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Intensified nitrogen and phosphorus removal in a novel electrolysis-integrated tidal flow constructed wetland system

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ABSTRACT

A novel electrolysis-integrated tidal flow constructed wetland (CW) system was developed in this study. The dynamics of intensified nitrogen and phosphorus removal and that of hydrogen sulphide control were evaluated. Ammonium removal of up to 80% was achieved with an inflow concentration of 60 mg/L in wetland systems with and without electrolysis integration. Effluent nitrate concentration decreased from 2 mg/L to less than 0.5 mg/L with the decrease in current intensity from 1.5 mA/cm^2 to 0.57 mA/cm^2 in the electrolysis-integrated wetland system, thus indicating that the current intensity of electrolysis plays an important role in nitrogen transformations. Phosphorus removal was significantly enhanced, exceeding 95% in the electrolysis-integrated CW system because of the in-situ formation of a ferric iron coagulant through the electro-dissolution of a sacrificial iron anode. Moreover, the electrolyzed wetland system effectively inhibits sulphide accumulation as a result of a sulphide precipitation coupled with ferrous-iron electro-dissolution and/or an inhibition of bacterial sulphate reduction under increased aerobic conditions.

1. Introduction

Constructed wetlands (CWs) have proven to be an efficient ecological technology for the treatment of various kinds of contaminated waters (Williams, 2002; Haberl et al., 2003; Kadlec and Wallace, 2009). Compared with conventional treatment systems, CWs have lower costs and can be operated and maintained more easily (Inamori et al., 2007). The wetlands have become standard treatment technology for many countries because of the need for low-carbon, environmental friendly technologies (Brix, 1999; Vymazal, 2009).

CWs are generally categorized into surface flow wetlands and subsurface flow wetlands (SSFW). SSFW is the most common CW type in Europe; such systems have been consistently effective in the removal of biochemical oxygen demand, suspended solids, and pathogenic organisms (Vymazal et al., 1998; Garcıa et al., 2003, Akratos and Tsihrintzis, 2007). However, nutrient removal is generally limited because of a lack of the oxygen content that is necessary to oxidize ammonium and of the low sorption

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capacities of the common substrate materials utilized in phosphorus retention (Tanner et al., 2002). Thus, intensified CWs, such as artificially aerated and tidal-flow CWs, were developed to improve oxygen transfer in CWs (Austin and Nivala, 2009; Wallace and Liner, 2011; Saeed et al., 2012).

Artificially aerated CWs can increase oxygen transfer rate to 160 g/m^2 d by compressing air from the atmosphere into the wetland bed with the use of a blower (Kadlec and Wallace, 2009). Consequently, nutrient removal is intensified and the required area is reduced. However, such technology is not widespread because aeration process consumes a great deal of energy. Also, the fouling of air diffusers within CWs must be considered, as well as the provisions for replacing or chemically cleaning diffuser assemblies. Tidal-flow constructed wetlands (TFCWs) are a relatively new technology that utilizes a novel oxygen transfer method (Tanner et al., 1999; Austin, 2006; Wu et al., 2011). TFCWs are regularly filled with wastewater and then drained, and TFCWs act as passive pumps that expel and draw air from the atmosphere into pore spaces (Zhao et al., 2004; Sun et al., 2006). In this way, the oxygen transfer rate reaches 450 g/m^2 d (Wu et al., 2011), and the ammonium and organics treatment capacities are consequently improved significantly (Hu et al., 2012). However, denitrifier growth and activity is inhibited by either high oxygen content or inadequate electron donor sources, thus resulting in the increase in effluent nitrate content in these systems (Zhao et al., 2004).

Phosphorus removal is necessary because this element stimulates algae growth responsible for eutrophication of rivers and closed water bodies (Ikematsu et al., 2007). Phosphorus in CWs is removed through the interaction among substrates, plants, and microorganisms (Wang et al., 2013). Substrates are widely known to play vital roles in the phosphate removal process (Vohla et al., 2011; Babatunde et al., 2009) because adsorption and precipitation are main factors in phosphorus removal (Richardson, 1985). Numerous scholars have devoted their efforts to the research and development of efficient and practical phosphorus adsorption wetland (Drizo et al., 2006; Kantawanichkul et al., 1999; Del Bubba et al., 2003). Studies have reported that although the removal is efficient at the beginning of the operation, the removal rate decreases significantly over time. Desorption of phosphorus has also been observed in treatment wetlands (Brix, 1994; Meuleman et al., 2002).

Electrochemical method has been successfully used for treating wastewater, and the electrocoagulation process removes phosphorus efficiently (Vlyssides et al., 1997, Bektaş et al., 2004, İrdemez et al., 2006). Coagulants are formed in-situ by the electro-dissolution of a sacrificial anode. The electrodes are typically composed of iron or aluminium (Cañizares et al., 2007) because these elements are cheap, readily available, and are proven to be effective at phosphorus removal (Chen et al., 2000). When iron is used as anode material, the overall reaction is as follows (İrdemez et al.,, 2006):

$$4Fe(s) + 10H_2O(l) + O_2(g) \rightarrow 4Fe(OH)_3(s) + 4H_2(g).$$

In the above chemical equation, the abbreviations of (s), (l) and (g) mean the state of solids, liquids and gases respectively.

Ferric hydroxide can be used as a flocculants to remove phosphorus in wastewater. This reaction also produces hydrogen gas which is an electron donor; thus, nitrate content is attenuated under a low-carbon-source condition. Autotrophic denitrification with hydrogen as electron donor has been studied (Lee et al., 2010; Mansell and Schroeder, 2002). Results show that the technology has a good development potential. Moreover, the research of Sakakibara and Kuroda (1993) posited that an electrically driven biological denitrification process is simple and feasible, especially in the treatment of low-strength nitrate solutions.

TN removal efficiency in TFCWs is not ideal because of the high oxygen content. $PO_4^{3-}-P$ removal in TFCWs is generally limited because of the low sorption capacity of substrate materials, as in other CWs. Electrolysis has an advantage when used in dephosphorization and has potential for use in denitrification under low-carbon-source condition. Electrolysis is thus coupled with TFCW technology to fully utilize their advantages.

In this study, a novel, tidal-operated, electrolysis-integrated CW system was developed. The dynamics of intensified nitrogen and phosphorus removal were evaluated, and the important role of current intensity in nitrogen transformations was examined. The inhibitory effect of the electrolytic process on sulphide accumulation was also analyzed.

2. Materials and methods

2.1. Laboratory-scale wetlands

The schematic diagram of two lab-scale CWs (systems A and B) is shown in Fig. 1. The electrolysis-integrated experimental wetland (system A) was composed of a perspex tube cylinder with an internal diameter of 13 cm

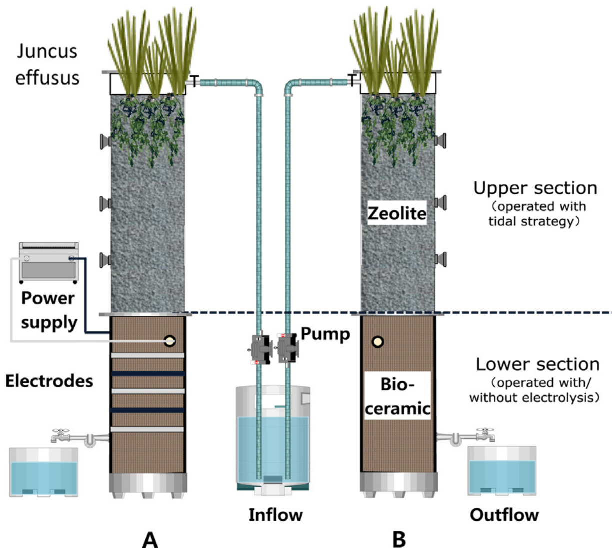

Fig. 1 – Schematic diagram of experimental laboratory-scale constructed wetlands (CWs) (system A: electrolyzed experimental CW; system B: non-electrolyzed contrast CW.).