Performance of the Iron-Caron Coupling Constructed Wetland for Rural Sewage Treatment

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Abstract. In recent years, rural decentralized sewage treatment have gained widespread attention. Although wastewater treatment facility has been developed for rural areas, most rural population are left without adequate wastewater treatment systems. In the present study, the performance of iron-carbon coupling constructed wetland system (ICCWS) and constructed wetland system (CWS) receiving synthetic domestic waste water were compared in side-by-side trials. Studies have found that CWS filled with spherical iron-carbon packing showed better treatment efficiency than normal CWS. When the HRT is 3 days, the ICCWS have 95.8% COD and 96.6% \( \text{PO}_4^{3-} \) removal rate, higher than 67.0% COD and 74.3% \( \text{PO}_4^{3-} \) removal rate in CWS respectively. The use of ICCWS planted with canna and cattail proved to be efficient technology for the removal of rural wastewater pollutants.

1. Introduction

In China, rural residents accounted for 57.36% of the population. By 2014, more than 768 million people lived in the 2.79 million villages. As the living standards of the rural areas increase, rural water consumption is growing greatly \( (11.6 \times 10^9 \text{ m}^3 \text{ per annual} [1]) \). As a result, excess generation of wastewater is taking place and subsequently discharged to the environment. This leads to the deterioration of water quality in rural areas. According to data released by the Ministry of Housing and Urban Rural Development of China in 2010, 94% of rural areas are left without adequate wastewater drainage and treatment systems [2]. It is a common practice to discharge the domestic wastewater without efficient and proper treatment processes to the nearby lakes or rivers, resulting in serious environmental pollution and impairment of human health [3]. Water pollutants discharged in rural areas are responsible for almost 50% of the total pollution in China. Now, septic tanks are mainly onsite treatment solution for decentralized treatment of rural domestic wastewater in China. The digested wastes generated in septic tanks are commonly used in agriculture as fertilizers or discharged to nearby lakes or rivers. Both the
disposing ways could causing potential environmental risks. Excessive application of digested wastes in farmland for a long time can cause groundwater pollution and the point source and the non-point source pollutions to varying degrees [4]. There is a pressing need to develop dependable technologies that are of simple structure, low cost, low maintenance and highly efficient for rural decentralized wastewater treatment.

Conventional centralized treatment systems are operated in large and small cities with aim to control water environment pollution. But the centralized treatment systems are impractical in rural areas due to the requirement of considerable investment in construction and operation. It’s particularly urgent for the small towns and rural areas in our country to develop a simple, reliable and affordable wastewater treatment solution. The use of constructed wetlands have turn out to be the practical way. Constructed wetlands work as a typical artificial ecological treatment system and have been commonly used in many small towns and rural areas because of their advantages like low investment, low energy consumption and convenient operation management [5].

The key elements of the applications of constructed wetlands in sewage treatment are plants and media [6-7]. The traditional vertical flow constructed wetland technology had been studied by some researchers, but the process about Iron-Carbon coupling Constructed Wetland System (ICCWS) has been not reported yet. So in this work, an attempt has been made to integrate iron carbon micro-electrolysis technology with constructed wetland to treat rural domestic wastewater. ICCWS offer several advantages such as "using waste to treat waste", high performance efficiency and low investment. The system can be widely applied. The iron-carbon reduction method had been studied by many researchers. Iron-carbon micro-electrolysis process intergraded with biochemical treatment process have several uniqueness including increase biodegradability of the wastewater, improvement of the wastewater quality and decrease the biochemical treatment load. The iron-carbon micro-electrolysis has an obvious advantage in improving the wastewater treatment ability. Given the treatment of high strength organic wastewater, there are several solutions integrated with micro-electrolysis like biological contact oxidation process integrated with micro-electrolysis system, biological contact oxidation process integrated with anaerobic digestion and micro-electrolysis system and SBR integrated with micro-electrolysis system [8-9]. Under anoxic conditions, the micro-electrolysis treatment operates on a principle of galvanic cell reaction. Anodic Fe(0) serves as an active electron donor ($E^0(Fe^{2+}/Fe^0) = -0.44$ V). Hydrogen ions (H+) was first reduced into hydrogen (H2) by accepting electrons, and then the freshly formed hydrogen drove the reductions in cathodic region [10-11].

Anode: $\text{Fe} - 2e^{-} \rightarrow \text{Fe}^{2+}$

Cathode: $2\text{H}^{+} + 2e^{-} \rightarrow 2[\text{H}] \rightarrow \text{H}_2$

Products released from the galvanic cell reaction include hydroxyl, atomic hydrogen and Fe(II) which have high activities to decompose contaminants. The structure of the organic compounds in wastewater can be destroyed, thus, improving the sewage biodegradability and decreasing the COD concentration of the effluent [12-13]. In addition, Fe(II) is often used as a coagulant to remove phosphate in wastewater. Thus, it could be promising to combine micro-electrolysis with CWS together in a same system to enhance nutrient removal efficiency [14-15].

According to the government report [1], the wastewater generated in rural areas mainly comprises of grey water from household activities, toilet wastewater and livestock wastewater from family backyard. The wastewater typically contains no heavy metals,
CODcr(150-400mg/L) and TP(2.0-6.0mg/L) [16]. Dispersed distribution of the population in rural areas determines the inherent variability of rural domestic wastewater characteristics like quantity and quality. Additionally, Rural wastewater treatment emphasizes on removal of the main pollutant of the CODcr and Phosphorus [17]. Ideally, a practical decentralized wastewater treatment systems can fill the criteria of affordability, sustainability and environmental friendly. The designed system is to approach a high removal efficiency of the COD and Phosphorus at reduced treatment costs through the combination of micro-electrolysis with constructed wetland. A new packing material named as spherical iron-carbon packing composes of one of bed medias of constructed wetland for COD reduction and phosphorous retention. In this study, laboratory scale vertical subsurface constructed wetlands integrated with spherical iron-carbon packing were set up to evaluate and compare the removal efficiency of COD and PO$_4^{3-}$ in treating synthetic domestic wastewater. The study was also conducted to evaluate the stability of the system performance under different experiment conditions.

2. Methods

2.1. Test materials and devices

Two types of laboratory scale reactors were set up using plexiglass containers (height, 80cm, diameter, 25cm). Figure 1 represents the schematic diagram of the designed traditional CWS set-up with 5~8 mm diameter gravel. Figure 2 represents the schematic diagram of the designed ICCWS set-up with 10 mm diameter iron-carbon packing on bottom and 5~8 mm diameter gravel on top. Wastewater was pump into vale 1 via a peristaltic pump and discharged from valve 3. There were various aquatic plants like cattail, Cyperus alternifolius, canna on the wetland top layer. The CWS and ICCWS were operated under the same conditions and the same time, to ensure the comparability of the research systems.

2.2. Test methods and water quality

The synthetic rural domestic wastewater was prepared by dissolved KH$_2$PO$_4$, glucose(C$_6$H$_{12}$O$_6$), beef extract, peptone and starch in tap water to make it contain about 3~5mg/L PO$_4^{3-}$ and 200~230mg/L COD. The hydraulic retention time (HRT) in this experiment was set to a 2 and 3 day period. The COD and PO$_4^{3-}$ of influent and effluent water was measured in consecutive time, and their removal efficiencies finally calculated. The water quality of the influent water, effluent water and water samples respectively from various sampling points was analyzed, using measuring methods in accordance with the 2002 “Water and Wastewater Monitoring and Analysis Methods” released by the Ministry of Environmental Protection of the People's Republic of China (MEP), formerly State Environmental Protection Administration (SEPA). The COD was measured using the potassium dichromate method-UV spectrophotometric method [18-19], and PO$_4^{3-}$ using the ammonium molybdate spectrophotometric method [20].
3. Test results and discussion

3.1. Removal of COD
It is known that different medias in constructed wetland play a certain role in COD removal efficiency. In addition to absorb some inorganic pollutants, the media providing a larger surface area can create good living conditions for the reproduction and role of microorganisms. Therefore, more efficient purification can be achieved through the effective adsorption and degradation of water pollutants in the wastewater. According to the figures 3-5 below, the high removal values of COD may be explained as in ICCWS, settable organics were rapidly removed by deposition and filtration due to coagulation effect of Fe$^{2+}$, while the organic compounds were degraded by the micro-electrolysis function.

3.2. Removal of phosphorus
The removal of phosphorus by constructed wetlands mainly depends on the filler layer's substrate, the aquatic plants and microorganisms in constructed wetland, as well as the combined effects of the three. The canna-ICCWS and cattail-ICCWS exhibited excellent performance in PO$_4^{3-}$ removal throughout the whole study period(figures 6-8). The PO$_4^{3-}$ removal efficiencies of the canna-ICCWS and cattail-ICCWS grow with the increase of HRT 2 to 3days. The filler plays the most important role in Phosphorus removal, with the combined effect of aquatic plants and microorganisms being second only after the filler substrate. Fe$^{2+}$ released from the galvanic reaction of iron carbon granular filler layer form iron phosphate precipitates with PO$_4^{3-}$ removal in wastewater, thus improving PO$_4^{3-}$ removal efficiency.

Figure 1. Traditional CWS cylindrical simulation diagram.

Figure 2. The new ICCWS cylindrical simulation diagram.

Figure 3. The Canna-CWS/ICCWS in Different HRT.

Figure 4. The Cattail-CWS/ICCWS in different HRT.
3.3. The comparison of different plants

When canna was planted in the both systems to treat the rural sewage. According to the figures 9-10 below, the resulting mean COD removal efficiency of 87% and 88%, respectively with corresponding HRT of 2 and 3 days, observed in the CWS laboratory system, are in contrast to the higher COD removal of approximately 87% and 91% in the ICCWS. When cattail was select as the wetland plant, the average effluent COD concentrations from CWS reach 30.2mg/L and 23.4mg/L, respectively with corresponding HRT of 2 and 3 days. In comparison, the average effluent from ICCWS has lower COD concentrations of 19.2mg/L and 16.1mg/L. When Cyperus alternifolius was select as the wetland plant, the average effluent COD concentrations from ICCWS reach 66.0mg/L and 8.33mg/L, respectively with corresponding HRT of 2 and 3 days. In comparison, the average effluent from CWS has higher COD concentrations of 80.33 mg/L and 31.8mg/L.

The results indicate that the COD removal efficiency of the ICCWS is better than that of the CWS. With the increase in HRT, the COD removal efficiency increases. Among the three plant species, the COD removal efficiency of ICCWS with canna and cattail are best.
4. Then main research and conclusion
The use of ICCWS planted with canna and cattail proved to be efficient technology for the removal of rural wastewater pollutants. The system can effectively degrade COD and phosphorus in rural household wastewater. The effluent water quality can meet the first class of A standard of the "Discharge standard of pollutants for municipal wastewater treatment plant" (GB18918-2002). The process is also very practical when it is used to deal with household wastewater in tourist areas, resorts or scenic areas without service of urban drainage system. The treated water can be recycled as irrigation water to generate economic benefits, further reducing the cost of investment.

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