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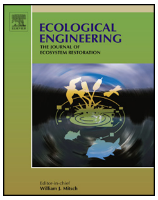

Removal of nitrogenous compounds from polluted river water by floating constructed wetlands using rice straw and ceramsite as substrates under low temperature conditions

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ABSTRACT

To reduce the loading of nitrogenous compounds under low temperature conditions (4.3–9.2 °C), we used two floating constructed wetlands (FCWs), assembled from either rice straw (FCW-RS) or light ceramsite (FCW-LC) as a substrate for microorganisms and macrophytes. Under batch conditions, the concentrations of total nitrogen (TN), ammonium nitrogen (NH_4^+—N), nitrate nitrogen (NO_3^-—N) and nitrite nitrogen (NO_2^-—N) in raw water were 1.32–2.97, 0.50–1.32, 0.41–1.10, and 0.18–1.24 mg/L. The average removal rates of TN, NO_3^-—N and NH_4^+—N after 7 d using FCW-RS and FCW-LC were 78.2%, 62.1%, 81.2% and 65.5%, 42,2%, 71.6%, respectively. Both the FCW-RS and FCW-LC systems proved to be proficient in nitrogenous compounds removal, and FCW-RS showed less NO_2^-—N accumulation.

1. Introduction

Over the past 20 years, pollutants from point and non-point sources have been discharged into rivers. These discharges can result in high concentrations of microbial pathogens, biochemical oxygen demand, suspended solids, and other pollutants in the receiving waters, particularly nitrogen and phosphorus (Cao and Zhang, 2014). The phosphorus pollution can be effectively removed by coagulation and controlled by the ban of detergent containing phosphorus (Zhang et al., 2014). But nitrogenous compounds removal by using biological methods was the most effective and environmental-friendly. Consequently, the high nitrogenous compounds concentrations became a main inducement to eutrophication. Eutrophication has played a major role in a number of serious pollution incidents. More than 66% of lakes in China have became eutrophic, and eutrophication has become a matter of concern in aquatic ecological research (Zhao et al., 2012; Cao and Zhang, 2014). It is therefore necessary to reduce nitrogenous compounds from river water for human consumption and ecological safety. Many studies have been conducted to devise ways of limiting eutrophication (Zhi et al., 2015; Yuan et al., 2014; Wang et al., 2013).

Bio-remediation of nitrogenous compounds from eutrophic waters has been widely applied in ecological engineering for the treatment of both surface water and wastewater, because of their efficiency in assimilating nutrients and creating favorable conditions for the microbial decomposition of organic matter (Li et al., 2010; Zhao et al., 2012; Cao et al., 2012). However, despite their high nutrient removal ability and low costs for the bioremediation of eutrophic waters, some phyto-remediation technologies, e.g., constructed wetlands (CWs), occupy a large area of land. Ecological floating beds have been widely used, and have been shown to be more efficient and convenient for the treatment of eutrophic waters due to their low cost and ease of management, with no need for an on-site operator (Sun et al., 2009).

The purification processes of traditional ecological floating beds (EFBs) have numerous disadvantages, including low purification efficiency under low temperature, and limited stand biomass and growth rates of the plants used. The addition of bio-carriers into the EFBs is an economical and practical method due to the greater biomass and longer biological chain.

However, the hybrid EFBs mentioned above also have the following disadvantages, particularly for the removal of nitrogenous

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compounds. (1) Hybrid EFB technology still relies on hydrophytes for bioremediation, although they are strongly influenced by low temperature conditions (Luo et al., 2010; Zheng et al., 2008). (2) Although hybrid EFBs can be used to purify eutrophic water, these technologies are not efficient for removing nitrogenous compounds, particularly nitrate nitrogen (NO_3^-—N), because most eutrophic waters lack bi-degradable organic matter which can be efficiently utilized by denitrifying bacteria. This results in a low removal efficiency of nitrogenous compounds (Zhi and Ji, 2014; Xiong et al., 2012). Instead of having a coupling function between the bio-carriers and hydrophytes, their activity is relatively independent of each other, because the location of the bio-carriers and hydrophytes is relatively well separated. (3) The roots of hydrophytes are suspended in the water, as trace elements are mainly metals which are rather toxic to plant growth (Jin et al., 2007). In addition, the roots of hydrophytes can be damaged by aquatic animals. Consequently, an improvement of the EFB structure and NO_3^-—N removal efficiency, and an assessment of the removal performance for nitrogenous compounds under low temperatures is urgently needed.

Bio-film techniques have been widely studied and used in the ecological restoration of water bodies. Bio-carriers are helpful in remediating polluted surface water as well as directly influencing the treatment efficiency and energy consumption (Cao, 2012). In addition to the inert fillings previously used (Zhang et al., 2013), rice straw has been introduced for the bioremediation of eutrophic water, because it has three main advantages: (1) up to 70–90% cost reduction for the treatment of agricultural waste; (2) it is an environmentally sustainable technique for water, air and soil protection as well as achieving waste reduction; and (3) no secondary pollution is produced with almost all of the rice straw consumed during application. The principal idea behind its use is the known efficiency of “solid phase de-nitrification” in biological de-nitrification (Shen et al., 2013; Aslan and Türkman, 2003; Alvarez et al., 2007).

Based on the known defects of hybrid EFBs mentioned above, i.e., the bio-carrier techniques and solid phase de-nitrification technology, we developed two floating constructed wetlands (FCWs) using either rice straw (FCW-RS) or light ceramsite (FCW-LC) as a substrate for microorganisms and macrophytes. Compared with conventional EFBs, FCWs have the following advantages: (1) the coupling function between bio-carriers and hydrophytes can be realized because of their intimate contact, which are helpful for enhancing the biomass; (2) the advantages of EFBs and CWs are combined.

some experimental researches on FCWs have been accomplished under high water temperature (Cao and Zhang, 2014; Zhang et al., 2013), and purification efficiency was obtained. But the use of eutrophic water bodies as influent under low temperature conditions have still not been investigated. The objective of this study was to determine the performances of FCW-RS or FCW-LC for about 3 months under low temperature conditions, and to undertake a comparison of the purification performances and operational mechanisms of two FCWs.

2. Material and methods

2.1. Micro-organisms substrates and hydrophytes

(1) Rice straw, which is composed of cellulose and lignin, was cut into 20–30 mm long pieces. The physical characteristics of the rice straw were as follows: porosity, 85%; specific surface area, about158 m^2/m^3; and bulk density, 1.1 kg/L.

(2) The production process of light ceramsite was as follows. First, the raw material (a surface sediment) was obtained from a polluted river. The sediment was air dried for about 5–7 d at room temperature (28 °C) and under strong sun for a further 2–3 d. It was then fully milled. The sediment was crushed and screened using a 35 mesh sieve with a diameter of 0.47 mm. The raw material was mixed with water in a 1:1 ratio (V/V) to produce raw light ceramsite. Finally, the raw light ceramsite was quickly sintered for 1 h under high temperature (about 1000–1050 °C) in a muffle furnace. The light ceramsite was cooled in a desiccator (12 h).

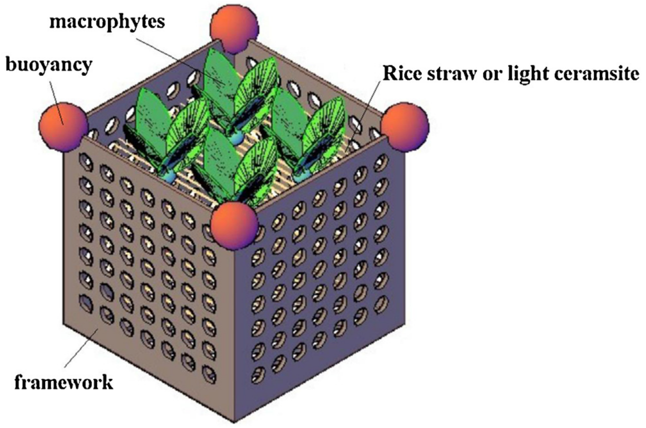

Fig. 1. Schematic diagram of the FCW.

(3) Hydrophytes: *Canna* were selected for the FCWs because they could grow in a relatively low-temperature environment with flourishing roots. The *Canna* plantlets were purchased from a garden center in Xuzhou city, Jiangsu, China. The heights of the plantlets ranged from 5 to 7 cm. The *canna* were cleaned and transplanted into the FCWs at a water temperature of 10 °C.

2.2. FCWs and raw water quality

The framework of the FCWs consisted of perforated polypropylene random copolymer (shape: cuboid), which was 20 × 20 mm on the underside and 24.3 mm in height, rice straw and light ceramsite were respectively filled into the framework of two FCWs, each FCW was planted four *Canna* with the separation distance of 15 cm, the two FCWs included either FCW-RS or FCW-LC (Fig. 1) were developed. The two FCWs were established in two separate tanks (shape: rectangular) with an inner dimensions of 40 cm in length and 55 cm in depth.

Each FCW was affixed the different amounts of foam to float on the surface of tank, and installed two underwater stirrers (model: JGB, Nanjing, China) at the bottom to enhance water recirculation. Each tank was filled with 40 L of raw water obtained from an actual eutrophic river near Xuzhou Institute of Technology (Xuzhou, China), which has been influenced by agricultural nonpoint source pollution. The quality of raw water is summarized in Table 1.

2.3. Bioremediation experiment

The two FCWs were cultivated for approximately 3 weeks from 16 October 2013 to 9 November 2013, and the experiments were initiated from 9 November 2013 to 15 March 2014 (i.e., lasting more than 4 months). The water temperature ranged between 0.9 °C and 4.3 °C from 21 December 2013 to 22 February 2014, when the experiment was suspended due to the freezing of water (concentrations of nitrogenous compounds were monitored but not assessed, while other water quality parameters were not monitored). The experimental temperature ranged between 4.3 °C and 9.2 °C, the water exchange period was set at 7 d, and the rate of coverage of