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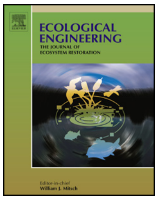

Full research paper

Dye wastewater treatment by vertical-flow constructed wetlands

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ABSTRACT

Wetlands have long played an important role as natural purification systems. Textile industry processes are among the most environmentally unsustainable industrial processes, because they produce coloured effluents in large quantities polluting water resources. In this study, two different azo dyes (Acid Blue 113 (AB113) and Basic Red 46 (BR46)) have been fed as part of synthetic wastewater recipes to a laboratory-scale vertical-flow construction wetland set-up comprising wetlands with gravel media as controls and wetlands planted with *Phragmites australis* (Cav.) Trin. ex Steud. (Common Reed) for each dye. Two different concentrations (7 mg/l and 215 mg/l) were used for each dye at two different hydraulic retention times (48 h and 96 h). According to results for the low concentration of BR46, there is no significant ($p > 0.05$) difference between wetlands (unplanted and planted) in terms of dye removal. The use of plants concerning the short contact time scenario for ammonia-nitrogen (NH_4-N) and a low concentration of AB113 is linked to good removal. In case of low dye concentrations, the presence of plants for the long contact time scenario impacted significantly ($p < 0.05$) positive on the removal efficiencies of nutrients. For chemical oxygen demand (COD), the removal percentages were 50%, 59% and 67% for the control and for the wetlands with short and long retention times, respectively. All reductions were statistically significant ($p < 0.05$). For the high concentration of BR46, the removal percentages for this dye and COD were 94% and 82%, and 89% and 74% for the long and short retention times, respectively. For the low concentration of AB113, the percentage corresponding removals for the dye were 71%, 68% and 80%. The COD removals were 4%, 7% and 15% for the control, and the short and long retention times, respectively. Finally, for the high concentration of AB113, the percentage removals for the dye and COD were 71% and 73%, and 50% and 52% for the 48-h and 96-h retention times in this order.

1. Introduction

Azo dyes are important colouring agents in the textile, food and pharmaceutical industries (Tee et al., 2015; Yaseen and Scholz, 2016), and are linked to a relatively high toxicity, mutagenicity and carcinogenicity. Azo dyes and their corresponding breakdown products are difficult to treat in traditional wastewater treatment systems according to Erkurt (2010). Many technological solutions such as coagulation-flocculation and advanced oxidation process (Sivakumar et al., 2013), which have been applied to treat dyes, are not feasible in practice, because of too high costs and complex processes involved. Furthermore, some developing countries such as China and Bangladesh (Chen et al., 2007; Islam et al., 2011), which have a strong textile industry, but unreliable energy sources, may benefit from less-energy demanding methods of wastewater treatment.

Textile wastewater causes considerable environmental pollution. The main challenges are high concentrations of organic matter and particular persistent colorants (dyes) that have to be resistant to the effects of sweat, soap, water, light and oxidants (Olejnik and Wojciechowski, 2012). The azo dyes AB113 and BR46 are, therefore, widely used in the textile industry (Pervez et al., 2000; Olgun and Atar, 2009; Deniz and Karaman, 2011; Yaseen and Scholz, 2016). Typically, textile industry-processing effluents contain dyes in the range between 10 and 200 mg/l (Yassen and Scholz, 2016). Most textile dyes at a rather low concentration of even >1 mg/l can be detected by the human eye (Pandey et al., 2007).

Abbreviations: AB, acid blue; ANOVA, analysis of variance; AO, acid orange; AY, acid yellow; BR, basic red; CASRN, chemical abstracts survey registry number; COD, chemical oxygen demand; DO, dissolved oxygen; DY, disperse yellow; EC, electric conductivity; HF, horizontal-flow; N, nitrogen; NH_4-N, ammonia-nitrogen; n/a, not applicable; NO_2-N, nitrite-nitrogen; NO_3-N, nitrate-nitrogen; PO_4–P, ortho-phosphate-phosphorus; RB, reactive black; SD, standard deviation; SE, standard error; TDS, total dissolved solids; T-N, total nitrogen; TOC, total organic carbon; T-P, total phosphorus; TSS, total suspended solids; VF, vertical-flow; VY, vat yellow; Λ_{max}, maximum absorbance.

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Vertical-flow constructed wetlands are engineered ecosystems designed to remove pollutants from wastewater (Kadlec and Wallace, 2009). These systems mimic the treatment that occurs in natural wetlands by relying on heterotrophic microorganisms, aquatic plants and a combination of naturally occurring processes (Scholz, 2015).

Researchers previously investigated the performance of ponds (Yaseen and Scholz, 2016) and, in particular, constructed wetlands to treat textile wastewater (Table 1). However, results rarely cover all seasons (Vymazal, 2014). Pervez et al. (2000) used aerated vertical-flow wetlands to remove two textile Azo dyes (RB171 and AB113) from synthetic wastewater for a period of 70 days. The percentage removal of 98% was high for both dyes. However, the results did not assess the removal of COD, phosphorus and nitrogen.

Davies et al. (2006) used vertical-flow wetlands for aerobic degradation of Acid Orange 7 (AO7) in a short-term study (Table 1). The results showed colour and COD removals of 99% and 93%, respectively. However, phosphorus and nitrogen removal were not recorded.

Yalcuk and Dogdu (2014) used vertical-flow constructed wetlands to treat Acid Yellow 2G E107 Dye-containing wastewater (Table 1). The constructed wetland consisted of three vertical wetland filters, which were filled with fine gravel, sand and zeolite. One wetland was kept unplanted as a control and the other two were planted with *Canna idica* L. and *Typha angustifolia* L., respectively. The period of operation was only three months. The results showed that the average colour removal percentages were 87% for the control and 98% for the other wetlands. For NH_4-N, the average percentages removals were 43%, 61% and 46% for the control, *C. idica* and *T. angustifolia*, respectively. The average percentages of ortho-phosphate-phosphorus (PO_4-P) for the control, *C. indica* and *T. angustifolia* were 84%, 87% and 88% respectively. Only 90 days was the time of operation.

The presence of *Phragmites australis* in vertical-flow constructed wetlands has a significant impact on the removal of organic matters, aromatic amines and NH_4-N (Ong et al., 2011). The growth cycle of *P. australis* traditionally completes between May and September in Britain (Haslam, 1972). Ferreira et al. (2014) detected normal growth for *Phragmites* with absence of toxic signs or depletion of leaf nitrogen content, when they used vertical-flow wetlands to treat an effluent comprising Diazo dye (DR81).

The aim of this study is to assess the efficiency of vertical-flow constructed wetlands in removing dye, COD, PO_4-P and other nutrients. The corresponding objectives are to assess (a) the role of *P. australis* on dye removal; (b) the influence of two groups of dyes (Acid and Direct) on the performance of constructed wetlands on dyes removal; and (c) the influence of operational parameters such as contact time, resting time and loading rate on dye removal.

2. Materials and methods

2.1. Wetland rig and operation

The study has been conducted between 1 May 2015 and 31 May 2016. The first month may be viewed as the start-up period. An experimental constructed wetland rig (Fig. 1) treating textile wastewater has been operated within a greenhouse located on top of the Newton Building (The University of Salford). The rig has been designed to assess the system performance by simulating processes occurring within full-scale constructed wetlands. The rig comprises twenty-two vertical-flow wetland filters, allowing wastewater to drain vertically, enhancing aerobic biodegradation of organic matter and nitrogen (Fuchs 2009). The experimental wetland filters were located randomly in the experimental rig to minimise random impacts of parameters such as sunlight direction and temperature differences on the wetland performances.

Fig. 1. Experimental vertical-flow constructed wetland rig located within a greenhouse at the beginning of the experiment (Picture taken by Mr. Amjad Hussein on 15 May 2015).

Operational parameters such as contact time, retention time and hydraulic loading rate on dye removal were assessed. Contact time is defined as the duration the wastewater is in contact with the wetland filter content. In comparison, resting time is the duration when the wetland filter is empty (i.e. no wastewater input). The dyes AB113 and BR46 were tested at two different concentrations (target concentrations of 7 mg/l and 215 mg/l) for different retention times (approximately 48 h and 94 h) to assess their influence on the performance of vertical-flow constructed wetlands.

Round and black plastic drainage pipes were used to construct the vertical-flow wetlands (Fig. 1). All twenty-two wetlands were designed according to the following dimensions: height of 100 cm and diameter of 10 cm. One wetland was filled with water, another one was filled to a depth of 90 cm with unwashed gravel and the other wetlands were filled to a depth of 90 cm with washed gravel (Table 2). Two different layers of gravel were used as filter media. Large gravel with a diameter of 10–20 mm was applied as the bottom layer to prevent clogging of the outlet. Pea gravel with a diameter of 5–10 mm was located at the top layer. The outlet valves were located at the centre of the bottom plate of each wetland. The internal diameter of the vinyl outlet tubing was 10 mm.

Selected wetlands were planted with *P. australis* (Table 2). The growth of *P. australis* was monitored. Dead above-ground plant parts were cut down to about13 cm height. The cuttings were recycled by placing them into their corresponding wetland filters.