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Review article

Fungal dye decolourization: Recent advances and future potential

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ABSTRACT

Dyes released by the textile industries pose a threat to the environmental safety. Recently, dye decolourization through biological means has gained momentum as these are cheap and can be applied to wide range of dyes. This review paper focuses on the decolourization of dye wastewaters through fungi via two processes (biosorption and bioaccumulation) and discusses the effect of various process parameters like pH, temperature, dye concentration etc. on the dye removing efficiency of different fungi. Various enzymes involved in the degradation of the dyes and the metabolites thus formed have been compiled. Genetic manipulations of microorganisms for production of more efficient biological agents, various bioreactor configurations and the application of purified enzymes for decolourization, which constitute some of the recent advances in this field, have also been reviewed. The studies discussed in this paper indicate fungal decolourization has a great potential to be developed further as a decentralized wastewater treatment technology for small textile or dyeing units. However, further research work is required to study the toxicity of the metabolites of dye degradation and the possible fate of the utilized biomass in order to ensure the development of an eco-friendly technology.

Contents

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1. Introduction

Due to the accessibility of small scale industries to the masses, these industries have helped in decentralizing the industrial technology in India. However, due to the financial constraints posed on the treatment of pollutants, these are discarded into the environment. This contributes to about 40% of the total industrial wastewater (Agarwal, 2001). One such example of small scale industry is the Textile Industry. In order to produce quality product a number of dyes and auxillary chemicals are used in these industries which has now become a critical environmental concern (Jacob and Azariah, 2000). The waste water of the industry is highly alkaline and has high Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Dissolved Solids (TDS). Such a wastewater is capable of causing hazardous environmental problems unless treated (CPCB, PSI-III Division). Table 1 tabulates the various characteristics of the wastes produced by the Textile Industry. Dyes used in the textile industries are aromatic organic compounds, and are based on the structure of benzene. On the basis of structure, dyes fall into cationic (basic dyes), anionic (direct, acid and reactive dyes) or nonionic (disperse dyes) type (Mishra and Tripathi, 1993).

Effluents from the textile industries containing dye are highly coloured and are therefore visually identifiable (Kilic et al., 2007). The complex aromatic structure of the dyes is resistant to light, biological activity, ozone and other degradative environmental conditions. Thus conventional waste water treatment remains ineffective. Also, anionic and nonionic azo dyes release toxic amines due to the reactive cleavage of azo groups (Joshi et al., 2004). Presence of heavy metals like chromium, cobalt, nickel and copper (metallized dyes) in wastewater is also an environmental concern (Freeman et al., 1996). Up till now scientists have been trying to develop a single and economical method for the treatment of dyes in the textile waste water but still it remains a big challenge (Santos et al., 2007). There are various methods for the treatment of textile wastewater for the removal of dye. These broadly fall into three categories: Physical, Chemical and Biological. These methods have earlier been extensively reviewed (Hao et al., 2000; Robinson et al., 2001; Forgacs et al., 2004; Joshi et al., 2004). The major disadvantage of physico-chemical methods has been largely due to the high cost, low efficiency, limited versatility, interference by other wastewater constituents and the handling of the waste generated. Microbial decolourization being cost-effective is receiving much attention for treatment of textile dye waste water (Banat et al., 1996; Stolz, 2001; Zee and Villaverde, 2005).

Biological treatment may involve either aerobic or anaerobic degradation of the dyes by microorganisms. Biodegradable components of industrial wastewater can be removed by aerobic treatment. But it is ineffective in degrading xenobiotic compounds such as dyes (Joshi et al., 2004). Anaerobic treatment of dye waste waters includes the use of various anaerobic bacteria producing the enzyme azoreductase. However, combination of anaerobic (for reductive cleavage of the dyes' azo linkages) and aerobic treatment (for the degradation of products obtained from azo dye cleavage) for the removal of azo dyes in wastewater systems has been proposed by many researchers (O'Neill et al., 2000; Panswad and Luangdilok 2000; Frijters et al., 2006). Frijters et al. (2006) observed 90–95% colour reduction in the anaerobic phase of the wastewater treatment but no colour removal was observed in the aerobic phase. Toxicity of the treated effluent disappeared in aerobic phase. Zee and Villaverde (2005) has reviewed the work done utilizing the combined, sequential or integrated anaerobic–aerobic bioreactor treatment of wastewater containing azo dyes. Kudlich et al. (1996) employed both anaerobic and aerobic treatments through co-immobilized *Sphingomonas* bacteria and an uncharacterized 5-Aminosalicylate degrading isolate on alginate beads to degrade Mordant yellow 3 dye. In the anoxic environment present at the centre of the beads, *Sphingomonas* sp. bacteria reduced mordant yellow 3 dye to 5-Aminosalicylate and 6-Amino naphthalene-2-sulfonate. In aerobic conditions *Sphingomonas* bacteria converted 6-Amino naphthalene-2-sulfonate to 5-Aminosalicylate. In the aerobic environment which prevails on the surface of the beads, mineralization of 5-Amino Salicylate took place by an uncharacterized isolate. Application of bacteria for dye removal has been extensively reviewed (Banat et al., 1996; McMullan et al., 2001; Pearce et al., 2003; Forgacs et al., 2004; Santos et al., 2007). Certain algae like *Chorella* (Banat et al., 1996; Aksu, 2005), *Oscillatoria* (Banat et al., 1996) and *Azolla filiculoides* (Padmesh et al., 2005) have also been employed for dye removal.

Table 1
Characteristics of wastes produced by the textile industries

Serial number	Waste	Process in which it is released	Concentration
	Process waste water		pH-alkaline, BOD — 700–2000 mg/l, COD — 2–5×BOD
1	Toxic organics including phenols	Dying and finishing	
2	Halogenated organics	Bleaching	
3	Dyes	Dying, printing	Below 1 g/dm^3 (O'Neill et al., 1999)
4	Heavy metals		Cr — 0.35–170 mg/l, Cu — 0.12–4.20 mg/l, Ni — 0.10–0.96 mg/l, Pb — 0.10–4.00 mg/l, Zn — 0.10–58 mg/l, Mg — 0.50–10 mg/l (Netzer et al., 1975)
5	Pesticides (preservation of natural fibres)	Washing and scouring	–
6	Brominated flame retardants (synthetic fibres)		
7	Isocyanates	Lamination	
8	Volatile organic Compounds (VOC)	Finishing and drying	10–350 mg Carbon/m^3
9	Oils		

Source: Pollution Preservation and Abatement Handbook (1998).

2. Fungal dye removal

The role of fungi in the treatment of wastewater has been extensively researched (Azmi et al., 1998; Coulibaly et al., 2003; Brar et al., 2006). Fungus has proved to be a suitable organism for the treatment of textile effluent and dye removal. The fungal mycelia have an additive advantage over single cell organisms by solubilising the insoluble substrates by producing extracellular enzymes. Due to an increased cell-to-surface ratio, fungi have a greater physical and enzymatic contact with the environment. The extra-cellular nature of the fungal enzymes is also advantageous in tolerating high concentrations of the toxicants. Many genera of fungi have been employed for the dye decolourization either in living or dead form (Table 2). Based