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Research paper

Treatment of farmer household tourism wastewater using iron-carbon micro-electrolysis and horizontal subsurface flow constructed wetlands: A full-scale study

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ABSTRACT

A full-scale hybrid system utilizing horizontal subsurface flow constructed wetlands (HFCWs) with iron-carbon micro-electrolysis (ICME) pre-treatment was developed for farmer household tourism wastewater (FHTWW) treatment in Wuhan, Hubei Province, China. Results of the 12 months study revealed that the optimal iron-to-active carbon mass ratio (Fe/C), initial pH value and iron with active carbon-to-water volume ratio (Fe-C/water) of ICME were 1:1, 4.0 and 1:4 respectively. Meanwhile, the BOD_5-to-COD concentration ratio (B/C) of FHTWW was increased from an average value of 0.16–0.39, which indicated the effluent of ICME not only met the national standard for subsequent HFCWs, but also was appropriate to further biological treatment. Generally, the COD removal efficiency of the hybrid system could increase by more than 30% compared with HFCWs only. Although the concentration of ammonia nitrogen (NH_4^+-N) and total nitrogen (TN) in raw FHTWW varied greatly between seasons, their average removal rate reached 96.8 ± 1.2% and 95.9 ± 1.4% respectively depending on appropriate COD-to-TN ratio (C/N) of 3.08–6.19 and limited dissolved oxygen (DO) of 0.5–0.7 mg/L. The hybrid system has withstood the unusually rainy season in July 2016. Results showed that the average COD, BOD_5 and NH_4^+-N concentration in the final effluent were 28.3 mg/L, 5.8 mg/L and 1.3 mg/L respectively, which satisfied the environmental quality standards for surface water in China (COD ≤ 30 mg/L, BOD_5 ≤ 6 mg/L, NH_4^+-N ≤ 1.5 mg/L).

1. Introduction

In recent decades, tourism as an economic activity has grown substantially and is increasing local and seasonal pressures on the wastewater treatment systems of tourist destinations around the world (Gössling 2015; Tekken and Kropp, 2015), particularly in developing countries such as China (Qiuyun et al., 2011; Xue et al., 2017). However, increasing FHTWW may become a major source of pollution in rural environments when it is not disposed of properly. As a result, ecological problems near polluted bodies of water have attracted much attention (Gössling et al., 2012; Hadjikakou et al., 2013).

Unlike traditional rural sewage, the FHTWW is characterized by more complex composition, higher pollution load, significant load variation, and larger amounts of oils and surfactants (Becken 2014; Calheiros et al., 2015; Goronszy et al., 1995). Nowadays, the mainstream processes mainly utilize the physical treatment, treatment through chemical oxidation, and biological treatment (Zhang et al., 2016). As one of the biological treatment processes, constructed wetlands (CWs) have proven to be a promising alternative for developing countries (Kaseva 2004; Kivaisi 2001; Zhang et al., 2015b; Zhang et al., 2014). In contrast with other biological treatment technologies such as activated sludge and biofilm process, CWs require lower investment and operating costs, produce high quality effluent with less dissipation of energy, bring little secondary pollution and favorable environmental appearance (Chen et al., 2011; Mantovi et al., 2003; Seo et al., 2005; Seo et al., 2008; Wu et al., 2015). Furthermore, CWs are modeled after

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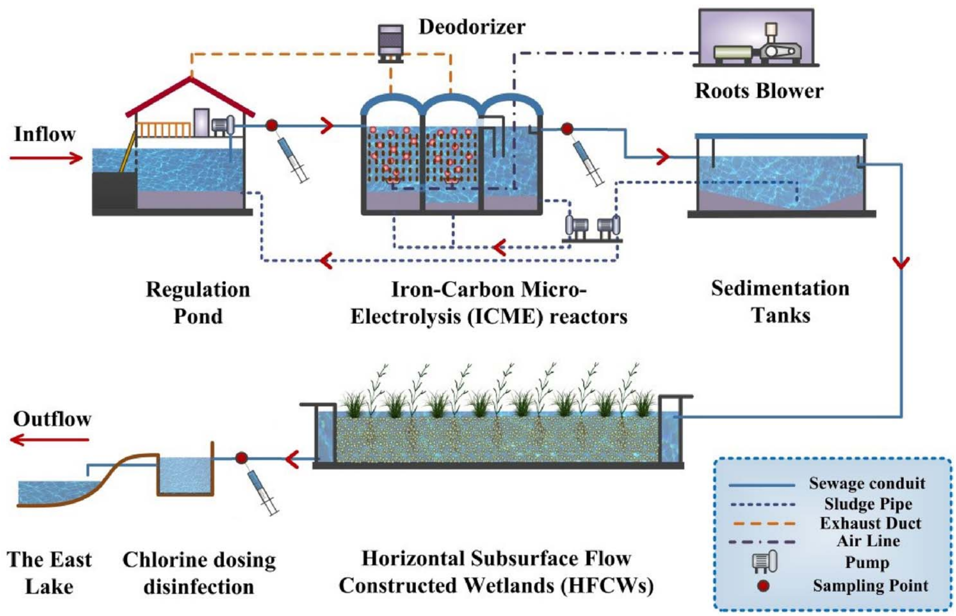

Fig. 1. Schematic representation of the full-scale FHTWW treatment process using ICME-HFCWs.

natural processes, which are comprised of water, substrates, soils, aquatic vegetation and microorganisms (Liu et al., 2016). So, they also have value as scenic tourist attractions.

In recent years, a type of CWs, HFCWs are attractive for small urban areas, rural villages and moderately sized wastewater treatment plants due to their small energy input, low maintenance/operating costs and surplus sludge generation (Andreo-Martínez et al., 2017; Ansola et al., 2003; Corbella and Puigagut, 2015; Vymazal and Březinová, 2014). However, due to the peculiar characteristics of FHTWW (Zhang et al., 2010), HFCWs alone are not capable of removing the highly concentrated organic matter and nitrogen both in terms of economic viability and efficiency (Grafias et al., 2010). To improve the degradation efficiency of organic contaminants and reduce the required area, preprocessing methods such as aerobic oxidation, anaerobic digesters, Fenton process, oxidation with ozone and ICME are applied before CWs (Álvarez et al., 2008; Gao and Hu 2012; Liu et al., 2015; Teodoro et al., 2014). However, decentralized domestic sewage in most developing countries such as China, is characterized by the low C/N (Wang and Li, 2011). The removal of a large proportion of COD in the anaerobic digesters further depletes the carbon sources which could support complete denitrification of nitrate in the subsequent end processing facilities such as CWs (Zhang et al., 2011). The high costs for maintenance, large amount of sludge accumulation of the aerobic oxidation process may directly restrict its long-term usability (Gao and Hu, 2012). The Fenton method is also quite expensive due to high demand for the Fenton agent. Consequently, the proposed pretreatment process should be able to efficiently remove pollutants, and decrease the costs of operation and maintenance.

In the past few years, ICME method has been used for various wastewater treatment, including landfill leachate (Ying et al., 2012b), dye wastewater (Wang et al., 2013), oilfield produced water (Li et al., 2010), bromoamine acid wastewater (Fan et al., 2009), coking wastewater (Lv et al., 2011) and Fischer–Tropsch wastewater (Wang et al., 2016). It has been reported that ICME can lead to a mean COD and TN reduction of more than 40% and 15% respectively (Deng et al., 2016; Guan et al., 2012; Qin et al., 2012). Yang has also reported that ICME pretreatment could achieve a high COD removal rate and improve the B/C ratio of refractory wastewater with high organic matter concentration (Yang, 2009). As the effluent from ICME provides more favorable biodegradation and C/N for pollutant biological treatment, it can potentially be combined with process such as HFCWs. Although the outcome is similar to the Fenton method, the ICME method is more cost-effective and simple to operate. (Liu et al., 2012; Nurul Amin et al., 2008; Wang et al., 2013).

Though previous studies have shown widespread application of both ICME and HFCWs for various wastewater treatment, full-scale projects combining ICME and HFCWs for FHTWW treatment are rarely reported. Therefore, the objectives of this research are to (1) evaluate the performance and the practicality of a full-scale project for FHTWW treatment applying ICME-HFCWs system; (2) verify the optimal operational parameters and conditions of this hybrid system for FHTWW treatment; (3) investigate the shock resistance capacity and stability of the system.

2. Methods and materials

2.1. Project description

This research relied on a full-scale project treating the FHTWW from an agritourism village, located in Wuhan, Hubei Province, China, with the coordinates of longitude and latitude of 114°20′25″–114°28′33″ and 30°30′19″–30°37′40″, respectively. This area was in the warm temperate zone and the climate was continental monsoon with an average annual temperature and precipitation of 16.7 °C and 1204.5 mm, respectively. Average seasonal temperature of the region was 3.2 °C in winter (December–February) and 37.6 °C in summer (June–August). The selected agritourism village had about 400 inhabitants and tourists during the winter but 900 in summer. During the sampling period, mean wastewater flow was 150 m^3/d in winter and 400 m^3/d in summer.

2.2. Characterization of the ICME-HFCWs system

An ICME-HFCWs system was designed to operate on the maximum flow rate of 600 m^3/d considering the development plan of the agritourism village. This hybrid system consisted of four main units (Fig. 1), namely a regulation pond (net volume of 80 m^3), ICME reactors (net volume of 50 m^3), sedimentation tanks (net volume of 50m^3) and HFCWs (1000 m^2 and 1.2 m depth). FHTWW was first drained into the regulation pond to regulate the water quantity and quality, then pumped into the consequent ICME reactors with three sequence units, the first two of which were micro-electrolysis reaction units. Iron filings (IFs, 0.5–0.8 m^2/g) and columnar activated carbon particles (ACs, Φ4 mm) were blended into a macroscopic electrode material after being