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Sequential anaerobic-aerobic decolourization of a real textile wastewater in a two-phase partitioning bioreactor

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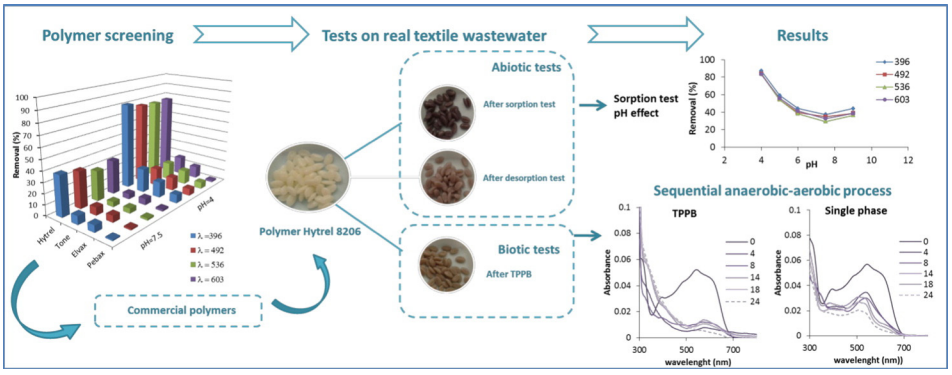
HIGHLIGHTS

- A two-phase partitioning bioreactor is applied to treat real textile wastewater.
- DuPont polymer Hytrel 8206 is effective in colour absorption reaching removal of 84%.
- Low pHs favour the sorption process with equilibrium times ≤24 h.
- The polymer improves biological colour removal in the two-phase system.

GRAPHICAL ABSTRACT



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ABSTRACT

This work describes the application of a solid-liquid two-phase partitioning bioreactor (TPPB) for the removal of colour from a real textile wastewater containing reactive azo-dyes. Four polymers were tested over the pH range of 4–9 to select the most effective absorbant to be used as the partitioning phase in the TPPB. The best results were obtained with Hytrel 8206 at pH 4 achieving ~70% colour removal, based on the dominant wavelength, in the first 5 h of contact time, and 84% after 24 h. Wastewater treatment was undertaken in a solid-liquid TPPB operated with Hytrel 8206 in sequential anaerobic-aerobic configuration. The reaction time of 23 h was equally distributed between the anaerobic and aerobic phases and, to favour colour uptake, the pH was controlled at 4.5 in the first 4 h of the anaerobic phase, and then increased to 7.5. Colour removal (for the dominant wavelength, 536 nm) increased from 70 to 85% by modifying the bioreactor operation from single-phase to TPPB mode. Based on COD measurements nearly complete biodegradation of the intermediates produced in the anaerobic phase was obtained, both in the single-phase and two-phase mode, with better performance of the TPPB system reaching 75% COD_{Dye} removal.

1. Introduction

The textile industry is one of the largest producers of aqueous industrial emissions since dyeing, and associated finishing operations, generate among the largest volumes and pollution levels of discharged water (Sen and Demirer, 2003). Because dyes are designed to provide a high degree of chemical and photolytic stability to resist breakdown over time, microbial attack, and the action of water and soap, they are recalcitrant and resistant to biodegradation (Solis et al., 2012). Azo dyes are the most common synthetic dyes used in industry, and thus the most commonly released into the environment and are used in

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the textile industry, paper printing (Chang et al., 2004) and in plastics, leather, cosmetics and food industries (Telke et al., 2008). Release of untreated or poorly treated effluents containing azo dyes is harmful to the aquatic environment, causing inhibition of photosynthesis and growth of aquatic biota, reduction of dissolved oxygen, potential toxicity to humans, flora and fauna (Saratale et al., 2011), and also for aesthetic reasons as colour in wastewater can be detected even at very low levels (<1 mg/L) (Pereira and Alves, 2012).

Conventional wastewater treatment, such as activated sludge, can be ineffective for decontaminating dye effluents because of the physical-chemical stability and poor biodegradability of these pollutants, as noted above (Forgacs et al., 2004), but, it is worth noting that relative to chemical and/or physical processes, biological methods have the advantages of being cost-competitive and more environmentally friendly. Moreover, if operated with effective technologies, are often able to achieve complete mineralization of the pollutants at ambient conditions. Several research and review articles have focused on the biological decolourization of textile wastewater, especially on synthetic azo dye solutions summarizing the use of different microorganisms, reaction environments and technologies (Sponza and Isik, 2002; Pandey et al., 2007; Saratale et al., 2011; Solis et al., 2012).

The biodegradation of reactive azo dyes is difficult since their complex structure and synthetic nature often require a variety of bacteria, both aerobic and anaerobic, able to achieve the reductive cleavage of the —N═N— bond, resulting in the formation of generally colourless, but potentially hazardous, aromatic amine by-products. These aromatic intermediates could in principle be degraded aerobically or anaerobically (Joshi et al., 2004), however these metabolites can be more toxic than the parent dyes (Solis et al., 2012), and their biodegradation is generally more effective under aerobic conditions (van der Zee and Villaverde, 2005). This has led to the use of sequential anaerobic-aerobic processes aimed at more effective removal of azo dyes from wastewater, recently reviewed by Popli and Patel (2015), who have considered biological anaerobic-aerobic decolourization of azo dyes for various types of reactors, under different operating conditions. They concluded that the anaerobic stage of the sequential process can be negatively affected by the high initial concentration and complex structure of dyes, and confirmed the possibility of achieving mineralization of the intermediates under aerobic conditions.

Here, we propose the application of two-phase partitioning bioreactors (TPPBs), which have been demonstrated to be advantageous for xenobiotic removal (Tomei et al., 2011b). Employment of a TPPB in this case can be effective in reducing the exposure of biomass to toxic substrate concentrations, with the additional feature, in contrast to the use of activated carbon proposed by Kuai et al. (1998) for the same purpose, of providing gradual substrate release and subsequent biodegradation in the aqueous phase. The uptake of toxic substrates by amorphous polymers in TPPB systems occurs via absorption rather than adsorption: i.e. when biodegradation occurs in the cell-containing aqueous phase the thermodynamic equilibrium of the system is restored by the release of the absorbed compound driven by the cellular metabolic demand. This feature maintains sub-inhibitory concentration levels in the liquid phase to allow the biomass to achieve high biodegradation rates of the compound, which is consumed, and not simply adsorbed. The mechanism of uptake-release also provides for polymer bioregeneration, and the consequent restoring of its sorption capacity, which is not exhausted. As a final distinction between absorptive amorphous polymers and adsorptive activated carbon, rational selection of such polymers allows the use of materials, which are specifically targeted to the substrate in question, unlike activated carbon which is generally non-selective to organic molecules.

To date, most studies and applications of this powerful technology were related to synthetic solutions, and in this study we have investigated for the first time the application of TPPB systems to a real wastewater. The main objective of this study was to evaluate colour removal for a sequential anaerobic-aerobic process operated in a conventional single-phase mode and in a TPPB system for the treatment of an industrial effluent containing Remazol Black 5, Remazol Yellow RR and Remazol Brilliant Red 21. In addition, COD levels during the treatment steps were followed to have a cumulative estimate of the fate of the intermediates during the biodegradation process. Finally, according to Muda et al. (2011) and Ricco et al. (2004), on line measurement of the specific oxygen uptake rate (SOUR) was used to assess the toxicity of dyes/by-products on the aerobic biomass in the different contacting configurations.

2. Materials and methods

2.1. Textile wastewater

Textile wastewater was obtained from the dyeing bath of a factory located in the textile district of the Como area, in the North of Italy. The contaminant load is mainly comprised of a mixture of mono and di-azo reactive dyes (commercially named Remazol Black 5, Remazol Yellow RR and Remazol Brilliant Red 21), accounting for ~90% of the pollution load, and chemical additives used for industrial processing. Wastewater characterization is reported in Table 1.

2.2. Polymers

A first selection of the polymers has been performed on the basis of their previous applications in TPPBs and on their predicted affinity for the dyes under investigation (Bacon et al., 2014).

Four commercial polymers were tested in this study, and their source, properties and composition are shown in Table 2. Before use, the polymers were pre-treated in order to remove any impurities arising from the manufacturing process by adding a known mass of polymer (~100 g) to an equal volume of methanol (Fluka, Italy) in a flask and mixing it vigorously for at least 20 min. The polymers were then repeatedly washed with distilled water until a clean (i.e. non-turbid) wash water was obtained. Each step lasted 20 min and, generally, five washing steps were sufficient, at the end of which the polymers were dried by air exposure for several days.

2.3. Sorption and desorption tests

Sorption tests of the wastewater colour by polymers were performed in batch mode in flasks containing a fixed volume (in the range of 100–200 mL) of wastewater diluted 1:10 with tap water. Magnetic stirrers provided the mixing, and the temperature was controlled at 25 ± 0.5 °C. The duration of the tests varied in the range of 24–72 h, i.e. a time estimated to be sufficient to reach equilibrium. Liquid samples were taken from the flasks at time intervals of 1 h, during the first 8 h, then after 24 h and then at subsequent intervals of 24 h. The pH was regularly monitored and adjusted by acid/base addition in order to maintain the desired pH values, which were pH 4 and 7.5 at a fixed polymer/solution ratio of 5% (v/v).

Table 1
Textile wastewater characteristics: average values and standard deviation (SD).

Parameter	Unit	Average value	SD
pH	–	9	0.50
COD	mg/L	1117	58.00
TSS	g/L	0.54	0.10
VSS	g/L	0.23	0.05
TC	mg/L	471.1	35.2
TOC	mg/L	158.0	9.80
$N\text{-}NH_4$	mg/L	40.0	4.50
Chlorides	g/L	38.6	3.10
Nitrate	g/L	3.8	0.35
Phosphates	g/L	3.2	0.33
Sulphates	g/L	4.5	0.38