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Review

A review on the sustainability of constructed wetlands for wastewater treatment: Design and operation

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HIGHLIGHTS

- Sustainable operation and successful application is critical to CWs.
- We review the application of CWs as a green technology.
- We summarize the key design parameters for the sustainable operation of CWs.
- Future research is given on improving the stability and sustainability of CWs.

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ABSTRACT

Constructed wetlands (CWs) have been used as a green technology to treat various wastewaters for several decades. CWs offer a land-intensive, low-energy, and less-operational-requirements alternative to conventional treatment systems, especially for small communities and remote locations. However, the sustainable operation and successful application of these systems remains a challenge. Hence, this paper aims to provide and inspire sustainable solutions for the performance and application of CWs by giving a comprehensive review of CWs' application and the recent development on their sustainable design and operation for wastewater treatment. Firstly, a brief summary on the definition, classification and application of current CWs was presented. The design parameters and operational conditions of CWs including plant species, substrate types, water depth, hydraulic load, hydraulic retention time and feeding mode related to the sustainable operation for wastewater treatments were then discussed. Lastly, future research on improving the stability and sustainability of CWs were highlighted.

1. Introduction

At present, there are growing issues of water environment including water shortage, water pollution and degradation of water resources worldwide. Moreover, the situation is becoming more serious due to the combined effects of worsening environmentally-unfriendly activity and large population especially in developing countries (Vymazal, 2011; Wu et al., 2014). Historically, traditional centralized sewage treatment systems have been used successfully for water pollution control in most countries (Li et al., 2014). However, these wastewater treatment technologies such as activated sludge process, membrane bioreactors and membrane separation are rather expensive and not entirely feasible for widespread application in rural areas (Chen et al., 2014b). Furthermore, they are limited and insufficient when facing ever more stringent water and wastewater treatment standards (Wu et al., 2013a). Thus, selecting low-cost and efficient alternative technologies for wastewater treatment is significant especially in developing regions. For this purpose, constructed wetland (CWs), as a reasonable option for treating wastewater, are attracting great concern owing to lower cost, less operation and maintenance requirements (Rai et al., 2013).

CWs, a green treatment technology by simulating natural wetlands, has been widely used to treat various kinds of wastewater such as domestic sewage, agricultural wastewater, industrial effluent, mine drainage, landfill leachate, storm water, polluted river water, and urban runoff in the last few decades (Yalcuk and

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Ugurlu, 2009; Harrington and Scholz, 2010; Saeed and Sun, 2012, 2013; Badhe et al., 2014). Currently, numerous studies have focused on the design, development, and performance of CWs, and it was also reported that CWs could be efficient for removing various pollutants (organic matter, nutrients, trace elements, pharmaceutical contaminants, pathogens, etc.) from wastewater (Cui et al., 2010; Saeed and Sun, 2012).

However, long-term effective treatment performance in CWs and the sustainable operation remain a challenge. On one hand, plant species and media types are crucial influencing factors to the removal performance in CWs as they are considered to be the main biological component of CWs and change directly or indirectly the primary removal processes of pollutant over time (Arias et al., 2001; Li et al., 2008). On the other hand, the treatment performance of CWs is critically dependent on the optimal operating parameters (water depth, hydraulic retention time and load, feeding mode and design of setups, etc.) which could result in variations in removal efficiency of contaminants among different studies (Kadlec and Wallace, 2009; Wu et al., 2014). Additionally, a variety of pollutant removal of processes (e.g., sedimentation, filtration, precipitation, volatilization, adsorption, plant uptake, and various microbial processes) are generally directly and/or indirectly influenced by the different internal and external environment conditions such as temperatures, availability of dissolved oxygen and organic carbon source, operation strategies, pH and redox conditions in CWs (Calheiros et al., 2009; Chen et al., 2011; Saeed and Sun, 2012; Meng et al., 2014).

While much advancement has been made in the contaminant removal processes in CWs over the years, there is still a gap in the understanding of these systems that is limited to achieve sustained levels of water quality improvement. Meanwhile the in-depth knowledge published in international journals and books on optimizing the treatment performance has increased dramatically in recent years. Therefore, it is necessary to review and discuss the recent development and knowledge on the sustainability of CW treatment technology. The objective of this paper is to categorize a great variety of CW treatments and provide an overall review on the application of CWs for wastewater treatment in recent years. This paper also reviews the developments in CWs considering plants and substrates selecting and operational parameters optimizing for the sustainability of wastewater treatments. Moreover, future research considerations for improving the sustainability of CWs are highlighted.

2. Constructed wetlands

2.1. Definition and classification

Constructed wetlands are engineered wetlands which are designed and constructed to mimic natural wetland systems for treating wastewater. These systems, mainly comprised of vegetation, substrates, soils, microorganisms and water, utilize complex processes involving physical, chemical, and biological mechanisms to remove various contaminants or improve the water quality (Vymazal, 2011; Saeed and Sun, 2012).

A simple scheme for various types of CWs is shown in Fig. 1. As can be seen in Fig. 1, constructed wetlands for wastewater treatment are typically classified into two types according to the wetland hydrology: free water surface (FWS) CWs and subsurface flow (SSF) CWs (Saeed and Sun, 2012). FWS systems are similar to natural wetlands, with shallow flow of wastewater over saturated substrate. In SSF systems, wastewater flows horizontally or vertically through the substrate which supports the growth of plants, and based on the flow direction, SSF CWs could be further divided into vertical flow (VF) and horizontal flow (HF) CWs. A combination of various wetland systems, known as hybrid CWs was also introduced for the treatment of wastewater, and this design generally consisted of two stages of several parallel CWs in series, such as VF–HF CWs, HF–VF CWs, HF-FWS CWs and FWS-HF CWs (Vymazal, 2013a). In addition, the multi-stage CWs that were comprised of more than three stages CWs were used (Kadlec and Wallace, 2009). In recent years, to intensify removal processes of CWs, enhanced CWs such as artificial aerated CWs, baffled flow CWs, hybrid towery CWs, step feeding CWs and circular flow corridor CWs have been proposed to enhance the performance of systems for wastewater treatment (Wu et al., 2014).

2.2. Cost–benefit analysis of CWs for wastewater treatment

Based on the concept of sustainable development defined at Brundtland Commission, cost–benefit analysis has been considered

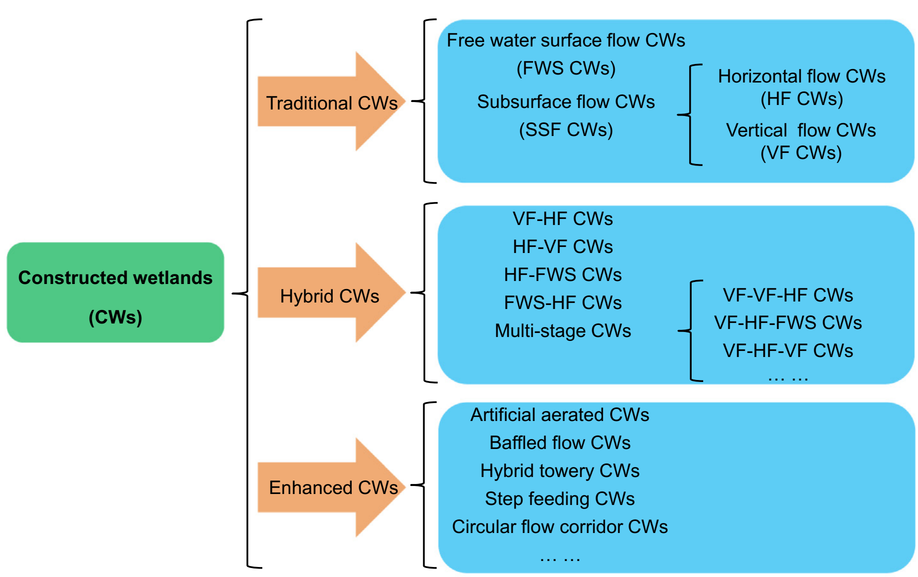

Fig. 1. The classification of CWs used in wastewater treatments.