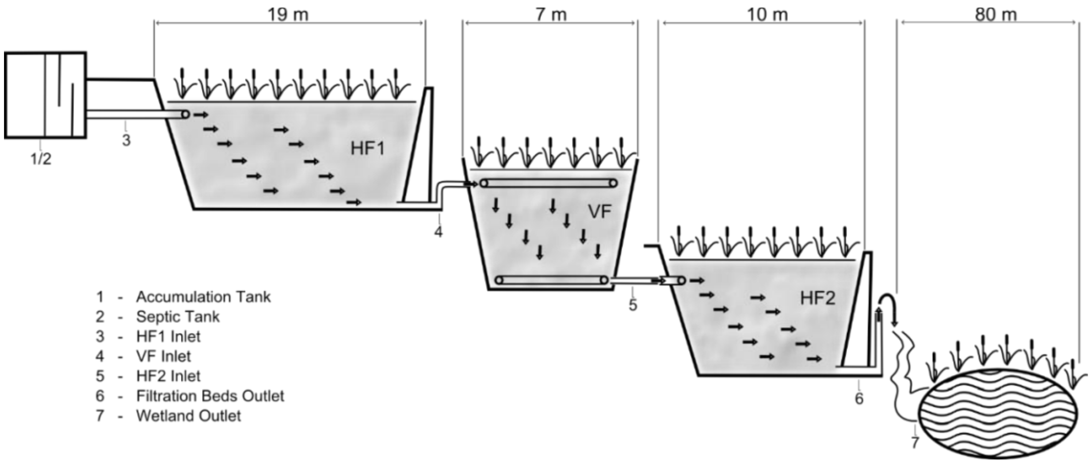

Figure 1. Layout of the constructed wetland Chrámce.

Table 2

Wastewater effluent standards set by Czech legislation.

Parameter	*Average value, mg L^{-1}*	*Max. value, mg L^{-1}*	*Removal efficiency,%*
COD	110	170	70 - 75
BOD_5	30	50	80 - 85
TSS	40	60	90 - 95
TN	-	-	-
NH_4^+	-	-	75 - 80
TP	-	-	80

Table 3

Constructed wetland performance, period September – November 2013*.

Parameter	*Influent*		*Effluent*		*Removal efficiency,%*
	Average, mg L^{-1}	*Max., mg L^{-1}*	*Average, mg L^{-1}*	*Max., mg L^{-1}*	
COD	12780	25400	34.1	66.1	93.4
BOD_5	1358	2640	1.1	1.6	96.7
TSS	32795	65500	3.5	6	86.9
TN	116.7	449	9.2	10	61.8
NH_4^+	88.9	350	0.07	0.13	99.7
TP	10.25	14.5	0.05	0.05	99.3

**after 1 year of operation*

Table 4

Constructed wetland performance, period April – July 2014*.

Parameter	*Wetland system*		*Removal efficiency, %*
	Influent, mg L^{-1}	*Effluent, mg L^{-1}*	
COD	552.1 ± 363.9	15.1 ± 6.0	95.4
BOD_5	187.5 ± 127.7	2.5 ± 2.0	96.7
TSS	500.6 ± 562.6	2.8 ± 1.0	98.4
TN	48.4 ± 19.6	6.5 ± 4.7	86.3
NO_2^-	0.03 ± 0.001	0.04 ± 0.01	-
NO_3^-	2.2 ± 2.1	4.1 ± 4.1	-
NH_4^+	38.8 ± 14.9	0.07 ± 0.001	99.8
TP	7.7 ± 3.7	0.3 ± 0.2	81.6

**after 2 years of operation*

Hybrid constructed wetland at Chrámce exhibited high treatment efficiency for all parameters limited by the Czech legislation and the results are comparable with other hybrid constructed wetlands [3,13]. CW under both loading strategies showed high removal efficiencies for all parameters up to 93.4 and 95.4% for COD, 96.7 and 96.7% for BOD, 86.9 and 98.4% for TSS and 99.7 and 99.8% for ammonium (Tables 3 and 4). Startlingly high removal efficiencies for ammonium removal are not common for constructed wetlands and confirm applicability of the system for agricultural wastewaters. However, constructed wetlands, in general, are very effective in removing organic matter from wastewaters. Also, the percentage efficiency depends on the inflow concentration, the higher inflow concentration, the higher treatment efficiency [32,33]. The concentrations of both parameters slightly increased at the outflow from the tertiary treatment, however, the concentrations were well below the discharge limits. The increase could be explained by decay of plants or growth of algae in the ponds.

Mean inflow TSS concentration of 500.6 mg L^{-1} was reduced by 98.4% with the average TSS outflow concentration of 2.8 mg L^{-1}. At the end of the monitored period, the outflow TSS concentrations exceeded those from the inflow (Figure 2). It is a common phenomenon observed in free water surface constructed wetlands. However, there are various explanations for this phenomenon. Hijosa-Valsero *et al.* [31] explained the increase of TSS concentration by the presence of planktonic algae, while Coleman *et al.* [34] explained the TSS concentration increase by filtration material decomposition due to vegetation growth. Ghermandi *et al.* [33] pointed out that constructed wetland may be a source of TSS.

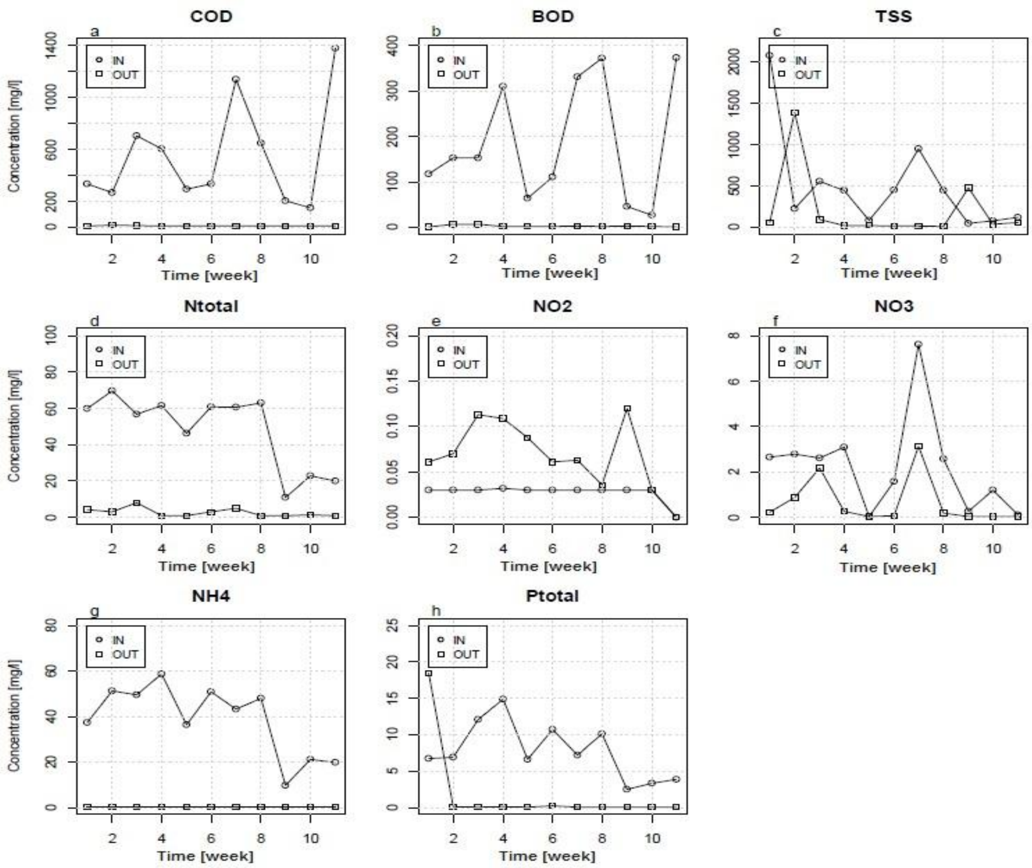

Figure 2. Removal of organic matter, TSS, nitrogen and phosphorus at CW Chrámce during the period April – July 2014.

Nitrogen and phosphorus compounds are the substantial components in the agricultural wastewaters. Total nitrogen (sum of inorganic and organic nitrogen forms) was removed very effectively. This is quite common for Hybrid Constructed Wetlands as compared to single HF or VF CWs [13]. The average inflow TN concentration of 48.4 mg L^{-1} was reduced by 86% with the mean outflow TN concentration of 6.5 mg L^{-1}. Most nitrogen in the inflowing wastewater was in the form of ammonium (80%), which is effectively removed in VF CW and also in HF CW, where the concentrations of dissolved oxygen are high enough to support nitrification. Ammonia could also be volatilized and fixed by the vegetation biomass [5]. The overall efficiency of the system amounted to 99.8% and it is comparable with the efficiency of integrated constructed wetlands [28] that, however, have much longer retention time. Inflow ammonium concentration is a concern as concentration > 100 mg L^{-1} could be harmful for plants and can hamper the treatment efficiency of the system. Elimination of nitrite and nitrate was apparently incomplete, indicated by the increase of nitrite concentrations in the outflow from constructed wetlands. Also, nitrate concentration substantially increased after HF2 stage, nitrate concentrations being five times higher in comparison to outflow from the VF stage. One possible explanation is that some nitrification proceeds in HF2 bed but denitrification is limited by low concentration of organic matter. The final polishing stage, a pond with littoral vegetation, substantially reduced the nitrate concentration to < 0.6 mg L^{-1}.

Nitrogen is removed in constructed wetlands primarily by biological processes, while phosphorus is mostly removed through physico-chemical processes [35]. In comparison with most constructed wetlands, the overall TP removal amounted to 81.6%, which is very high removal effect [3]. The data shown in Figure 3 revealed that phosphorus is mostly removed in the ponds beyond the constructed wetlands. High removal efficiency in the system could be explained by the use of slag with high phosphorus sorption capacity (up to 44.2 g kg^{-1}) and represents one of the most efficient materials for phosphorus removal [36].

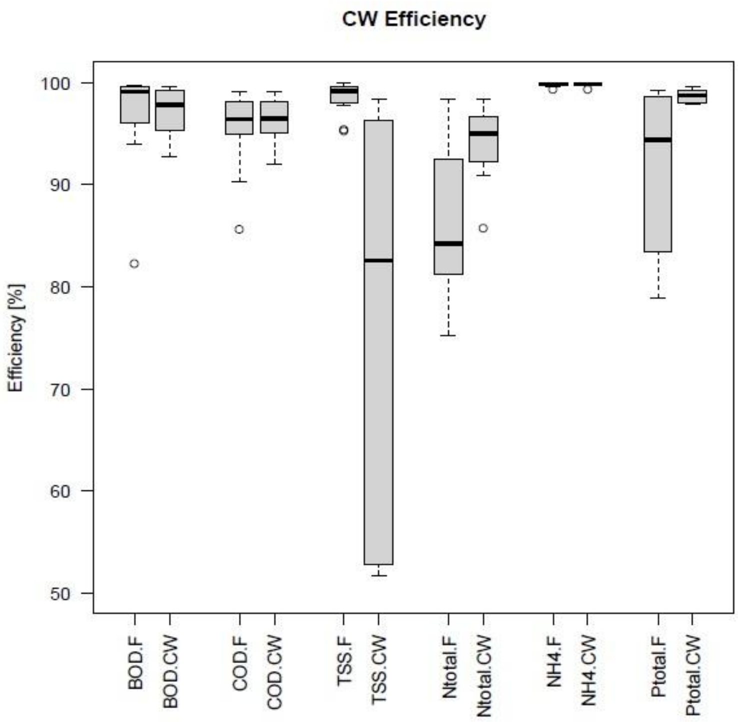

Figure 3. Treatment efficiency of monitored parameters in vegetated wetlands cells and the whole wetland system (after stabilization ponds).

Conclusions

A hybrid constructed wetland combining the horizontal (HF), vertical filter (VF) and horizontal (HF) filter stages with polishing ponds with littoral zones proved to be a suitable and effective solution for treatment of concentrated wastewaters from agricultural facilities. Despite quite high inflow concentrations of organic matter (mean values: 522 mg L^{-1} for COD and 188 mg L^{-1} for BOD_5), the outflow concentrations of these parameters are very low (15.1 mg L^{-1} and 2.5 mg L^{-1}, respectively) with removal efficiency amounting to 95.4% and 96.7%, respectively. Wetland system effectively removed the nitrogen compounds due to combination of three subsurface wetlands with various feeding strategy. The use of slag as filtration material contributes to the more efficient removal of phosphorus. The hybrid constructed wetland was improved and stabilized during the second operational year, especially for total suspended solids and nitrogen (up to 95% for both parameters).

Acknowledgements

The study was financial supported by the Technology Agency of the Czech Republic, grant no. TA01020573 “Biotechnological system for treatment of wastewaters from agriculture and their recycling”.

References

1. Brix, H.; Arias, C.A. The use of vertical flow constructed wetlands for on-site treatment of domestic wastewater: New Danish guidelines. Ecological Engineering, 2005, 25, pp. 491–500. DOI: https://doi.org/10.1016/j.ecoleng.2005.07.009.
2. Kadlec, R.H.; Wallace, S. Treatment Wetlands. CRC Press: Boca Raton, Florida, 2nd Ed., 2009, 965 p.
3. Vymazal, J. Horizontal sub-surface flow and hybrid constructed wetlands systems for wastewater treatment. Ecological Engineering, 2005, 25, pp. 478–490. DOI: https://doi.org/10.1016/j.proeng.2012.07.592.
4. Vymazal, J. Constructed wetlands for wastewater treatment: five decades of experience. Environmental Science & Technology, 2011, 45, pp. 61–69. DOI: 10.1021/es101403q.
5. Cronk, J.K. Constructed wetlands to treat wastewater from dairy and swine operations : A review. Agriculture Ecosystems and Environment, 1996, 58, pp. 97–114.
6. Knight, R.L.; Payne, V.W.E.; Borer, R.E.; Clarke, R.A.; Pries, J.H. Constructed wetlands for livestock wastewater management. Ecological Engineering, 2000, 15, pp. 41–55. DOI: https://doi.org/10.1016/S0925-8574(99)00034-8.
7. Dunne, E.J.; Culleton, N.; O’Donovan, G.; Harrington, R.; Olsen, A.E. An integrated constructed wetland to treat contaminants and nutrients from dairy farmyard dirty water. Ecological Engineering, 2005, 24, pp. 219–232.

DOI: https://doi.org/10.1016/j.ecoleng.2004.11.010.
8. Harrington, R.; McInnes, R. Integrated Constructed Wetlands (ICW) for livestock wastewater management. Bioresource Technology, 2009, 100, pp. 5498–5505. DOI: https://doi.org/10.1016/j.biortech.2009.06.007.
9. Solano, M.; Soriano, P.; Ciria, M. Constructed wetlands as a sustainable solution for wastewater treatment in small villages. Biosystems Engineering, 2004, 87, pp. 109–118. DOI: https://doi.org/10.1016/j.biosystemseng.2003.10.005.
10. Vymazal, J. The use of sub-surface constructed wetlands for wastewater treatment in the Czech Republic : 10 years experience. Ecological Engineering, 2002, 18, pp. 633–646. DOI: https://doi.org/10.1016/S0925-8574(02)00025-3.
11. Vymazal, J. Ed. Water and Nutrient Management in Natural and Constructed Wetlands. Springer: Dordrecht, Heidelberg, London, New York, 2010, 330 p. DOI: 10.1007/978-90-481-9585-5.
12. Vymazal, J.; Kröpfelová, L. Wastewater Treatment in Constructed Wetlands with Horizontal Subsurface Flow. Springer: Dordrecht, Heidelberg, London, New York, 2008. 566 p. DOI: 10.1007/978-1-4020-8580-2.
13. Vymazal, J. The use of hybrid constructed wetlands for wastewater treatment with special attention to nitrogen removal: A review of a recent development. Water Research, 2013, 47, pp. 4795-4811. DOI: https://doi.org/10.1016/j.watres.2013.05.029.
14. Tunçsiper, B. Nitrogen removal in a combined vertical and horizontal subsurface-flow constructed wetland system. Desalination, 2009, 247, pp. 466–475. DOI: https://doi.org/10.1016/j.desal.2009.03.003.
15. Kantawanichkul, S.; Neamkam, P.; Shutes, R. Nitrogen removal in a combined system: vertical vegetated bed over horizontal flow sand bed. Water Science & Technology, 2001, 44, pp. 137–142.
16. Seidel, K. New approaches to groundwater recharge in Krefeld. II. Hydrobotanic cleaning method. GWF Wasser/Abwasser, 1965, 30, pp. 831-833. (in German).
17. Vymazal, J. Ed. Wetlands-Nutrients, Metals and Mass Cycling. Backhuys: Leiden, 2003, 374 p.
18. Vymazal, J.; Kröpfelová, L. A three-stage experimental constructed wetland for treatment of domestic sewage: First 2 years of operation. Ecological Engineering, 2011, 37, pp. 90–98. DOI: https://doi.org/10.1016/j.ecoleng.2010.03.004.
19. Hudcová, T.; Vymazal, J.; Kriška, M. Reconstruction of a constructed wetland with horizontal subsurface flow after 18 years of operation. Water Science & Technology, 2013, 68, pp. 1195–1202. DOI: https://doi.org/10.2166/wst.2013.374.
20. Xue, Y.; Kovacic, D.A.; David, M.B.; Gentry, L.E.; Mulvaney, R.L.; Lindau, C.W. *In situ* measurements of denitrification in constructed wetlands. Journal of Environmental Quality, 1999, 28, pp. 263–269.
21. Poe, C.A.; Piehler, M.F.; Thompson, S.P.; Paerl, H.W. Denitrification in a constructed wetland receiving agricultural runoff. Wetlands, 2003, 23, pp. 817–826. DOI: 10.1672/0277-5212(2003)023[0817:DIACWR]2.0.CO;2.
22. Healy, M.G.; Rodgers, M.; Mulqueen, J. Treatment of dairy wastewater using constructed wetlands and intermittent sand filters. Bioresource Technology, 2007, 98, pp. 2268–2281. DOI: https://doi.org/10.1016/j.biortech.2006.07.036.
23. Masi, F.; Conte, G.; Martinuzzi, N.; Pucci, B. Winery high organic content wastewaters treated by constructed wetlands in mediterranean climate. Proceeding IWA 8th International Conference Wetland Systems for Water Pollution Control, Tanzania and IWA, 2002, pp. 274-282.
24. Grismer, M.E.; Carr, M.A.; Shepherd, H.L. Evaluation of constructed wetland treatment performance for winery wastewater. Water Environment Research, 2003, 75, pp. 412–421. DOI: https://doi.org/10.2175/106143003X141213.
25. Shepherd, H.L.; Grismer, M.E.; Tchobanoglous, G. Treatment of high-strength winery wastewater using a subsurface-flow constructed wetland. Water Environment Research, 2001, 73, pp. 394–403.
26. Agudelo, R.M.; Jaramillo, M.L.; Penuela, G. Science of the total environment comparison of the removal of chlorpyrifos and dissolved organic carbon in horizontal sub-surface and surface flow wetlands. Science of the Total Environment, 2012, 431, pp. 271–277. DOI: https://doi.org/10.1016/j.scitotenv.2012.05.045.
27. Arias, M.E.; Brown, M.T. Feasibility of using constructed treatment wetlands for municipal wastewater treatment in the Bogotá Savannah, Colombia. Ecological Engineering, 2009, 35, pp. 1070–1078. DOI: https://doi.org/10.1016/j.ecoleng.2009.03.017.
28. Harrington, C.; Scholz, M. Assessment of pre-digested piggery wastewater treatment operations with surface flow integrated constructed wetland systems. Bioresource Technology, 2010, 101, pp. 7713–7723. DOI: https://doi.org/10.1016/j.biortech.2010.03.147.
29. Galloway, J.N.; Dentener, F.J.; Capone, D.G.; Boyer, E.W.; Howarth, R.W.; Seitzinger, S.P.; Asner, G.P.; Cleveland, C.C.; Green, P.A.; Holland, E.A.; Karl, D.M.; Michaels, A.F.; Porter, J.H.; Townsend, A.R.; Vöosmarty, C.J. Nitrogen cycles: past, present, and future. Biogeochemistry, 2004, 70, pp. 153–226. DOI: 10.1007/s10533-004-0370-0.
30. APHA, AWWA, WEF Eds. Standard Methods for the Examination of Water and Wastewater. APHA: Washington. 1995, 19th Edition, 1108 p.
31. Hijosa-Valsero, M.; Sidrach-Cardona, R.; Bécares, E. Comparison of interannual removal variation of various constructed wetland types. Science of the

Total Environment, 2012, 430, pp. 174–183. DOI: https://doi.org/10.1016/j.scitotenv.2012.04.072.

32. Cooper, P.F.; Findlater, B.C. Eds. Constructed Wetlands in Water Pollution Control. Pergamon Press: Oxford, 1990, pp. 495-504.

33. Ghermandi, A.; Bixio, D.; Thoeye, C. The role of free water surface constructed wetlands as polishing step in municipal wastewater reclamation and reuse. Science of the Total Environment, 2007, 380, pp. 247–258. DOI: https://doi.org/10.1016/j.scitotenv.2006.12.038.

34. Coleman, J.; Hench, K.; Garbutt, K.; Sextone, A.; Bissonnette, G.; Skousen, J. Treatment of domestic wastewater by three plant species in constructed wetlands. Water, Air, Soil Pollution, 2001, 128, pp. 283–295. DOI: 10.1023/A:1010336703606.

35. Abe, K.; Komada, M.; Ookuma, A. Purification performance of the FWS constructed wetland in biotope area over three years. 19th World Congress on Soil Science, Soil Solutions for a Changing World, Brisbane, Australia, 2010, pp. 18–21.

36. Sakadevan, K.; Bavor, H.J. Phosphate adsorption characteristics of soils, slags and zeolite to be used as substrates in constructed wetland systems. Water Research, 1998, 32, pp. 393–399. DOI: https://doi.org/10.1016/S0043-1354(97)00271-6.