

Review Article

Reduction of Color Intensity from Textile Dye Wastewater Using Microorganisms: A Review

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Abstract

Keywords

Reduction, Color Intensity, Textile Dye, Wastewater

Introduction

Water pollution has gained a paramount importance due to the industrial effluents. Textile industries consume large quantities of water in wet processing operations generating huge quantities of dyestuffs.

More than 10,000 dyes are used in the textile industry and approximately 28,000 tonnes of dyes are being discharged into the public drains without proper treatment that eventually go into the river (Hsueh et al., 2005). 10% of dyes are lost during coloration process and 2% of these are directly discharged in aqueous effluent (Easton, 1995). Azo dyes are widely used among synthetic dyes in the textile industry and represent about 80 % of commercial dyes produced in the world with an annual production of 7×10^5 tonnes (Fu and Viraraghavan, 2001). The concentration of dyes in wastewater from textile dyeing industry can vary from 10 to 250 mg/l (O’Neill et al., 1999) whereas in another research it was reported that the concentrations may as high as 1,500 mg/l (Pearce et al., 2003).

The release of these dyes in large quantities is a serious threat to the environment. Besides aesthetic and problem towards photosynthetic process, azo dyes also have an adverse impact in terms of total organic carbon (TOC), biological oxygen demand (BOD) and
chemical oxygen demand (COD) (Saratale et al., 2009) and many of its metabolites are toxic, carcinogenic and mutagenic (Myslak and Bolt, 1998). Moreover various research reveal that the toxic effects of dyes have a major influence over the germination rates and biomass of several plant species (Ghodake et al., 2009). As a result, treatment of industrial dye effluents and their metabolites is necessary prior to their final discharge to the environment. Therefore this topic is gaining great interest of many researchers to study the pros and cons of color removal.

There are three methods to treat the industrial effluent such as physical, chemical and biological method. Physical method involve the use of bio-sorbsents, coagulants and filtration techniques. Activated carbon, alumina, silica gel, clays, chitin, chitosan, zeolite, rice husk, orange peels, peat, sawdust, red mud, maize cobs, fly ash, and bagasse pith which are known as bio-sorbsents, are being used to remove dyes from waste water (Gupta, 2009).

The most drawback of solid adsorbents is that adsorbents contain toxic dyes on their surfaces generating sludge as secondary pollutant solid waste. Chemical methods such as ozonation, fenton oxidation, electrochemical oxidation, ultrasonic chemical oxidation and irradiation oxidation has limited usability for the treatment of dyes due to high cost of the electricity, radiation, and ozone (Pearce et al., 2003; Esteves and Silva, 2004). On the other hand, microorganisms for decolorizing dyes effluent is considered relatively cost effective.

Moreover biological treatment are eco-friendly because it exhaustively removes pollutants from the effluent. In this review, we will discuss about the different processes of dye removal with microbial de-colorization process and several parameters related to the mechanism.

Physico-chemical characteristics of textile raw wastewater and its impact towards degradation

Different azo dyes, salts and metals, along with other compounds that make textile raw wastewater very difficult to decolorize from wastewater containing simple dye mixtures and sodium chloride (Saratale et al., 2009; Alinsafi et al., 2006). Polyvinyl alcohol (PVA), carboxymethyl cellulose, surfactants, organic processing acids, sulfide, formaldehyde, detergents, and oil and dispersants that are used in textile industry either to give strength to the fiber or to improve the adsorption of dyes on the fiber (Rosli and Habibah, 2006) which are not readily biodegradable and can be toxic to the microbial cultures. Some characteristics of raw textile wastewater that are important from the viewpoint of de-colorization are discussed in detail here.

Dyes with methyl, methoxy, nitro or sulfo groups are found to be degraded very difficult as compared with dyes which have hydroxyl or amino groups (Nigam et al., 1996). On the other hand, direct dyes are easily degraded comparing with acid and reactive dyes (Saratale et al., 2009) whereas high molecular weight dyes are degraded slowly than low molecular weight dyes. Thus the composition of the azo dyes has a great influence over the de-colorization of dyes. The effluents are found toxic, xenobiotic and carcinogenic to aquatic life where dyes are released in the textile wastewater (Tüfekci et al., 2007; Adinew, 2012). In order to improve the fixation of dyes on fabrics NaNO₃, NaCl and Na₂SO₄ salts are generally added to the baths for improving the fixation of dyes. High concentrations of salts can reduce the rate of biodegradation of dyes as salts can cause plasmolysis and reduce biological activity (Manu and Chaudhari, 2003). Electrophilic agents such as nitrate and sulfate compete
with the dye molecule for electrons from azoreductases, causing negative effect on the de-colorization of dyes (Meng et al., 2012). Metal complex dyes or chemicals existing metals are also used in the dyeing process. It was reported in an article that about 30% metal complex dyes are used in dyeing wool and 40 % for dyeing polyamide (Hunger, 2003). Various metals such as Cd, Cr, Co, Cu, Hg, Ni, Mg, Fe and Mn are found in the raw textile effluents which are found to inhibit microbial growth and enzymatic activities (Saranraj et al., 2010). In addition, temperature is a great factor for de-colorization. The temperature of the dye effluent can be as high as 70°C which inhibits the microbial activities (Saratale et al., 2009; Abu-Ghunmi and Jamrah, 2006). The favorable condition for dye degrading of microbes is 30-40°C. But some bacterium *Anoxybacillus rupiensis* was identified that can de-colorize at about 60°C. In general high temperature reduces the rate of de-colorization and hence a pretreatment of cooling is necessary for wastewater treatment through biological process. Another important driver of textile wastewater treatment is fluctuating pH that can vary on the particular dye process. It may be highly alkaline, neutral or acidic depending on the nature of the salts and dyes (Imran et al., 2014). It has been recorded that the pH of the dye-containing wastewater can change the rate of degradation of the dyes (Hussain et al., 2013). Hence either the pH of the wastewater should be adjusted according to the microbial culture or else requires the use of microbial strains that are capable of de-colorization. On the other hand, Biological oxygen demand (BOD) and chemical oxygen demand (COD) are also important factors for biodegradation process. BOD refers to the amount of oxygen that would be consumed if all the organics are oxidized by the biological process (ReVelle and ReVelle, 1988) while the COD is the amount of oxygen consumed for oxidizing organic and inorganic contaminants chemically. BOD (800mg L-1) and COD (2,300 mg L-1) values are observed in the textile wastewater (Jang et al., 2007) whereas in another research it was recorded as COD values in the range of 1,067–2,430 and BOD values in the range 163–645 mg L-1 (Yusuff and Sonibare, 2004). Generally, easily decomposed organic compounds by microbes can enhance the rate of dye removal from wastewater by serving as source of reducing equivalent (NADH, NADPH) which are needed for the azo reductases to reduce azo bonds; but textile wastewater contains organics (oil, waxes, PVA and formaldehyde) which are not easily decomposed by microbes and thus their presence in wastewater can suppress microbial activities (Imran et al., 2014).

**Preference of biological treatment relative to physicochemical methods**

Several physical/chemical methods, such as adsorption, chemical precipitation, photolysis, chemical oxidation and reduction, electrochemical treatment, have been used for the removal of dyes from wastewater (Saratale et al., 2011) depicted in the Fig. 1.

Coagulation–floculation based physical methods of dyes are effective for the removal of mainly sulphur and disperse dyes, but exhibit very low efficiency for acid, direct, reactive and vat dyes (Saratale et al., 2011). Moreover, huge amount of sludge and lower color removal efficiency limit the application of these techniques (Vandevivere et al., 1998). In chemical oxidation methods, various oxidizing agents such as ozone (O₃), hydrogen peroxide (H₂O₂) and permanganate (MnO₄⁻) are used which modify the chemical composition of compound dye molecules that make susceptible to degradation (Metcalf, 2003). Ozonation, advanced oxidation process (AOP), fenton reaction are widely used for the removal of dye color.
Table 1: Current available technologies for color removal with advantages and disadvantages (Pearce et al., 2003)

<table>
<thead>
<tr>
<th>Physical and/or chemical methods</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxidation</td>
<td>Rapid process</td>
<td>High energy costs and formation of by-products</td>
</tr>
<tr>
<td>Adsorption</td>
<td>Good removal of wide range of dyes</td>
<td>Absorbent requires regeneration or disposal</td>
</tr>
<tr>
<td>Membrane technologies</td>
<td>Removal of all types of dyes</td>
<td>Concentrated sludge production</td>
</tr>
<tr>
<td>Coagulation/flocculation</td>
<td>Economically feasible</td>
<td>High sludge production</td>
</tr>
</tbody>
</table>

Table 2: De-colorization of dyes from industrial effluent using microorganisms-studies reported

<table>
<thead>
<tr>
<th>Name of the dyes</th>
<th>Organisms used</th>
<th>Comments</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramazol black b</td>
<td>Pseudomonas putida</td>
<td>97.12% de-colorization efficiency (DE), 48 h, 35°C, pH 7.00, 300 ppm.</td>
<td>(Kannan et al., 2013)</td>
</tr>
<tr>
<td>Reactive orange 16</td>
<td>Lactobacillus delbruckii</td>
<td>46% &amp; 49% DE, 37°C, pH 6.00, 10 ppm.</td>
<td>(SitiZuraida et al., 2013)</td>
</tr>
<tr>
<td>Reactive black 5</td>
<td>Aeromonas hydrophilia</td>
<td>90% DE, 20-35°C, pH 5.5-10.00, 300 ppm.</td>
<td>(Chen et al., 2003)</td>
</tr>
<tr>
<td>Brown 3REL</td>
<td>Bacillus sp. VUS</td>
<td>100% DE, 50°C, pH 7.00, 2 h</td>
<td>(Jadhav et al., 2008)</td>
</tr>
<tr>
<td>Reactive red 120</td>
<td>Xanthomonas campestris</td>
<td>60-97% DE</td>
<td>(Khehra et al., 2005)</td>
</tr>
<tr>
<td>Reactive blue 13</td>
<td>Pseudomonas sp.</td>
<td>83.2% DE, 35°C, pH 7.00, 70 h</td>
<td>(Lin et al., 2010)</td>
</tr>
<tr>
<td>Reactive yellow 84</td>
<td>Aeromonas hydrophilia</td>
<td>66.5% DE, 30°C, pH 7.5</td>
<td>(Hsueh et al., 2009)</td>
</tr>
<tr>
<td>Reactive orange 16</td>
<td>Bacillus genus</td>
<td>88% DE, 30°C, pH 7-8.00, 24 h</td>
<td>(Telke et al., 2009)</td>
</tr>
<tr>
<td>Congo red</td>
<td>Pseudomonas sp.</td>
<td>97% DE, 30°C, pH 7, 12 h</td>
<td>(Telke et al., 2009)</td>
</tr>
<tr>
<td>Direct red 5B</td>
<td>Comamonassp. UVS</td>
<td>100% DE, 40°C, pH 6.5, 13 h</td>
<td>(Jadhav et al., 2008)</td>
</tr>
<tr>
<td>Acid orange 7</td>
<td>Sphingomonas sp.</td>
<td>90% DE, 1 h</td>
<td>(Coughlin et al., 2002)</td>
</tr>
<tr>
<td>Dimethyl yellow</td>
<td>Aeromonashydrophilia var. 24B</td>
<td>54-90% DE</td>
<td>(Idaka et al., 1978)</td>
</tr>
<tr>
<td>Orange 1 &amp; 2</td>
<td>Pseudomonas sp.</td>
<td>35% &amp; 90% DE respectively</td>
<td>(Kulla et al., 1983)</td>
</tr>
<tr>
<td>C.I. Acid Orange 12</td>
<td>Pseudomonas capacia13 NA</td>
<td>90% DE, 68 h</td>
<td>(Ogawa et al., 1986)</td>
</tr>
<tr>
<td>Amaranth</td>
<td>Bacteroidesfragilis</td>
<td>80% DE</td>
<td>(Bragger et al., 1997)</td>
</tr>
<tr>
<td>Remazol black b</td>
<td>Shewanellaputrefaciens</td>
<td>95% DE</td>
<td>(Willmott, 1997)</td>
</tr>
<tr>
<td>Acid red GR</td>
<td>ShewanelladecolorationsS12</td>
<td>100% DE, 30°C</td>
<td>(Xu et al., 2007)</td>
</tr>
<tr>
<td>Reactive orange 96</td>
<td>Desulfovibriodesulfuricans</td>
<td>95% DE, 28°C</td>
<td>(Yoo et al., 2000)</td>
</tr>
<tr>
<td>Disperse blue 79</td>
<td>Bacillus fusiformisKMK5</td>
<td>100% DE, 37°C, pH 9.0, 48 h</td>
<td>(Kolekar et al., 2008)</td>
</tr>
<tr>
<td>Triphenylmethane dyes</td>
<td>Kurithasp.</td>
<td>98% DE, 30 mins</td>
<td>(Sani and Banerjee, 1999)</td>
</tr>
<tr>
<td>C.I Reactive red 22</td>
<td>Pseudomonas luteola</td>
<td>86.3 mg dye l⁻¹ h⁻¹</td>
<td>(Chang and Lin, 2000)</td>
</tr>
<tr>
<td>Remazol black b</td>
<td>Panbacillusazoreducenssp. nov.</td>
<td>98% DE</td>
<td>(Meehan et al., 2001)</td>
</tr>
</tbody>
</table>
Fig.1 Treatment methods for the removal of dyes from wastewater effluent (Hussain et al., 2013)

Physical and chemical methods have several drawbacks for the removal of dye color whereas biological methods have following advantages: (1) eco-friendly, (2) economical, (3) generating less sludge, (4) non-toxic end products or have complete mineralization; and (5) requiring less water consumption compared to physicochemical methods (Banat et al., 1996; Rai et al., 2005).

Mechanism for color removal

There are two mechanisms for the decoloration of azo dyes in bacterial systems (Pearce et al., 2003):

“Direct electron transfer to azo dyes as terminal electron acceptors via enzymes during bacterial catabolism, connected to ATP-generation (energy conservation)“.

“A gratuitous reduction of azo dyes by the end products of bacterial catabolism, not linked to ATP-generation”.

Drivers for color removal

There are several factors for dye removal such as temperature, aeration, pH, dye structure, electron donor, redox potential and redox mediator (Pearce et al., 2003).

The optimum temperature for bacterial cell growth is about 35-45°C whereas some microbes can grow at 60°C (Pearce et al., 2003). The loss of cell viability or denaturation of the azoreductase enzyme are occurred at higher temperature (Chang et al., 2001).

Both aerobic and anaerobic conditions have great role on dye removal. The concentration of oxygen can be high by the presence of aeration and agitation which should be controlled for efficient dye removal (Chang and Lin, 2000).

Oxygen has a vital role for the cell growth of bacteria but oxygen with high redox potential
electron acceptor can inhibit the dye reduction process (Pearce et al., 2003).

Neutral pH and slightly alkaline pH are the optimum conditions for efficient dye removal that is between 6.0 and 10 (Guo et al., 2007). The rate of color removal decreases at strongly acidic or strongly alkaline pH.

The greater the concentration of dyes, the lower the removal efficiency because of the formation of toxic metabolites. Aromatic rings with sulfonic acid groups of reactive azo dyes impedes the growth of microorganisms at high dye concentration (Kalyani et al., 2008). Hydroxyl or amino group containing azo compounds can be easily degraded than those with a methyl, methoxy, sulpho or nitro groups (Nigam et al., 1996).

Moreover, the presence of electron donors, the more positive redox potential and the presence of redox mediator has a positive impact on dye removal process.

The residual color of dye effluent has not only aesthetic problem but also environmental pollution factor that should be taken care by the industry to make a sustainable practice.

Among different processes, microbial and enzymatic de-colorization and degradation have great advantages such as low cost and environmentally friendly over other conventional processes. The reviewed literature suggests a wide variety of microbes are suitable for de-colorization of dyes that should be considered for real life application.

At the time of de-colorization process some toxic elements such as aromatic amines and other residues may be formed which should be required further mineralization process. It is also necessary to study the genetic basis of bacteria tolerance for salts, toxic elements and heavy metals.

**References**


Rosli M, and Habibah N. 2006. Development of biological treatment system for
reduction of COD from textile wastewater (Doctoral dissertation, UniversitiTeknologi Malaysia, Faculty of Science)


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