

Review Article

<https://doi.org/10.20546/ijcmas.2019.802.397>

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

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ABSTRACT

Keywords

Reduction, Color Intensity, Textile Dye, Wastewater

Article Info

Accepted:

22 January 2019

Available Online:

10 February 2019

Nowadays, synthetic dyes are widely used in textile, leather, cosmetics, paper, food and pharmaceutical industries instead of natural dyes due to its availability, stability, low cost and color intensity which emerges a new problem of residual color in the discharged effluent. Improper discharge of dye effluent in aqueous ecosystems is aesthetically unpleasant and impedes photosynthetic activity reducing sunlight penetration, dissolved oxygen concentration and water quality in total. Recalcitrant azo dyes which are mostly used in textile industries are not exhaustively removed from effluent by the existing effluent treatment plant. Biological method has gained momentum over physical and chemical process to remove color of dyes because of economic viability, ecofriendly and suitable for wide range of dyes. This review primarily focuses on color removal efficiency of different organisms, its mechanism and several responsible physicochemical parameters for dye removal.

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-sorbents, 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-sorbents, 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 sulpho 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 NaNO_3 , NaCl and Na_2SO_4 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–flocculation 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.

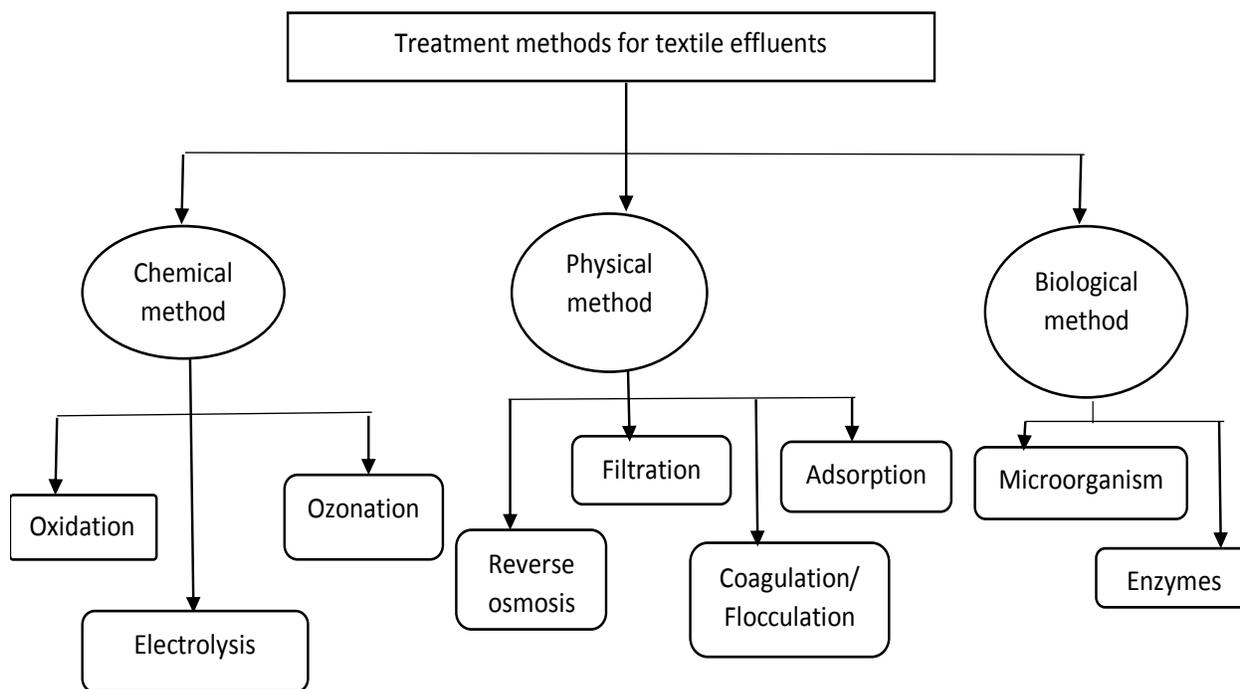
Table.1 Current available technologies for color removal with advantages and disadvantages (Pearce *et al.*, 2003)

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

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

Name of the dyes	Organisms used	Comments	Reference
Ramazol black b	<i>Pseudomonas putida</i>	97.12% de-colorization efficiency (DE), 48 h, 35 °C, pH 7.00, 300 ppm.	(Kannan <i>et al.</i> , 2013)
Reactive orange 16, Reactive black 5	<i>Lactobacillus delbruckii</i>	46% & 49% DE, 37 °C, pH 6.00, 10 ppm.	(SitiZuraida <i>et al.</i> , 2013)
Red RBN	<i>Aeromonashydrophilia</i>	90% DE, 20-35 °C, pH 5.5-10.00, 300 ppm.	(Chen <i>et al.</i> , 2003)
Brown 3REL	<i>Bacillus</i> sp. VUS	100% DE, 50 °C, pH 7.00, 2 h	(Jadhav <i>et al.</i> , 2008)
Reactive red 120	<i>Xanthomonascampestris</i>	60-97% DE	(Khehra <i>et al.</i> , 2005)
Reactive blue 13	<i>Pseudomonas</i> sp.	83.2% DE, 35 °C, pH 7.00, 70 h	(Lin <i>et al.</i> , 2010)
Reactive yellow 84	<i>Aeromonashydrophila</i>	66.5% DE,, 30 °C, pH 7.5	(Hsueh <i>et al.</i> , 2009)
Reactive orange 16	<i>Bacillus</i> genus	88% DE,, 30 °C, pH 7-8.00, 24 h	(Telke <i>et al.</i> , 2009)
Congo red	<i>Pseudomonas</i> sp.	97% DE, 30 °C, pH 7, 12 h	(Telke <i>et al.</i> , 2009)
Direct red 5B	<i>Comamonassp.</i> UVS	100% DE, 40 °C, pH 6.5, 13 h	(Jadhav <i>et al.</i> , 2008)
Acid orange 7	<i>Sphingomonassp.</i>	90% DE, 1 h	(Coughlin <i>et al.</i> , 2002)
Dimethyl yellow	<i>Aeromonashydrophiliavar.</i> 24B	54-90% DE	(Idaka <i>et al.</i> , 1978)
Orange 1 & 2	<i>Pseudomonas</i> sp.	35% & 90% DE respectively	(Kulla <i>et al.</i> , 1983)
C.I. Acid Orange 12	<i>Pseudomonas capacia</i> 13 NA	90% DE, 68 h	(Ogawa <i>et al.</i> , 1986)
Amaranth	<i>Bacteroidesfragilis</i>	80% DE	(Bragger <i>et al.</i> , 1997)
Remazol black b	<i>Shewanellaputrefaciens</i>	95% DE	(Willmott, 1997)
Acid red GR	<i>Shewanelladecolorations</i> S12	100% DE, 30 °C	(Xu <i>et al.</i> , 2007)
Reactive orange 96	<i>Desulfovibriodesulfuricans</i>	95% DE, 28 °C	(Yoo <i>et al.</i> , 2000)
Disperse blue 79	<i>Bacillus fusiformis</i> KMK5	100% DE, 37 °C, pH 9.0, 48 h	(Kolekar <i>et al.</i> , 2008)
Triphenylmethane dyes	<i>Kurithasp.</i>	98% DE, 30 mins	(Sani and Banerjee, 1999)
C.I Reactive red 22	<i>Pseudomonas luteola</i>	86.3 mg dye l ⁻¹ h ⁻¹	(Chang and Lin, 2000)
Remazol black b	<i>Panibacillusazoreducens</i> ssp. nov.	98% DE	(Meehan <i>et al.</i> , 2001)

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.

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How to cite this article:

Md. Rayhan Sarker, Manjushree Chowdhury and Amal Kanti Deb. 2018. Reduction of Color Intensity from Textile Dye Wastewater Using Microorganisms: A Review. *Int.J.Curr.Microbiol.App.Sci*. 8(02): 3407-3415. doi: <https://doi.org/10.20546/ijcmas.2019.802.397>