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Enhancement of azo dye Acid Orange 7 removal in newly developed horizontal subsurface-flow constructed wetland

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A B S T R A C T

Horizontal subsurface-flow (HSF) constructed wetland incorporating baffles was developed to facilitate upflow and downflow conditions so that the treatment of pollutants could be achieved under multiple aerobic, anoxic and anaerobic conditions sequentially in the same wetland bed. The performances of the baffled and conventional HSF constructed wetlands, planted and unplanted, in the removal of azo dye Acid Orange 7 (AO7) were compared at the hydraulic retention times (HRT) of 5, 3 and 2 days when treating domestic wastewater spiked with AO7 concentration of 300 mg/L. The planted baffled unit was found to achieve 100%, 83% and 69% AO7 removal against 73%, 46% and 30% for the conventional unit at HRT of 5, 3 and 2 days, respectively. Longer flow path provided by baffled wetland units allowed more contact of the wastewater with the rhizomes, microbes and micro-aerobic zones resulting in relatively higher oxidation reduction potential (ORP) and enhanced performance as kinetic studies revealed faster AO7 biodegradation rate under aerobic condition. In addition, complete mineralization of AO7 was achieved in planted baffled wetland unit due to the availability of a combination of aerobic, anoxic and anaerobic conditions.

1. Introduction

Azo dyes, which are aromatic compounds with one or more —N═N— groups, are the most commonly used synthetic dyes in commercial applications especially in textile industry. They account for the majority of all textile dyestuffs produced because of the ease and cost effectiveness of their synthesis, their stability and the variety of colours available in them compared to natural dyes (Chang et al., 2004). They are extensively used in the textile, paper, food, leather, cosmetics and pharmaceutical industries. Their discharge into water courses leads to aesthetic problems and obstructs light penetration and oxygen transfer into waters, hence affecting aquatic life. Although the acute toxicity of azo dyes is low, the potential health effects are recognized with the values of LD_{50} between 250 and 2000 mg/kg body weight (Danish EPA, 1998). In addition, the metabolic cleavage of azo linkage leads to toxic by-products, such as aromatic amines, which have been described as mutagenic and carcinogenic (Davies et al., 2009). Therefore, treatment of industrial effluents containing azo dyes and their degradation products is essential prior to their final discharge to the environment.

Many processes are available to treat the dye-containing wastewaters. Among others, several physic-chemical processes have been used for the removal of dyes from wastewaters such as coagulation—flocculation (Moghaddam et al., 2010), absorption (Wang and Li, 2013; Ravikumar et al., 2007), advanced oxidation processes (Guimarães et al., 2012), photodegradation (Li et al., 2012) and ozone treatment (Muthukumar et al., 2004). Although high dye removal can be achieved, the disadvantages of physico-chemical processes include higher cost and production of large amount of sludge. Most physical processes strictly do not remove the dye but merely transfer the dye from the solution to solid phase.

In contrast, biological processes are receiving more and more attention since they are cost effective, environmentally friendly and do not produce large quantities of sludge. In most cases, azo dyes are easily decolorized via the cleavage of the azo bonds under anaerobic conditions. The main drawback of azo dye reduction under anaerobic conditions is the generation of aromatic amines which resist further degradation (Van der Zee et al., 2001). The aromatic amine residues, however, can be mineralized aerobically. Thus, many researchers have adopted sequential anaerobic—aerobic (A/O) systems for complete degradation of azo dyes (Ong et al., 2005; Lourenco et al., 2006; Li et al., 2010). A wastewater treatment system which can nurture both anaerobic and aerobic conditions sequentially is therefore the most logical concept for removing azo dyes from wastewater. In this sense, hybrid

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constructed wetlands which consist of a combination of horizontal-flow (HF) and vertical-flow (VF) constructed wetlands fit the concept very well. In fact, hybrid constructed wetlands are being operated in many countries around the world with reported applications in the treatment of various types of wastewaters (Abidi et al., 2009; Serrano et al., 2011; Ghrabi et al., 2011; Saeed et al., 2012). Nonetheless, there was essentially no information on the use of hybrid constructed wetlands in the treatment of azo dyes though limited information on dye removal using conventional constructed wetlands are available (Davies et al., 2006; Ong et al., 2009; Yadav et al., 2012). Recently, a newly designed horizontal subsurface-flow (HSF) constructed wetland incorporating baffles to facilitate up and down flows sequentially along the treatment path for the removal of nitrogen has been reported (Tee et al., 2012). The design was able to nurture sequential aerobic, anoxic and anaerobic conditions within the same wetland bed, thus overcoming the limitations of hybrid system which require a relatively large land area and a recycling system for wastewater treatment under oxidation and reduction conditions repeatedly. To date, the use of HSF constructed wetland of this particular design for the removal of azo dye which requires the availability of both anaerobic/anoxic and aerobic conditions is yet to be reported.

In the light of the above observation, the objectives of this study are: (i) to compare the performance of the baffled and conventional HSF constructed wetlands, planted and unplanted, in the removal of Acid Orange 7 (AO7), (ii) to investigate the fate of AO7 in the wetland systems and (iii) to propose a degradation pathway of AO7.

2. Material and methods

2.1. Description of HSF constructed wetland system

The construction and set up of four fibre-glass experimental-scale HSF constructed wetland units outdoors, each of dimensions 2.0 × 0.5 × 0.8 m (Length × Width × Height), as well as the locations of sampling positions have been described in detail in Tee et al. (2012). Briefly, five vertical baffles were placed lengthwise to each of the two wetland units to facilitate upflow and downflow conditions sequentially in different segments of the units. Each of the baffled (NDP) and conventional (ODP) units was planted with cattails (*Typha latifolia*). The other two unplanted wetland units of baffled and conventional designs were labelled as ND and OD, respectively. The support media which were packed to a depth of 0.6 m consisted of a combination of raw rice husk and pea gravel in a volume ratio of 2:1 with raw rice husk occupying the first two third of the wetland bed. Fig. 1a shows the cross section of the baffled wetland unit whereas Fig. 1b shows the experimental system.

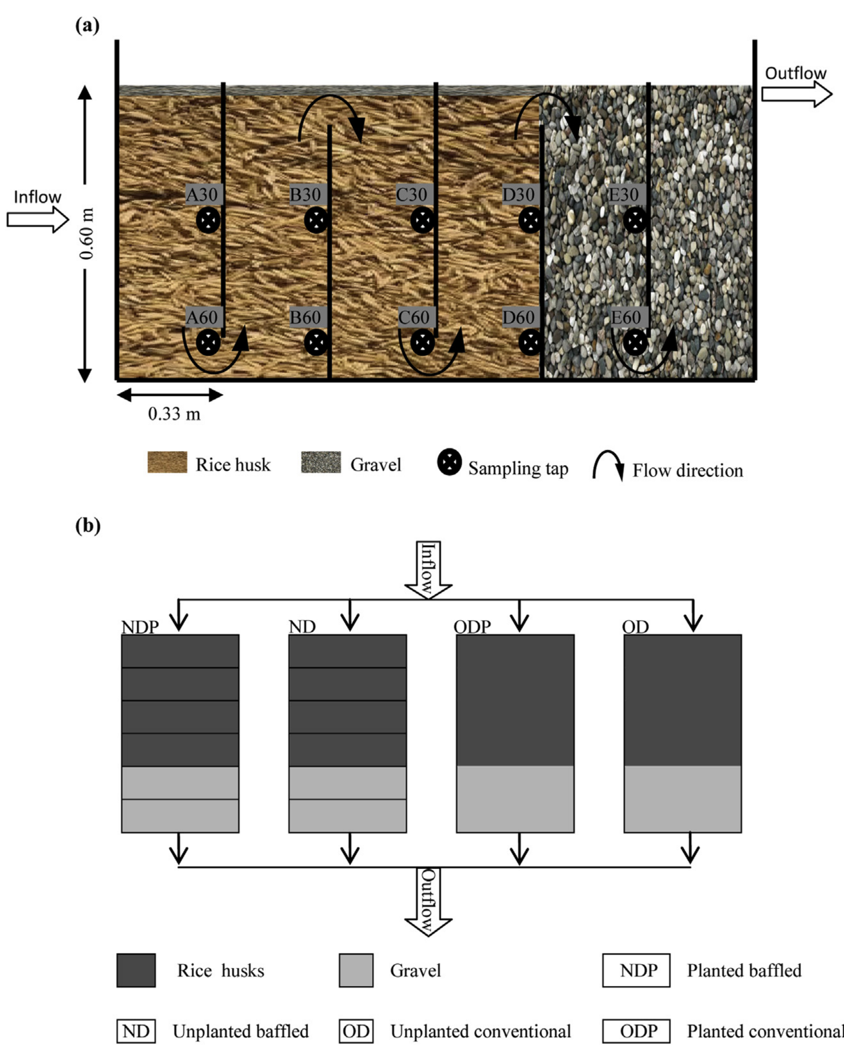

Fig. 1. (a) Cross section of the baffled wetland unit and (b) diagram of the experimental system.