Environmental and Health Hazards of Textile Industry Wastewater Pollutants and Its Treatment Approaches

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Abstract

Textile industry wastewater (TIWW) causes serious water and soil pollution. TIWW has high pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), total organic carbon (TOC), solids suspended (SS), total solids suspended (TSS) sulfate, nitrate, and chloride. It also has a variety of recalcitrant chemicals like dyes, detergents, salts, phenol, and metals like arsenic (As), cadmium (Cd), copper (Cu), lead (Pb), and chromium (Cr), which cause serious threats in the environment and severe health hazards in human/animals. Textile dyes are well known for its highly toxic, mutagenic, carcinogenic, and genotoxic effects on living beings. Physicochemical methods are not efficient for the removal of TIWW due to the requirement of expensive chemicals and the production of a large amount of sludge as a secondary pollutant. Whereas biological methods use different classes of microbes and plant species for the removal and treatment of dyestuff and wastewater. Combined and membrane treatments are highly effective methods for the degradation and detoxification of textile wastewater. This chapter provides an overview of the textile industry, wastewater generation, and environmental pollution. Further, toxicity profile and bioremediation methods for degradation and detoxification of TIWW are also explained in this chapter.

Keywords

Textile industry wastewater · Wastewater characterization · Environmental pollution · Bioremediation methods · Constructed wetland

Introduction

Rapid industrialization discharges a number of unwanted toxic chemicals to the environment, which causes serious environmental threats and toxicity in living beings (Kishor et al. 2019). The textile industry is a key player in the economy of several countries, but it is also the major source of environmental pollution due to the discharge of huge volume of potentially toxic wastewater containing a variety of organic and inorganic pollutants (Kishor et al. 2019; Saxena et al. 2019a). W. H. Perkin discovered the first synthetic organic dye, mauve or aniline, in 1956. Nowadays, in India alone, around 80,000 dyes and pigments are produced annually (Lalnunhlimi and Krishnaswamy 2016). Globally, approximately 700,000– 10,000,000 metric tons of dyes are produced annually and more than 100,000 tons of synthetic dyestuffs are commercially available (Gupta and Suhas 2009).

In addition, around 280,000 tons of dyestuffs are discharged within the wastewaters annually (Jin et al. 2007). Different natural fibers such as jute, cotton, raw silk, linen, and wool and a variety of synthetic fibers like polyester, nylon, and acrylic have been used by textile industries (Holkar et al. 2016; Pensupa et al. 2017). Textile industries extensively used a number of synthetic dyes such as azo, anthraquinone, methane, triphenylmethane, quinoline, and nitro during the dyeing process (Khan et al. 2013; Chen et al. 2018). Most of the dyes are recalcitrant in nature, highly toxic and discharged along with wastewaters into the natural water bodies including river, pond, and lakes. Textile industry wastewater have dark color, high pH, biological oxygen demand (BOD), chemical oxygen demand (COD), total oxygen-carbon (TOC), total suspended solids (TSS), total nitrogen (TN), total solid (TS) sulfate, phosphate, chlorides, and toxic metals (Khan and Malik 2017; Kishor et al. 2019). This wastewater causes a deadly impact on water bodies due to the reduced light penetration that decreases the dissolved oxygen in the receiving water bodies, which ultimately affected the flora/fauna and also reduced microbial diversity (Bhatia et al. 2017; Bharagava et al. 2018). Many industries discharge a large volume of dyes containing wastewater such as pulp and paper, leather, and food, dyeing, cosmetic and pharmaceutical industry (Khandare and Govindwar 2015). Textile industry wastewater (TIWW) contains a variety of heavy metals like arsenic (As), chromium (Cr), zinc (Zn), cadmium (Cd), copper (Cu), manganese (Mn), and cobalt (Co) which are non-degradable in nature; these heavy metals accumulate in living cells through the food chain and cause severe effects on living organisms (Khan and Malik 2017).

The dyes are organic compounds, used as coloring agents due to the capability to permanently color to various fabric, and are highly resistant against light, detergents, chemicals, and microbial action (Saratale et al. 2011). Along with dye molecules, TIWW also contains high load of chemical pollutants, i.e., acids, salts, alkalis, binders, dispersants, dyestuffs, hydrogen peroxide, humectants, surfactants, reducing agents, dioxin, detergents, which cause severe health hazards in the environment (Singh et al. 2015; Bhatia et al. 2017). A large number of hazardous chemicals such as sizing, brightening, anticreasing, sequestering, softening, and finishing agents are used in the textile industries at different stages and subsequently discharged into the environment (Khandare and Govindwar 2015). TIWW is well reported for its toxicity, mutagenic, carcinogenic, and cytotoxic effects on living cells (Bhatia et al. 2017; Kishor et al. 2019). TIWW, if discharged directly into the aquatic resources, causes serious environmental threats and toxic effects to living beings. Therefore, it is essential to adequately treat the wastewater to protect the environment and public health.

A number of physicochemical, advanced oxidation processes, and biological methods have been used in the treatment/removal of industrial wastewaters. Physicochemical methods like adsorption, coagulation/flocculation, ion exchange, sedimentation are generally used for the removal of TIWW (Bhatia et al. 2017; Bharagava et al. 2018). Fenton, photo-Fenton, photocatalytic, sonocatalytic, ozonation, and many electrochemical methods are extensively used in the treatment and detoxification of textile dyes and wastewater (Singh et al. 2015). But, these methods are environmentally destructive as they utilize a huge amount of toxic chemicals, when entered into the environment can cause negative impact on the environment as well as well as generate a huge amount of sludge as a secondary pollutant (Bhatia et al. 2017; Bharagava et al. 2018). In contrast, bioremediation or biological approaches are the promising eco-friendly methods that utilize a variety of microbes for the environmental cleanup and thus are viewed as a low-cost strategy for the remediation and transformation of TIWW (Kishor et al. 2019).

This chapter provides brief information on the textile industry and its wastewater generation. The toxic effects in living cells and the environment of textile dyes and TIWW are discussed in the chapter. In addition, a number of current treatment methods reported for the removal and remediation of TIWW are also explained in this chapter.

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Overview of Textile Industry

The textile industries are the second largest and most important sources of the global economy, especially in developing countries (Bilińska et al. 2017). These industries contribute globally about 120 million employments directly and have an annual share of market value around $2000 billion worldwide. In India, approximately 3400 textile units are in operation, which contributes about 4% of national′s gross domestic product (GDP), 27% country′s export income, and ~14% to overall Index of Industrial Production (IIP) (Sahasrabudhe et al. 2014; Pensupa et al. 2017). Indian textile industries are one of the oldest industries in the country and the second-largest producers of textile fabric worldwide. These are shared around 5% global exports and nearly 5% global textile and apparel trade. Textile industry has three main traditional sectors such as handloom, handicraft, and small-scale power loom, which are the major sources of employment for millions of people in the urban and semi-urban areas. Currently, the size of the Indian textile market estimates to be ~US $108 billion and is expected to reach ~US $209 billion by 2021 (Satish 2018).

In addition, Indian textile industries also contribute about 24% of the world′s spindle capacity, 8% of global rotor capacity, and have the highest loom capacity with 61% of the world′s market share economy. Different kinds of natural fibers like cotton, jute, silk, rayon, linen, wool, and many man-made fibers such as polyester, nylon, and acrylic are extensively used in the textile manufacturing industries (Yagub et al. 2014). Among these fibers, cotton is one of the most important and largest about 25% of totally employed fibers in the textile industry worldwide. India is the biggest producer of cotton fiber in the world approximate 345 lakh bales in 2016–2017 and the second largest exporter of cotton. Different wet processes including sizing, desizing, bleaching, mercerizing, dyeing, washing, and finishing are commonly employed in the textile processing industries (Kishor et al. 2019).

Wastewater Generation and Its Characteristics

Textile industry wastewater is one of the major sources of environmental pollution due to the discharged huge volume of potentially toxic wastewater. Sizing, desizing, scouring, bleaching, mercerizing, dyeing, printing, and finishing steps are generally involved in the production of textile fibers (Khandare and Govindwar 2015; Bhatia et al. 2017). Among these steps, the dyeing and washing processes generates the largest amount of wastewater. A normal textile industry consumed approximately 1.6 million liters of water for the production of 80,000 kg of fabric (Khandare and Govindwar 2015).

According to the World Bank, around 17–20% of wastewater has been discharged from dyeing and finishing processes (Holkar et al. 2016). The Union Ministry of Environment and Forests (MoEF) estimated 4.4 million tons of toxic wastewater is released from the textile industries annually in India. Various analytical techniques including ultraviolet-visible spectroscopy (UV-vis), flourier-transform infrared (FT-IR), high-performance liquid chromatography (HPLC), gas chromatographymass spectrometry (GC-MS), proton nuclear magnetic resonance (^{1}H NMR), and gas chromatography high resonance mass spectrometry (GC-HRMS) are used extensively used in the detection and characterization of different pollutants of textile wastewater (Khandare and Govindwar 2015; Bharagava et al. 2018; Kishor et al. 2019). TIWW is characterized as dark-colored wastewater having high pH, temperature, COD, BOD, TOC, TSS, TS, TDS, chloride, phosphate, and sulfate (Bharagava et al. 2018; Kishor et al. 2019).

A number of different toxic pollutants such as acids, salts, alkalis, binders, dispersants, dyestuffs, hydrogen peroxide, humectants, surfactants, reducing agents, and dioxin are present in the textile wastewater (Khandare and Govindwar 2015; Bhatia et al. 2017). Many recalcitrant coloring pollutants like Congo red, methyl red, methylene blue, reactive blue, blank, orange, remazol brilliant blue, and methyl orange are present in the textile dyeing wastewater (Yagub et al. 2014). Furthermore, different types of metals like As, Cu, Cd, Pb, Ni, Zn, and Cr are also found in the TIWW (Khan and Malik 2017; Kishor et al. 2019). These chemicals all collectively make the wastewater highly toxic and thus causing severe health hazards in living beings and serious environmental threats.

Environmental Contamination and Health Hazards of Textile Industry Wastewater Pollutants

TIWW is well known for its toxicity, carcinogenicity, mutagenicity, genotoxicity, and cytotoxicity effects in human/animal health (Khandare and Govindwar 2015). Thousands of dyes are extensively utilized in the textile industry during the dyeing process and discharged to the water bodies. TIWW is a dark-colored wastewater having a variety of recalcitrant coloring pollutants (RCPs), dissolved and suspended solids, which are responsible to reduce sunlight penetration and decrease dissolved oxygen in water bodies and therefore ultimately effected the water life (fauna/flora) (Holkar et al. 2016; Bharagava et al. 2018). TIWW contains a variety of toxic chemicals such as salts, acids, detergents, surfactants, chlorine, formaldehyde, solvent, aromatic amines, and xenobiotic pigments that are created detrimental effects in the living cells (Saratale et al. 2011; Khandare and Govindwar 2015). Several organic and inorganic pollutants like As, Cu, Pb, Cd, Cr, and Ni are also present in the textile wastewater.

These are non-degradable and can accumulate in the living cell through the food chain, cause severe health hazards such as diarrhea, liver, neuromuscular, hemorrhage, dermatitis, central nervous system disorder, and kidney malfunctioning (USEPA 1999). These metals are also effecting plant growth parameters like reduction in seed germination, seedling growth, and also decrease in microbial activity/ diversity (Khan and Malik 2017; Bhatia et al. 2017). Dye effluents are responsible for the disturbed biogeochemical (nutrient) cycling which occurs in soil niche and thus creates soil pollution. Azo dyes and their various metabolites are reported as carcinogenic and mutagenic in living life. Therefore, degradation and detoxification of this wastewater are needed prior to the safe disposal into the natural ecosystem.

Treatment Approaches for Textile Industry Wastewater Pollutants

Physicochemical Approaches

The textile wastewater contains a variety of highly toxic organic and inorganic pollutants that cause severe health hazards in public health and serious environmental contamination (Kishor et al. 2019; Saxena et al. 2019). A number of treatment techniques are available for the removal and treatment of textile industrial wastewater pollutants. Physicochemical methods are effective for the treatment and removal of various pollutants from textile wastewater. Adsorption and coagulation/flocculation are the common processes of the physicochemical approach that are widely reported in the removal of industrial wastewater (Yagub et al. 2014).

Coagulation/Flocculation

Coagulation/flocculation is a major treatment method used for the remediation and removal of industries wastewater. This method is widely used for the decolorization of wastewaters containing disperse dyes. They are also employed in the removal and decolorization of vats and reactive dyes and thus a less effective method for the removal of these dyes (Holkar et al. 2016). Different coagulants such as aluminum sulfate (alum), ferrous sulfate, ferric chloride, and ferric chloro-sulfate are used in this method for the removal of textile dyes and dyes containing wastewater. Chitosan is a biodegradable, linear cationic, polymer with high molecular weight and nontoxic compound. Besides, it is an effective agent for the removal and decolorization of textile dyes, suspended and dissolved solids. In addition, a number of emerging pre-hydrolyzed coagulants like polyferric chloride (PFCl), polyaluminum ferric chloride (PAFCl), polyferrous sulfate (PFS), and polyaluminum chloride (PACl) are also employed in the decolorization of dyes and reduce various parameters like BOD, COD, TDS, and detoxify toxic heavy metals (Verma et al. 2012; Zou 2015).

Adsorption

Adsorption is an effective process for the removal and reduction of various hazardous organic and inorganic substances of industrial wastewater. Many eco-friendly, cost-effective, and potential adsorbents materials such as Annona squamosa, sawdust, Ananas comosus, rice hush ash, and peanut are reported in the treatment/ degradation of TIWW (Yagub et al. 2014; Holkar et al. 2016). Adsorption method has the capability to remove and reduce various hazardous recalcitrant coloring pollutants, BOD, COD, TDS, and TOC from textile industrial wastewater.

Activated carbon is the best and more effective adsorbent material for the decolorization of the wide number of textile dyes.

But this absorbent is a high costly and ineffective in the removal of many pollutants (dyes) of textile industry wastewater (Galan et al. 2013). For commercial application, many workers used different adsorbents like clay, peat, fly ash, bentonite clay, and polymeric resins. Various biological materials such as groundnut shell charcoal, date stones, wheat residues, treated ginger waster, and potato plant waste materials have also been used in the removal and decolorization of textile dyes (Holkar et al. 2016). However, their usages are restricted due to the large sludge formation and high cost of the adsorbents. Therefore, it is still a need for low cost, easily regenerated and potential adsorbents for the effective treatment of TIWW.

Biological Approaches

A biological process is an eco-friendly method widely used in the degradation and detoxification of various toxic organic and inorganic pollutants. Although, biological methods use a variety of microbial agents such as bacteria, fungi, yeast, and plant species in the decolorization and degradation of various unwanted toxic chemicals from textile wastewater (Bhatia et al. 2017; Kishor et al. 2019).

The microbial species are able to acclimatize themselves to various hazardous pollutants into the less and nontoxic form. The biological methods may be carried out under aerobic, anaerobic, and facultative anaerobic environment in the presence of various classes of microorganisms and their enzymatic machinery (Saratale et al. 2015; Holkar et al. 2016). The advantages of biological approaches are: sustainable, low cost, eco-friendly, less sludge forming, produced end products that are less/ nontoxic, and require less water as compared to the physicochemical methods (Saratale et al. 2011).

Bacterial Approach

Bacterial treatment is the most attractive process used in the degradation and detoxification of textile industrial wastewater pollutants. A number of bacterial species are used in the degradation and decolorization of various recalcitrant coloring chemicals from textile wastewater (Bharagava et al. 2018; Kishor et al. 2019).

These bacteria produce/secrete various kinds of primary/secondary substances like acid, enzymes, antibiotics, toxins, and some other components, which are directly involved in the conversion of hazardous chemicals and wastewater containing pollutants into the less and nontoxic form (Saratale et al. 2015; Bhatia et al. 2017). The bacterial process may be performed under aerobic and anaerobic environment. The bacterial cells are easy to culture and can grow more quickly as compared to other microbes.

Several bacterial species are capable to utilize various toxic compounds such as chlorinated, aromatic hydrocarbon and sulfur-containing molecules as sole source of energy (C/N) (Bhatia et al. 2017). A number of workers reported the bacterial cells are capable to degrade and decolorize the various azo dyes into the aromatic colorless amines. A variety of Gram-positive and Gram-negative species including Bacillus sp., Pseudomonas sp., Proteus sp., Klebsiella sp., and Enterococcus sp. are found to degrade and detoxify a number of different structural synthetic azo dyes (Kishor et al. 2019). Different bacterial strains used in degradation and decolorization of textile dyes and wastewater are listed in Table 1. In addition, the different bacterial group is capable of the biodegradation and biotransformation of various recalcitrant coloring pollutants under aerobic, anaerobic, and extreme environmental conditions.

Fungal Approaches

Fungi are the most important organisms that are widely used in the treatment and mineralization of industrial wastewater. Various fungal species can degrade/decolorize a wide number of textile dyes and wastewater pollutants into nontoxic metabolites (Sen et al. 2016). Most of the fungal species are capable of secreting extra- and intracellular enzymes such as laccase, manganese peroxidase (MnP), lignin peroxidase (LiP), and azoreductase (Bhatia et al. 2017). These enzymes widely participate in the degradation and mineralization of various toxic textile industrial wastewater pollutants during the treatment process. According to Chen and Ting (2015), fungal species like Coriolopsis are able to decolorize and mineralize various triphenylmethane dyes such as crystal violet, methyl violet, cotton blue, and malachite green from wastewater. Pleurotus sp., Pichia sp., Penicillium sp., and Candida sp. are capable for the degradation and decolorization of various synthetic dyes.

Different white-rot fungi like Phanerochaete sp., Trametes sp., Pleurotus sp., Pycnoporus sp., Irpex sp., and Phellinus sp. are widely capable for the removal and degradation of many dyes such as azo dyes; indigoid, triphenylmethane, as well as heterocyclic dyes. In addition, Ganoderma sp. En3 isolated from the forest of Tzu-chin Mountain in China was found to be capable of degrading and decolorizing a number of recalcitrant dyes like methyl orange, malachite green, bromophenol blue, crystal violet, and textile wastewater. Many researchers reported that fungal organisms have good potential to remove and decolorize a wide variety of dyes and many recalcitrant/xenobiotic compounds. However, removal and treatment of textile dyes and wastewater by fungal sp. have some major drawbacks such as long growth phase, unreliable enzymes production, and need nitrogen-restricted environment (Holkar et al. 2016).

Algal Approach

Algae are photosynthetic organisms that are commonly found in fresh and marine water. Algae treatment represents a green, low cost, environmentally friendly, and effective for the removal and disposal of TIWW. Degradation and decolorization of textile dyes and wastewater by algae occur through the three main mechanisms: (1) mineralize and transform the colored wastewater into the colorless intermediates or CO_2 and H_2O, (2) consumption of dyes and TIWW for biomass, and (3) adsorption of chromophores on algae. A large number of algae sp. have been reported to be able to decolorize and degrade dyes and dyeing wastewater: for example, Spirogyra sp., Chlorella sp., Lemna sp., Scenedesmus sp., and Closterium sp.; Chlorella and Oscillatoria algae are shown to decolorize azo dyes by cleaving the azo linkage into carcinogenic aromatic amines that are further degraded into the smaller and nontoxic products like CO_2 and H_2O (Bhatia et al. 2017).

According to Sinha et al. (2016), the Chlorella pyrenoidosa was able to decolorize Direct Red 31 dye and also reduce different pollution parameters like BOD, COD, TDS, sulfate, and phosphate from TIWW. Further, Dellamatrice et al. (2017) reported that the cyanobacteria species have the capability for degradation and decolorization of three different textile dyes like indigo, RBBR and sulfur black from textile wastewater. Diatoms are also reported in the decolorization of various dyes such as monoazo and diazo dyes.

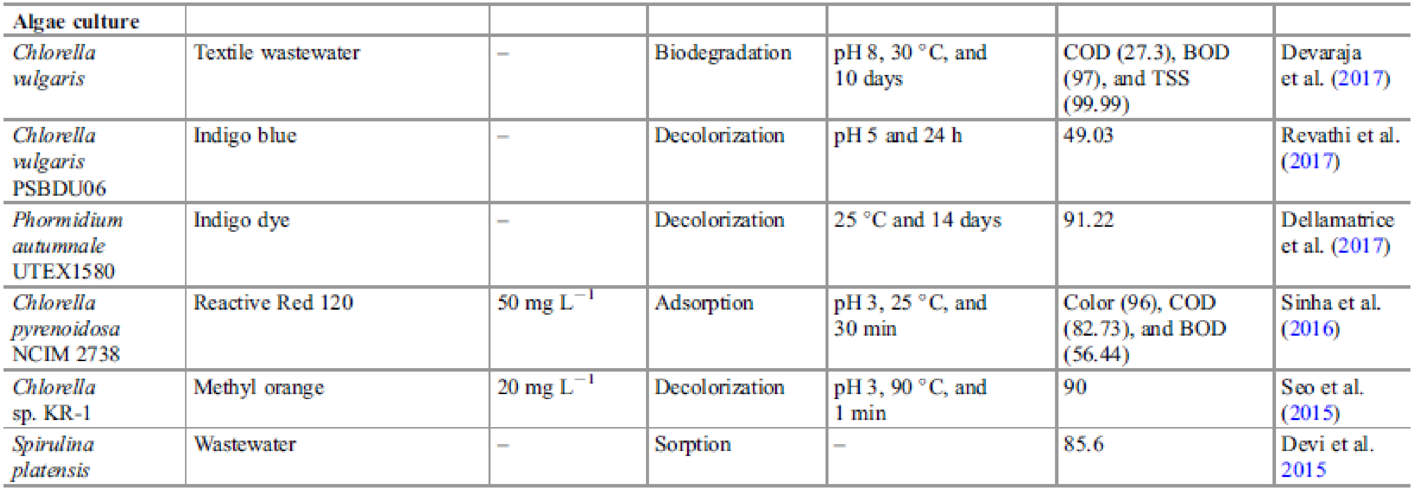
Table 1 Different microbial agents reported by various researcher in the decolorization and degradation of dyes and wastewater

Microbial strains	Dyes and wastewater	Concentration	Mechanism	Optimum conditions (pH, temperature, and time)	Efficiency (%)	References
Bacterial culture						
Aeromonas hydrophila	Crystal violet	50 mg L^{-1}	Degradation and decolorization	pH 7, 35 °C, 110 rpm, static, and 8 h	99	Bharagava et al. (2018)
Bacillus circulans BWL1061	Methyl orange	50 mg L^{-1}	Decolorization	pH 7.5, 42 °C, 180 rpm, anaerobic and 12 h	99.22	Liu et al. (2017)
Arthrobacter soli BS5	Reactive Black 5 and wastewater	50 mg L^{-1}	Decolorization and degradation	pH 5–9, 37 °C, and 120 h	98	Khan and Malik (2017)
Bacillus aryabhattai DC100	Coomassie Brilliant Blue G-250, Indigo carmine, and wastewater	150 mg L^{-1}	Decolorization	37 °C and 304.09 rpm	–	Paz et al. (2017)
Aeromonas hydrophila	Reactive Black 5	100 mg L^{-1}	Decolorization	pH 7, 35 °C, and 24 h	76	El Bouraie and El Din (2016)
Aeromonas veronii GRI (KF964486)	Methyl orange	1000 mg L^{-1}	Biodecorization	24 h	84.39	Mnif et al. (2015)
Lysinibacillus sp. RGS	Reactive Orange 4	50 mg L^{-1}	Decolorization	pH 6.6, 30 °C, 100 rpm, static, and 5 h	TOC (93) and COD (90)	Saratale et al. (2015)

(continued)

Table 1 (continued)

Microbial strains	Dyes and wastewater	Concentration	Mechanism	Optimum conditions (pH, temperature, and time)	Efficiency (%)	References
Fungal culture						
Pichia kudriavzevii CR-Y103	Reactive Orange 16	50 mg L^{-1}	Decolorization and degradation	pH 6, 30 °C, 120 rpm, shaking, and 24 h	100	Rosu et al. (2018)
Pichia occidentalis G1	Acid Red B	50 mg L^{-1}	Degradation	pH 5, 30 °C, 160 rpm, and 16 h	98	Song et al. (2017)
Aspergillus bombycis	Reactive Red 31	20 mg L^{-1}	Degradation and mineralization	pH 6, 35 °C, aerobic, static, and 12 h	Color (99.02), COD (94.19) and TOC (83.97)	Khan and Fulekar (2017)
Diaporthe sp.	Methyl violet	100 mg L^{-1}	Degradation	24 h	84.87	Ting et al. (2016)
Saccharomyces cerevisiae	Vinyl sulfone	100–600 mg L^{-1}	Decolorization	pH 2, 25 °C, 180 rpm, and 71 h	Color (100) and COD (61.82)	Mahmood (2016)
Pichia pastoris strain SMD1168H	Indigo carmine	–	Decolorization	pH 10, 40 °C, 100 rpm, and 1 h	99.92	Wang et al. (2015)
Coriolopsis sp. (1c3)	Crystal violet, methyl violet, and cotton blue	100, 100, and 50 mg L^{-}1	Biodecorization and biodegradation	24 h	94%, 97%, and 91%	Chen and Yien Ting (2015)



Algae culture						
Chlorella vulgaris	Textile wastewater	–	Biodegradation	pH 8, 30 °C, and 10 days	COD (27.3), BOD (97), and TSS (99.99)	Devaraja et al. (2017)
Chlorella vulgaris PSBDU06	Indigo blue	–	Decolorization	pH 5 and 24 h	49.03	Revathi et al. (2017)
Phormidium autumnale UTEX1580	Indigo dye	–	Decolorization	25 °C and 14 days	91.22	Dellamatrice et al. (2017)
Chlorella pyrenoidosa NCIM 2738	Reactive Red 120	50 mg L^{-1}	Adsorption	pH 3, 25 °C, and 30 min	Color (96), COD (82.73), and BOD (56.44)	Sinha et al. (2016)
Chlorella sp. KR-1	Methyl orange	20 mg L^{-1}	Decolorization	pH 3, 90 °C, and 1 min	90	Seo et al. (2015)
Spirulina platensis	Wastewater	–	Sorption	–	85.6	Devi et al. 2015

Enzymatic Treatment

Enzymatic treatment is the most attractive process employed for the remediation and degradation of TIWW. A variety of microbial species are capable to produce different types of enzymes during the treatment process. These enzymes, i.e., laccase, MnP, LiP, azoreductase, and other enzymes are widely used in the treatment of TIWW (Table 2). Enzymes have a potential for the degradation and mineralization of several toxic recalcitrant coloring chemicals of the TIWW.

Azoreductase is the major class of enzymes used for the decolorization and degradation of hazardous recalcitrant azo dyes and textile wastewater containing pollutants (Saratale et al. 2015). Azo dyes are the largest class of synthetic dyes used in the textile dyeing industry (account for about 60–70%). It is recalcitrant in nature and resistant to degradation. However, azo enzymes are able to decolorize various azo dyes through breakdown of the azo linkage under anaerobic environment by azoreductase enzyme and produced various carcinogenic aromatics amines. These aromatic amines are recalcitrant in nature and it can only be broken down into intermediate metabolites under the anaerobic condition with the release of H_2O and CO_2. Many other enzymes such as laccase, MnP, and LiP are also involved in the biodegradation and biotransformation of toxic recalcitrant pollutants but into less and nontoxic products. For example, according to Bharagava et al. (2018), Aeromonas hydrophila decolorized and degraded crystal violet dyes by producing laccases and LiP enzymes.

Table 2 Various enzymes reported in the biodegradation and biotransformation of dyes and textile wastewater

Name of enzyme	Sources of enzyme	Dyes and wastewater	Concentration and time (h/day)	Treatment efficiency (%)	References
Laccase and lignin peroxidase (LiP)	*Aeromonas hydrophila*	Crystal violet (CV)	50 mg L^{-1} and 8 h	99	Bharagava et al. (2018)
NADH-DCIP reductase and azo reductase	*Pichia kudriavzevii* CR-Y103	Reactive Orange 16 (RO 16)	1 mg L^{-1} and 24 h	100	Rosu et al. (2018)
Laccase, manganese peroxidase (MnP), lignin peroxidase (LiP), and azoreductase	Mixed culture: *Brevibacillus aydinogluensis* strain PDF25, *Geobacillus thermoleovorans* strain NP1, *Anoxybacillus flavithermus* strain 52-1A and *Bacillus thermoamylovorans* strain DKP, *Bacillus circulans* BWL1061	Direct Black G (DBG)	600 mg L^{-1} and 8 h	97	Chen et al. (2018)
Manganese peroxidase (MnP)	*Irpex lacteus* F17	Malachite green (MG)	200 mg L^{-1} and 1 h	96	Yang et al. (2016)
Laccase	*Ganoderma lucidum* BCRC 3612	Acid Orange 7 (AO7)	50 mg L^{-1} and 14 days	>90	Lai et al. (2017)
Laccase	*Trichoderma asperellum*		87.50 mg L^{-1} and 98.58 min	97.18	Shanmugam et al. (2017)

(continued)

Table 2 (continued)

Name of enzyme	Sources of enzyme	Dyes and wastewater	Concentration and time (h/day)	Treatment efficiency (%)	References
Azoreductase, manganese peroxidase (MnP), tyrosinase, phenol oxidase, and laccase	*Aspergillus bombycis*	Reactive Red 31 (RR 31)	20 mg L^{-1} and 12 h	99.2 of color, COD of 94.19	Khan and Fulekar (2017)
Laccase, phenol oxidase, and manganese peroxidase (MnP)	*Trichosporon akiyoshidainum* HP2023	Reactive Black 5 (RB 5)	300 mg L^{-1} and 12 h	90	Martorell et al. (2017)
Laccase	*Ceriporiopsis Subvermispora* ATCC90467	Triphenylmethane dyes	50 mg L^{-1}	87.7	Chmelová and Ondrejovič (2016)
Laccase, lignin peroxidase, and NADH-DCIP reductase	*Coriolopsis* sp.	Triphenylmethane	100 mg L^{-1} and 7 h	94	Chen and Yien Ting (2015)
Laccase, lignin peroxidase (LiP), azoreductase and NADH-DCIP reductase	Fungal-bacterial mixed culture (*Aspergillus ochraceus* NCIM-1146 and *Providencia rettgeri* strain HSL1	Textile effluent	100 mg L^{-1} and 30 h	92	Lade et al. (2016)
Lignin peroxidise (LiP), manganese peroxidise (MnP), and laccase	*Myrothecium roridum*	Malachite green (MG)	10 mg L^{-1} and 3 h	90	Jasinska et al. (2015)

Lysinibacillus sp. was isolated from textile wastewater that was found to be capable in the degradation and decolorization of textile dyes and wastewater by producing laccase and LiP enzymes (Saratale et al. 2015). Trichoderma asperellum was capable for the degradation and mineralization of malachite green dyes by producing laccase enzyme (Shanmugam et al. 2017). Aspergillus bombycis was able to produce different types of enzymes like azoreductase, laccase, tyrosinase, MnP, and phenol oxidase, and involvement of these enzymes was observed in the degradation and decolorization of Reactive Red 31 from stimulated wastewater (Khan and Fulekar 2017).

Plant Treatment (Phytoremediation)

Phytoremediation is an eco-friendly green technology employed for the transformation and detoxification of different types of toxic dyes and wastewaters. It uses diverse classes of plant species to remove, degrade, and detoxify a variety of recalcitrant organic pollutants (Saxena et al. 2019; Kishor et al. 2019). Phytoremediation is a potential tool to remove and transform many environmental contaminants like pesticide, dyes, surfactant, landfill leachate, heavy metals, polyaromatic hydrocarbon, biphenyls, and even the poisonous gases (Nwoko 2010; Saratale et al. 2011). Many wetlands and terrestrial/aquatic plants have been used for the removal and detoxification of hazardous organic and inorganic contaminants. A number of plant species are reported to have the capability to utilize the toxic recalcitrant coloring compounds as a sole source of C and N (Table 3). For example, Al-Baldawi et al. (2018) used Azolla pinnata in the remediation of methylene blue from wastewater.

According to Chandanshive et al. (2016), the water fern Salvinia molesta could degrade the azo dye Rubine GFL up to 97% at 100 mg L^1 within 3 days. Mixed culture of Chrysopogon zizanioides and Typha angustifolia was effective in the removal and treatment of scarlet RR dye and textile wastewater (Kadam et al. 2018). According to Rane et al. (2015), Ipomoea hederifolia was able to decolorize and degrade the sulfonated and diazo textile dye brown 5R. Further, many researchers reported the different plants species in reducing and detoxifing variety of hazardous chemicals from contaminates sites (Khandare and Govindwar 2015; Bhatia et al. 2017). Plant treatment is an emerging, cost-competitive, does not generate toxic waste, globally accepted, and highly effective method for the degradation, detoxification, mineralization, and transformation of the wide range of textile dyes and wastewater.

Constructed Wetland Treatment

Constructed wetland (CW) is an innovative and attractive approach for the remediation and removal of industrial wastewater contaminates. It uses various types of natural substances like soil, wetlands vegetation, and microbes for the effective treatment of synthetic dyes and real textile wastewater (Vymazal 2014). CW system mainly consists of two types: horizontal subsurface flow (HFCW) and vertical subsurface flow (VFCW). A number of studies reported that CW can remove and mineralize a large number of recalcitrant coloring pollutants from synthetic and real textile industry wastewater (Hua et al. 2015; Hussein and Scholz 2017). CW has been designed and employed for the treatment of wastewater, and treated wastewater is widely applied in the creation and restoration of wetlands for habitats wildlife, reuse in agriculture, and environmental enhancement.

Further, Chandanshive et al. (2016) used Salvinia molesta in shallow lagoons to decolorize color and reduce many pollution parameters such as COD and BOD from textile wastewater. CW developed with a microbial fuel cell (CW-MFC) was able to decolorize azo dyes along with the generation of bioelectricity (Fang et al. 2015). Moreover, the addition of different bedding materials like gravel, zeolite, and sand with VFCW system enhances the treatment efficiency of CWs plants (Vymazal 2014; Dogdu and Yalcuk 2015). Constructed wetlands are providing a promising alternative way for the decolorization and detoxification of TIWW because these are cheaper, globally accepted, bioelectricity generation, financially competitive, and also not toxic to environmental health.

Table 3 Plant used in the degradation and detoxification of dyestuffs and textile industry wastewater

Name of plant	Dyes and wastewater	Concentration and time (h/day)	Treatment efficiency (%)	References
Asparagus densiflorus	Disperse Rubin GFL (DRGFL) and wastewater	40 mg L^{-1} and 48 h	ADMI color of 65%, BOD of 66%, COD of 48%, TDS and TSS of 66%	Watharkar et al. (2018)
Co-plantation consortium *(Fimbristylis dichotoma* and *Ammannia baccifera)*	Textile effluent (methyl orange) (50 mg L^{-1})	50 mg L^{-1} and 48 h	ADMI color of 79%, BOD of 75%, COD of 70%, TDS of 66%, and TSS of 56%	Kadam et al. (2018)
Gaillardia grandiflora	Textile industry wastewater	30 h	73	Chandanshive et al. (2018)
Co-plantation of *Typha angustifolia* and *Paspalum scrobiculatum*	Textile industry wastewater	4 days	ADMI color of 76%, BOD of 77%, COD of 72%, TDS of 57%, and TSS of 47%	Chandanshive et al. (2017)
Scirpus grossus	Methylene blue (MB)	200–1000 mg L^{-1} and 72 days	86	Almaamary et al. (2017)
Salvinia molesta	Rubine GFL and textile dye wastewater	100 mg L^{-1} and 72 h	Color of 97%, COD of 76%, and BOD of 82%	Chandanshive et al. (2016)
Mixed culture *of Ipomoea hederifolia* and *Cladosporium cladosporioides*	Navy blue HE2R (NB-HE2R)	36 h	97	Patil et al. (2016)
Ipomoea aquatic	Brown 5R	200 mg L^{-1} and 72 h	94	Rane et al. (2016)
Alternanthera philoxeroides	Remazol Red	70 mg L^{-1} and 72 h	100	Rane et al. (2015)
Plant-bacterial mixed culture *Pogonatherum crinitum* and *Bacillus pumilus*	Textile wastewater		BOD (78%), COD (70%), and TDS (13%)	Watharkar et al. (2015)
Blumea malcolmii hook	Brilliant Blue R (BBR)	40 mg L^{-1} and 24 h	98	Kagalkar et al. (2015)

Membrane Treatment

Membrane treatment (MT) is one of the most effective methods for the purification and reuse of industry wastewaters. Various membranes including reverse osmosis, microfiltration, nanofiltration, and ultrafiltration have been used in the process. MT is commonly employed in the removal and treatment of different industrial wastewater such as textile dyeing, pulp and paper, tannery, and distillery. This approach can be considered as an effective cleanup technology for the recycling and reusing of TIWW (Lin et al. 2016). MTs are effective in the treatment of all types of textile dyes. Nanofiltration (NF) is an effective method used in the treatment of TIWW, because it requires lower pressure as compared to reverse osmosis (Liu et al. 2011). A flat-sheet polyvinylidene fluoride membrane is used in the direct contact membrane distillation (DCMD) process during the treatment of textile dyes (Laqbaqbi et al. 2018).

Tight ultrafiltration membrane (UH004, microdyn-nadir) is reported in the treatment and decolorization of various reactive dyes such as Direct Red 23, Direct Red 80, Reactive Blue 2, and Congo red from textile wastewater (Lin et al. 2016). NF and MF processes were capable to decolorize textile dyes of 99% color and reduce turbidity, chloride, salt content when operated collectively. The polytetrafluoroethylene and polyvinylidene fluoride hydrophobic membranes are used in the DCMD process for the treatment of aniline, sulfanilic acid, and phenols present in TIWW (Ji et al. 2018). Membrane approaches are recent emerging and efficient technologies that could be proven to be an effective solution for the management of TIWW.

Combined Treatment

Combined treatment is the most effective method for the remediation and degradation of textile dyes and dyeing wastewater. It uses a combination of physical, chemical, oxidation, and biological processes that provide better efficiency for decolorization and detoxification of dyeing wastewater compared to other traditional methods. For example, Bahmani et al. (2013) developed a Fenton-biological process which was capable to decolorize Reactive Black 5 at 250 mg L^{1} within 60 h. A combination of biological and advanced oxidation methods was capable in the removal and reduction of

99% of Acid Red 18, 97% of COD, and 87% of phosphorus from textile wastewater (Azizi et al. 2015).

Han et al. (2016) developed a novel combination of forwarding osmosis and coagulation/flocculation for the removal of textile wastewater. Combination of membrane bioreactor and reverse osmosis were effective methods for removal of color and reduction of various parameters like BOD, COD, and TDS from textile wastewater (Ali et al. 2016). Therefore, combined treatment is a highly effective process for the decolorization and degradation of a variety of recalcitrant coloring pollutants and various environmental parameters such as BOD, COD, TOC, TDS, and phosphate.

Mechanism of Dye Degradation and Decolorization

Awide variety of azo dyes are commonly used in textile dyeing, tannery, cosmetics, pulp and paper, food processing, and pharmaceutical industries for the addition of color to products (Kishor et al. 2019). Among these dyes, Congo red is one of the most important dyes; it is largely used in textile manufacturing processes and discharged along with partially and untreated wastewater to the water bodies. It is xenobiotic in nature and recalcitrant to light, chemicals, detergents, and microbial degradation and causes serious environmental concern and severe health hazards in living beings (Saratale et al. 2015; Holkar et al. 2016). It is well-known for its carcinogenic and mutagenic effects on public health and also causes water and soil pollution (Khandare and Govindwar 2015).

Degradation and detoxification of these dyes and dye-containing wastewater are an urgent requirement for the safe disposal into the environment. D'Souza et al. (2017) isolated a potential strain of Alcaligenes species from Indian West coastal sediments. This bacterium is highly capable for the degradation and decolorization of recalcitrant, carcinogenic, diazo Congo red dye ranging from 76.49% to 98.76% within 24–48 h. Degradation metabolites of this dye were characterized by FT-IR, HPLC, and LC-MS analysis. The Alcaligenes is able to produce oxidative and reductive enzyme-like (azoreductase) during the treatment process. The azoreductase enzyme initially cleaves the azo bond of Congo red dye and leading to produce biphenyl diamine and 12^0-diaminonaphthalene-4-sulfonic acid. Further, these products undergo deamination amine oxidation and desulfonation to make intermediates resulting in the transformation of complex dye compounds to simpler metabolites.

Prospects and Challenges

Textile manufacturing industries use a wide range of toxic chemicals and a huge amount of fresh water during textile production. These industries discharge partially and untreated wastewater into the environment and cause detrimental effects in water/soil ecology and public health. However, the treatment of these colored wastewaters is the major challenge worldwide. One of the major challenges includes the commercialization of environmental bioremediation technologies; continued efforts are required for the improvement in existing bioremediation treatment technologies.

Conclusion

Textile industries are the largest sources of environmental pollution due to the generation of a large volume of potentially toxic wastewater. The wastewater contains a number of organic and inorganic pollutants that cause severe health hazards in human/animals and serious environmental threats. Physicochemical methods are effective for the removal/treatment of textile dyes and wastewater. But these methods always required expensive chemicals, energy, as well as cause secondary pollution.

The biological methods including bacterial, fungal, algal, enzymatic, plant constructed wetlands treatment are effective processes for the degradation and detoxification of various types of dyes and wastewater. Combined and membrane treatment is a highly effective method in the removal and treatment of textile wastewater. But these methods are expensive in nature, and the generation of toxic byproducts can causes secondary environmental threats. Further, continued efforts are required to realize the economic feasibility and eco-friendly methods of mycoremediation and phytoremediation for field-scale applications for their commercialization in the near future.

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