Ecological Engineering 123 (2018) 135–140

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Review

Relationship between design parameters and removal efficiency for constructed wetlands in China

Xiaoyan Li[a,b], Aizhong Ding[a,*], Lei Zheng[a], Bruce C. Anderson[c], Linghua Kong[b], Aiguo Wu[b], Lei Xing[b]

[a] College of Water Sciences, Beijing Normal University, Beijing 100875, China
[b] Beijing ZEHO Waterfront Ecological Environment Treatment Company, Beijing 100085, China
[c] Department of Civil Engineering, Queen's University, Kingston, ON K7L 3N6, Canada

ARTICLE INFO

Keywords:
Constructed wetlands
Design parameter
Removal efficiency
Regression analysis
China

ABSTRACT

Constructed wetlands (CWs), as an important ecological engineering technology, are designed and built to utilize the natural functions of wetlands for wastewater treatment within a more controlled environment. CWs have been widely used across the world. This review specifically aims at analyzing design parameters, pollutant removal efficiencies and their relationships for CWs built in China. The ANOVA analysis indicated that the design parameters and pollutant removal efficiencies were significantly different in different types of CWs and in different wastewater sources, and that wastewater sources should be considered as important factors for design of CWs operating parameters. Regression analysis of design parameters and pollutant removal efficiencies showed that regression equations were Logarithmic for total suspended solids (TSS), Power for ammonium (NH_3-N), Compound for total nitrogen (TN) and Linear for biochemical oxygen demand (BOD_5), chemical oxygen demand (COD_{cr}) and total phosphorous (TP). However, the correlation index (R^2) was quite low because of poor correlativity between design parameters and removal efficiencies, probably because of the diverse nature of the data analyzed. The application of CWs is most appropriate and beneficial in decentralized wastewater treatment in small town and rural areas as well as for low polluted water of rivers and lakes due to low costs for construction, operation and maintenance.

1. Introduction

The concept of ecological engineering was initially formulated in the 1960s in China, and was first independently proposed by Professor Ma Shijun, who was known as “the father of ecological engineering in China” (Ma, 1998). As one of the fundamental ecological engineering technologies, constructed wetlands (CWs) are constructed as artificial wetlands to utilize the natural functions of wetlands for wastewater treatment within a more controlled environment (Kadlec and Knight, 1996). The three main components of CWs are pollution-resistant wetland vegetation, filled media typically consisting of sand, gravel and other materials and microorganisms within the system (Zhang et al., 2012). According to the water flow regime, CWs can be divided into free water surface (FWS) and subsurface flow CWs. Subsurface flow CWs can be further classified into horizontal subsurface flow (HF) and vertical flow (VF) CWs (Vamzal and Kropfelova, 2008). For optimal use of the different mechanisms and efficiencies of pollutant removal within HF and VF CWs, the combined/hybrid-type CWs of HF and VF have recently appeared to improve the effluent water quality.

The first experiments on treating wastewater by CWs were carried out by Kathe Seidel in the 1950s in Germany (Seidel, 1961). In 1974, the first HF CW was put into operation for treatment of municipal sewage in Liebenburg-Othfresen, Germany, based on the “Root-zone theory” researched by Kiehuth (Kickuth, 1980). As a new kind of wastewater treatment technology, CWs were formally accepted in the water pollution control area during the Fourth International Seminar in Austria, Vienna in 1996. At present, CWs have been constructed worldwidely and utilized to treat a variety of wastewaters including industrial wastewater, domestic sewage, storm water runoff, agricultural polluted water, surface water and effluent of wastewater treatment plants (WWTPs) (IWA, 2001; Zhang et al., 2012).

In China, the first CW was established in 1987 by the Tianjin Academy of Environmental Sciences, with an area of 60,000 m^2 and capacity of 1400 m^3 per day for domestic wastewater treatment (Peng et al., 2000). Another CW, the Bainikeng CW, was put into operation in July 1990 in the Shenzhen Special Economic Zone, which covered 2 ha

* Corresponding author.
E-mail address: ading@bnu.edu.cn (A. Ding).

https://doi.org/10.1016/j.ecoleng.2018.08.005
Received 30 November 2017; Received in revised form 31 July 2018; Accepted 7 August 2018

area and treated domestic wastewater at a rate of 500 m^3 per day. Other early CWs established in the 1990s include: the FWS system of 20,000 m^2 area constructed in Changping District, Beijing for municipal sewage treatment at 500 m^3 per day; the Yantian CW built for 1000 m^3 wastewater per day with about 6667 m^2 area in the Shenzhen Industry Development Zone; and the HF system for treating 350 m^3 domestic wastewater per day in Guangzhou (Chen, 1994; Chen and Ye, 1996). Since the 1990s, China has undergone rapid economic development, increasing urbanization and industrialization, and along with the significant increases in wastewater quantity, CWs have been applied in more than 80% of the province-level administrative regions in South China and along the coastal areas (Zhang et al., 2012).

Based on literature survey, this research investigated the data of CWs performance and operation published from 1988 to 2016 in China, including 790 CWs cases. These CWs were designed mainly by following the Technical Specification of Constructed Wetlands for Wastewater Treatment (HJ 2005–2010) (MEPC, 2010). Since the design parameters vary quite widely, it may be that the pollutant removal efficiencies also vary. Therefore, this research analyzed the type of CWs, their design parameters and pollutant removal efficiencies, operation costs and the relationship between design parameters and pollutant removal efficiencies from 168 CWs cases, and made recommendations for better CWs design and application in the future.

2. Methods

2.1. Data survey

In the past several decades, the number of CWs has been growing so rapidly that it makes it difficult to estimate an accurate number of such installations in China. This survey uses the literature investigation method to gain the relevant data of engineering cases of CWs in China. The first step was to survey cases of CWs published from 1988 to 2016, and then to analyze the correlation between design parameters and removal data of those published cases, including hydraulic load (HL), hydraulic retention time (HRT), pollutant loading, presence of pretreatment, influent and effluent concentration for conventional wastewater contaminants, and removal rate of pollutants according to the Technical Specification of Constructed Wetlands for Wastewater Treatment (HJ 2005-2010).

The main literature sources were: (1) consultant reports related to CWs obtained through the Beijing Normal University library and online book stores; (2) Wanfang database, China National Knowledge Infrastructure database (CNKI), CQVIP information system, SpringerLink, Elsevier ScienceDirect, Web of Science and other main databases; and (3) project information from the websites of environmental companies in China. We collected 790 CWs engineering cases up to 2017 March 30 of which 168 have design parameters and removal efficiencies available for the statistical analysis. The analyzed data were within three years after CWs operation. The FWS, HF, VF and hybrid systems are 31, 61, 48 and 28, respectively.

2.2. Statistical methods

The relationships in design parameters and removal efficiencies among four types of CWs and different wastewater sources treated were evaluated using the least-significant difference (LSD) test of the one-way ANOVA at 5% level of significance with SPSS® v. 13.0.

Analysis of the Pearson Correlation and Regression between design parameters and removal efficiencies was also performed using SPSS® v. 13.0.

3. Design parameters for the engineering of CWs

3.1. Design parameters for different types of all CWs

Table 1 summarizes the statistics for 168 wetland systems in China, and shows that design parameters have a variation for different types of CWs. The HL and HRT are the most important parameters for CWs design and removal efficiency. However, the actual engineering design parameters are not only higher than those specified in the technical specification in China but also much higher than those in western countries. The average HL of 0.2 m/d for FWS and 0.5 m/d for HF was larger than < 0.1 m/d and < 0.5 m/d in the technical specification, respectively. In addition, the average HRT of 11.1 d for FWS was out of the range of between 4 and 8 d in the technical specification. Although the average HL and HRT of VF systems were in the range of 0.2–0.8 m/d and 1–3 d in China, they were much higher than 0.2–0.3 m/d in western countries. The organic loading from 10.6 to 55.3 g BOD_5/m^2.d in China were also overloaded in comparison with loading varying from 6 to 10 g BOD_5/m^2.d in western countries. In China, the rapid growth of urban areas and the population explosion lead to higher land price and less available land space. As a result, the overloading is a common feature for Chinese CWs due to this land barrier.

3.2. Design parameters for different wastewater sources

3.2.1. Design parameters of different types of CWs for specific wastewaters

Considering different wastewater sources, the different types of CWs treating industrial wastewater, domestic sewage, polluted river water and effluent of WWTPs were analyzed by the ANOVA method. The statistical results in Fig. 1 show that the design parameters of CWs treating heavily polluted water, including industrial wastewater and domestic sewage, are in accordance with the Chinese technical specification requirement, but they are not for micro-polluted water, including polluted river water, polluted lake water and effluent of WWTPs.

For the CWs treating industrial wastewater, the HL of CW systems was 0.10 m/d for FWS, 0.57 m/d for VF and 0.59 m/d for hybrid systems. The HRT of FWS systems (2.4 d) was very different from that of VF (2.11 d, P = 0.002) and hybrid (1.13 d, P = 0.003) systems (Fig. 1).

The design parameters of domestic sewage treatment in different types of CWs showed similar trends with industrial wastewater CWs and both of them met the requirement for technical specification. The HL was 0.10 m/d for FWS, 0.36 m/d for HF, 0.46 m/d for VF and

Table 1
The mean value of design parameters for CWs (n = 168).

Types of CWs	HL (m/d)	HRT (d)	Inflow Loading (g/m^2.d)					
			TSS	BOD_5	CODcr	NH_3-N	TN	TP
FWS	0.2 ± 0.1*	11.1 ± 4.7	19.8 ± 8.8	10.6 ± 4.0	19.6 ± 5.6	1.8 ± 0.6	1.7 ± 0.8	0.2 ± 0.1
HF	0.5 ± 0.1	2.4 ± 0.3	80.3 ± 27.3	34.0 ± 8.8	82.6 ± 22.2	8.4 ± 2.1	6.5 ± 1.2	0.8 ± 0.1
VF	0.6 ± 0.1	1.4 ± 0.2	56.2 ± 9.8	55.3 ± 13.7	109.0 ± 29.3	10.9 ± 2.0	20.1 ± 5.0	1.6 ± 0.3
Hybrid	0.5 ± 0.1	1.8 ± 0.3	59.9 ± 26.6	16.1 ± 3.2	42.4 ± 6.3	4.0 ± 0.8	5.5 ± 1.3	0.8 ± 0.1

* The number means Mean ± S.E.