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Review

Microbial degradation of synthetic textile dyes: A cost effective and eco-friendly approach

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Synthetic dyes extensively used in different industries are maximally toxic, mutagenic and carcinogenic in nature. Being recalcitrant, if not treated, they will remain in nature for extended period of time. Wide range of known methods for dye removal is categorized viz. Physical, chemical, biological and electrochemical. Advantage of biological, chemical and electrochemical method over physical involves the complete destruction of the dye molecule. Advantage of biological method over chemical and electrochemical is of being cost-effective also. Large numbers of micro flora including bacteria, fungi, algae and yeasts have been explored to decolorize and degrade dyes. The intent of the present review paper is to present the dye decolorizing and degrading potential of known microflora. To emphasize on the aspect of biological method for making it cheaper and non-polluting for cost effectiveness, it may be an effective environmental friendly technology especially for the developing nations.

Key words: Dye, textile wastewater, biological method, biodegradation.

INTRODUCTION

Presence of color and causative compounds has always been undesirable in water used for either industrial or domestic needs (Kiran et al., 2012). The inefficiency in dyeing processes has resulted in 10-15% of unused dyestuff entering the wastewater directly (Dwivedi et al., 2012).The effluents with high levels of biochemical oxygen demand (BOD) and chemical oxygen demand (COD) values are highly toxic to biological life (Palamthodi et al., 2011). In textile industry, the process of dyeing results in the production of large amounts of wastewater exhibiting intense coloration that has to be eliminated before release into natural water streams (Rezaee et al., 2008). In addition, colored water is objectionable as it can spoil the beauty of water environments (Andleeb et al., 2010; Ashutosh et al., 2010). Discharging of such wastewaters into receiving streams not only affects the aesthetic aspects but also interferes with transmission of sunlight into streams and therefore reduces photosynthetic activity (Cicek et al., 2007). Without adequate treatment, such dyes will remain in the environment for an extended period of time (Olukanni et al., 2006). The existence of the colorless aromatic amines in the aqueous ecosystems is of a serious environmental and health concern; therefore a complete removal of such compounds from aquatic system is required (Celik et al., 2012).

DIFFERENT METHODS FOR DYE DEGRADATION

Several methods were adapted for the reduction of dyes to achieve decolorisation. They are divided into four major categories: Physical, chemical, biological and electrochemical. A review on dyes physicochemical treatment technologies, their working principle, advantages and disadvantages will provide the summary

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Abbreviations: BOD, Biochemical oxygen demand; **COD,** chemical oxygen demand; **ABS,** aminobenzenesulfonates.

on different aspects of this technology (Table 1). Biological and chemical methods involve the destruction of the dye molecule, whilst physical methods usually transfer the pollutant to another phase (Ramalho, 2005). The versatility of microorganisms makes them capable to degrade wide varieties of dye. Moreover, in case of high xenobiotic compounds, electrochemical or physicchemical techniques can be merged with biological means to make the process eco-friendly and cost-effective.

Biological treatments

The fate of environment pollutants is largely determined by abiotic processes, such as photooxidation, and by the metabolic activities of microorganisms. Various microbes such as bacteria, fungi, actinomycetes and algae have been reported to degrade different pollutants (Pandey et al., 2011; Chandra et. al., 2012).

Dye degradation using bacteria

Efforts to isolate bacterial cultures capable of degrading azo dyes started in the 1970s with reports of a *Bacillus subtilis* (Horitsu et al., 1977). Based on the available literature, it can be concluded that the microbial decolorisation of azo dyes is more effective under anaerobic conditions (Elisangela et al., 2009). The study aim to investigate the potential of isolated bacterial strains to decolorize the important textile dyes in liquid system under anaerobic conditions. In phtalocyanine dyes, reversible reduction and decolorisation under anaerobic conditions have been observed (Van der Zee, 2002). Interest is now focused on the bacteria which can perform high rate of discoloration under anoxic conditions and provide detoxification of aromatic products under aerobic environment (Stolz, 2001; Upadhyay, 2002; Chen et al., 2007). Several isolates of *Pseudmonas, Alcaligenes, Acinetobacter* and *Bacillus* are a few important bacteria useful in bioremediation of halogenated organic compounds (Pandey et al*.,* 2011). The bacterial strain *Arthobacter sp.* isolated from textile effluents for the first time is capable of degrading pararosaniline chloride dye almost completely (Dwivedi et al., 2012). Actinomycetes, particularly *Streptomyces* species are known to produce extracellular peroxidases that have a role in the degradation of lignin and were also found effective in the degradation of dyes (Bhaskar et al., 2003). Under aerobic conditions, azo dyes are not readily metabolized, although the ability of bacteria with specialized reducing enzymes to aerobically degrade certain azo dyes were reported (Stolz, 2001). Moreover, it has been observed that several bacteria can degrade anthraquinone dyes (Fontenot et al., 2001). Aminobenzenesulfonates (ABS) are important constituents of many azo dyes, pesticides and pharmaceuticals (Linder, 1985). Bacterial consortium AS1 & AS2, which can utilize 2-ABS as the sole carbon and energy source (Singh et al., 2011). Moreover, bacterial species studies were also carried on the degra-dation of reactive dyes. *Rhodopseudomonas palustris* 51ATA strain is an excellent bacterium for the removal of reactive red 195 dye (Ozturk et al., 2012).

Mechanism of bacterial dye decolorisation and degradation

Lots of data is available on bacterial dye decolorisation and degradation. The mechanism of bacterial dye decolorisation and degradation has been divided in three parts (Table 2). Considering bacteria, it is well known that bacteria can degrade and even completely mineralize many reactive dyes under certain conditions (Moosvi et al., 2005; Wang et al., 2009). Complete biodegradation of a compound is termed mineralization. Mineralisation of dyes with Bacteria has been reported (Haug et al., 1991; Ramalingam and Shobana 2011; Singh et al., 2011). Moreover, large work has been done on biodegradation of dyes by bacteria. Biodegradation of dyes by bacteria has been reported (Gurulakshmi et al., 2008; Barragan et al., 2006; Chaube et al., 2010; Sugumar and Sadanandan 2010). In bacteria, two types of degradation occurs, aerobic and anaerobic. In case of reactive azo dyes namely, Remazol brilliant Orange 3R, Remazol Black B and Remazol Brilliant Violet 5R, total degradation was achieved by using an anaerobic-aerobic treatment (Supaka et al., 2003). Degradation of azo dyes is possible under integrated anaerobic/aerobic conditions if co-substrate and oxygen are in balance (Tan, 2001). Some specialized strains of aerobic bacteria have developed the ability to use azo dyes as sole source of carbon (Table 3) and nitrogen (Barragan et al., 2006).

Dye degradation using fungi

The most widely studied class of microorganisms in regard to dye degradation and decolorisation are the fungi (Agarry and Ajani, 2011). The most widely researched fungi in regard to dye degradation are the ligninolytic fungi (Zille, 2005). Different groups of fungi have been reported as producers of ligninolytic enzymes, but white-rot fungi have received extensive attention due to their powerful production of these enzymes and their unique ability to degrade lignin to CO_2 (Lopez et al*.,* 2012). Such an extent of degradation is due to the strong oxidative activity and low substrate specificity of their ligninolytic system, which is primarily composed of laccase (Lac), Lignin peroxidase (LiP), and manganese peroxidase (MnP) (Martinez et al., 2009). The most widely studied white rot fungi include *Phanerochaete chrysosporium* (Chagas and Durrant 2001; Martins et al., 2002), *Trametes versicolor* (Kapdan et al., 2000; Kapdan and Kargi, 2002) and *Bjerkandera adusta* (Heinfling-Weidtmann et al., 2001). Several other non-white rot fungi can also successfully decolorize dyes like *Aspergillus niger* (Abd El-Rahim and Moawad, 2003),

Table 1. A review on physicochemical treatment technologies, their working principle, advantages and disadvantages.

Method	Technique	Principle	Efficiency	Disadvantage	Reference
Physical	Adsorption	Pollutants in wastewater are adsorbed and removed on the surface of porous material or filter.	Effectively remove the water soluble dyes such as reactive dyes, basic dyes and azo dyes	Cannot adsorb suspended solids and insoluble dyes. Used in lower concentration of dye wastewater treatment. High cost of regeneration	(Wang et al., 2011).
	Membrane filtration	They are pressure driven process across membrane.	Remove all dye types. Recovery and reuse of chemicals and water.	High running cost. Concentrated sludge production. Dissolved solids are not separated in this process.	(Carmen and Daniela, 2012).
	Coagulation	Principle in this process is the addition of a coagulant followed by general rapid association between the coagulant and the pollutants.	Effectively eliminate insoluble dyes.	High cost of treating sludge. Increasing number of restriction concerning the disposal of sludge.	(Adinew, 2012)
Chemical	Irradiation		Effective oxidation at lab scale.	Requires a lot of dissolved O_2	(Andre et al., 2005)
	Fenton oxidation	The process is based on the formation of reactive oxidizing species, able to efficiently degrade the pollutants of the wastewater stream.	Decolorize a wide range of dyes and results in large COD reduction.	Fenton's process requires low pH. Sludge Production.	(Hao et al., 2000) ; (Adinew, 2012); (Nesheiwat and Swanson, 2000).
	Ozonation	Attacks the pollutant through two different reaction pathways: (1) the direct ozonation by ozone molecule (2) the radical ozonation by highly oxidative free radicals.	Ozonation do not cause sludge and raising wastewater volume	Short half life (20 min)	(Avsar and Batibay, 2010); (Andre et al., 2005)
	Advanced oxidation process	Based on the principle of generation of highly reactive oxidizing species able to attack and degrade organic substances	Rapid reaction rates. Potential to reduce toxicity and possibly complete mineralization of organics treated. Do not create sludge Does not concentrate waste for further treatment with methods such as membranes.	Capital Intensive. Complex chemistry must be trilored to specific application. For some applications quenching of excess peroxide is require.	(Bolton, 2001); (Kestioglu et al., 2005); (Sharma et al., 2011).
Electrochemical destruction		It works on the principle of addition of oxidizing agents to the process to stimulate reaction.	Breakdown compounds are non hazards	High cost of electricity	(Muthukumar et al., 2005); (Aplin and Wait, 2000); (Mouli et al., 2004).
Biological degradation		The biological process removes dissolved matter in a way similar to the self depuration but in a further and more efficient way than clariflocculation.	Cost effective. Diverse metabolic pathways. Versatility of microorganisms.	Evaluation of optimal environment favorable to microbial growth. Variation in characteristics of dye wastewater, limits the use of microorganisms for different dyes.	(Banat et al., 1996); (Singh et al., 2004); (Mendez –Paz et al., 2005); (Pandey et al., 2007); (Wang et al., 2011)

Table 2. Reported mechanism of bacterial dye remediation.

Mineralization
Biodegradation
Utilisation of carbon source

Table 3. Bacteria reported in utilization of dyes as sole carbon source.

Bacteria	Dye used as source of carbon	References
Bacillus sp, *Micrococcus* sp, *Staphylococcus* sp, *Pseudomonas* sp, *Lactobacillus* sp	Can utilize dye as a sole carbon source without any external carbon in the presence of nitrogen source under anoxic condition was found	(Palani et al., 2012)
Sphingomonas sp	Capable of aerobically degrading a suite of azo dyes, using them as a sole source of carbon and nitrogen	(Coughlin et al., 1999)
Bacillus sp	Utilisation of azo and triphenylmethane dyes as sole source of carbon, energy and nitrogen	(Oranusi and Mbah, 2005)
Bacillus subtilis	Cometabolize *p*-aminoazobenzene in the presence of glucose as carbon source.	(Sharma et al., 2010)

Table 4. Mechanism of fungal dye decolorisation and degradation (Courtesy: Pavko, 2011).

Adsorption
Biodegradation
Adsorption & Biodegradation
Mineralization
Utilization of carbon source

Geotrichum candidum (Kim et al., 1995; Shoda and Kim, 1999), *Pleurotus oestreatus* (Martins et al 2003; Palmieri et al., 2005) and *Cunninghamella elegans* (Cha et al., 2001; Ambrosio and Campos –Takaki 2004). The efficient use of different *Aspergillus* species (*A. niger, Aspergillus foetidus, Aspergillus fumigatus* and *Aspergillus terreus*) for decolorisation of different types of dye has been reported (Sumathi and Manju, 2000; Ali et al., 2007; Jin et al., 2007; Andleeb et al., 2010).

Mechanism of fungal dye decolorisation and degradation

Fungi has been reported in degradation of textile dyes. The mechanism of fungal dye decolorisation and degradation is given in Table 4. Adsorption of dyes to the microbial cell surface is the primary mechanism of decolorisation (Knapp et al., 1995). Based on mechanism of adsorption and enzymatic activity, Degradation of textile dyes, Congo red and Bromophenol using *Aspegillus flavus* has been reported by Singh and Singh (2010). Moreover, Zhou and Zimmermann (1993) has reported the adsorption of anthraquinone, phthalocyanine and azo dyes by actinomucete strains. Biodegradation is the transformation of a substance into new compounds through biochemical reactions. Biodegradation of Orange II dye by *P. chrysosporium* in simulated wastewater was reported by Sharma et al. (2009). Not much data is available on mineralization of dyes by fungi. The fungal action rarely leads to mineralization of dyes and very much depends on the chemical structure (Pavko, 2011). Utilization of dyes as carbon source has been reported by Machado et al. (2006) in their study of biodegradation of reactive textile dyes by *Basidiomycetes* fungi from Brazilian ecosystems. Much work is needed to be done in exploring enzymes and pathways involved in degradation of dyes by fungi. Not much work on mineralization of dyes by fungi has been reported.

Dye degradation using yeasts

In literature, the ability to degrade azo dyes by yeasts was only described in a few reports. The first two reports use the ascomycete yeasts *Candida zeylanoides* isolated from contaminated soil to reduce model azo dyes (Ramalho et al., 2002). The characterization of an enzymatic activity is described in further studies with the yeast *Issatchenkia occidentalis* (Ramalho et al., 2004), and the enzymatic system involved is presented in a work with *Saccharomyces cerevisiae* (Ramalho et al., 2005). Dye decolorisation by yeast generally occurs through three mechanisms, *viz.,* biosorption, bioaccumulation and biodegradation (Das and Charumathi, 2012). *Galactomyces geotrichum* MTCC 1360, a yeast species, showed more than 96% decolorization of the azo dye, Remazol Red (50 mg/L) within 36 h at 30°C and pH 11.0 under static condition with a significant reduction in the chemical oxygen demand (62%) and total organic carbon (41%) (Waghmode et al., 2012).

Mechanism of yeast dye decolorisation and degradation

Dye decolorisation by yeast generally occurs through three mechanisms, viz., biosorption, bioaccumulation and biodegradation (Das and Charumathi, 2012). Moreover, biodegradation of Basic Violet 3, a xenobiotic compound using *Candida krusei* was reported by Charumathi and Das (2011). Biodegradation of methyl red using *G. geotrichum* was achieved by Jadhav et al. (2008). *S. cerevisae* was reported to decolorize triphenylmethane dyes by biosorption, showing different decolorisation patterns (Jadhav and Govindwar, 2008). Biodegradation of Remazol Red dye by *G. geotrichum* was reported by (Waghmode et al., 2012). Bioaccumulation of the reactive textile dyes by *C. tropicalis* was reported by (Donmez, 2002). Moreover, bioaccumulation of synthetic dyes viz. Acid Blue 93, Direct red 28 and Basic Violet 3 was achieved by environmental yeast isolate, *C. tropicalis* (Charumathi and Das, 2010).

Dye degradation using algae

The use of algae for the degradation of dyes is mentioned in only few reports and is achieved by *Chlorella* (Jinqi and Houtian, 1992; Acuner and Dilek, 2004), *Oscillateria* (Jinqi and Houtain, 1992) and *Spirogyra* (Mohan et al., 2002) species. All these reports used azo dyes (Jinqi and Houtain, 1992) state that some of the tested azo compounds could be used as sole sources of carbon and nitrogen by the algae. This could mean that algae can play an important role in the removal of azo dyes and aromatic amines in stabilization ponds (Banat et al., 1996). Algae have been studied in the field of decolorization of industrial effluents (Semple et al., 1999; Jianwei et al., 1997; Daneshvar et al., 2007; Vijayaraghavan and Yun, 2008). Moreover, removal of synthetic dye basic violet 3 was carried out by immobilized *C. tropicalis* grown on sugarcane bagasse extract medium (Charumathi and Das, 2010). This is due to the versatile ability of the algae to degrade, partially or completely various dyes.

Mechanism of algae dye decolorisation and degradation

Both viable and non-viable algae have been used in textile wastewater treatment. This may be achieved via bioconversion and biosorption (Maghraby, 2013). Decolorisation of Malachite Green by microalgae *Cosmarium sp* through bioconversion (Daneshvar et al., 2007). Removal of synthetic dyes from textile industry wastewaters by biosorption on macroalgae was reported by (Vieira, 2013). Bioconversion of mono-azo dye, Tectilon Yellow 2G (TY2G), and di-azo dye, Erionyl Navy (ENR) to aniline using *Chlorella vulgaris* was reported by Acuner and Dilek (2002). More investigation on algal biodegradation of synthetic dyes is needed.

CONCLUSION

Microorganisms represent half of the biomass of our planet, yet we know as little as 5% of the microbial diversity of the biosphere (Sinha et al., 2009). Based on the above review, it may be concluded that

1. Microorganisms possess a vast potential to degrade and decolorize synthetic dyes.
2. Reports on complete mineralization of dyes using bacteria exhibit, potential of bacteria and work is needed in exploring novel ones and development of new consortia.
3. Potential of fungi in dye degradation is not yet completely explored; therefore study for complete mineralizetion of dyes using fungi is needed.
4. One of the disadvantages associated with bioremediation is cessation of growth of microorganism either by dye product or due to activity of other microorganisms, therefore antagonistic studies are needed.

Much work is needed for elucidating the mechanism involved in bioremediation and how chemical nature of dyes affects growth of microorganism.

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