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Strategies to Control the Pollution Caused by Textile Industry Effluents Containing Dyes

Farwa Kausar, Humaira Ramzan*, Uzma Zeeshan, Shazia Bukhari and Roheela Yasmeen

Biology department, Lahore Garrison University, Lahore, Pakistan
*Corresponding Author's Email: humairaramzan@lgu.edu.pk

ABSTRACT: *Textile industrial effluent contains recalcitrant dyes which are becoming a serious threat for environment. Bioremediation is becoming an emerging technique to control pollution in effluent treatment. The extensive information has been provided within this review about the pollution being caused in the environment and water bodies by textile industrial effluents primarily consisting of recalcitrant dyes. Therefore, for the remediation of textile industrial effluents, the most efficient technologies/techniques have been discussed. Strategies to control these hazardous pollutants include physical, chemical, biological and electrochemical methods. In textile industry, synthetic dyes are being used and highly concentrated wastewater is discharged as the fabrics absorbs the dyes in a very less quantity. These colored compounds have detrimental effects on the environment including human heath, aquatic life and plants due to the reduced penetration of light, oxygen consumption and toxic heavy metals present in the synthetic dyes.*

Key words: *Textile industry effluents, environmental impact, wastewater treatment, biological methods, chemical methods, physical methods*

INTRODUCTION

In the modern world of increasing industrialization, water pollution is emerging to be one of the major environmental pollution. Therefore, Industries are considered to be one of the major hazardous pollutants as the high liquid wastewater effluents are been produced particularly by the textile industry. The water is consumed in an immense amount for the production and processing of fabric. The composition of the wastewater varies as it consists of pigmented waster that it is released during the dyeing of fabrics is the mainly the hazardous component since ever, even a dye in a trace amount remains significantly detectable. Highly toxic wastewater is also been produced by some of the other industries as well such as tanneries, distilleries and dyestuff. The dyeing process releases dye effluents and aqueous wastes in a large quantity which are highly toxic effluents that cannot be degraded easily as they have a high biological oxygen demand with persistency in the pigmentation. These are the factors that contribute for making the effluents highly toxic and carcinogenic are not acceptable environmentally and aesthetically (Wang et al., 2007). Wastewater effluents are generally classified into three types depending upon the concentration of COD content such as, high, medium and low strength.

Generation of Textile Industry Pollution

In Textile industry, dyeing and printing procedure comprises printing, dyeing and pre-treatment. One of the chief pollutants is organic matters during pre-treatment of cotton gum, pulp, alkali, hemicelluloses and cellulose. Additives and dyes are the major polluting factors that are being employed in dyeing and printing processes. Approximately, dyeing/printing process and pre-treatment wastewater accounts for about 50%~55% and 45% of the total respectively while a little of the wastewater is produced in finishing process. Therefore, textile industry has a significant role in the financial system of some countries such as Asia is one of the countries that accounts for the 80% of the consumption dyes and pigments in each of the types of dyestuffs exploiting in each type of and the amount becomes nearly to 80,000 tones (Mathur et al., 2003). After China, Asia is considered to be the second largest exporting country of dyestuffs. Wastewater effluents constitutes of about 1–1.5 tons of every 105 tons that are being discharged into the water bodies out of the 106 tons of the total synthetic dyes being manufactured (Zollinger, 1987). The hazardous discharge depends upon the class of the dye as it is not because of all dyes that bind during the dyeing processes for the production of fabric. The wastewaters can differ from 2%-50% for basic and reactive dyes respectively primarily posing severe hazardous pollutants particularly in the localities of the textile dyeing industries (O'Neill et al., 1999). Every year, the textile industrial effluents being discharged consists of about 280,000 tons of textile dyes (Jin et al., 2007). Dyes are detrimental as they are affecting the living organisms badly in the water that is being discharged as effluent into the environment.

Types of Dyes

The textile dyeing industry exists for over last 4000 years. In ancient times, natural sources were used for the manufacturing of the dyes and these dyed fabrics do not exist commonly in that era. Natural coloring agents are being mainly produced from inorganic origin such as minerals, metal salts, earths, clays and malachite or traditionally organic dyestuffs that are categorized in two classes that comprises plant and animal source (Ackacha et al., 2003). Certainly, plant sources are considered to be the most momentous sources however the diverse variety of other organisms have also being exploited such as insects, shellfish and lichens. Natural and synthetic dyestuffs are available in a large variety and they are being utilized in the food industry and the production of colored fibres respectively. In general, a dye can be considered to be the pigmented substance; this dye has the affinity for its substrate when it is being employed for dyeing process. The reason for the coloration is the absorbance at a certain wavelength at the range at which its spectrum is visible. Generally, in aqueous solution, a vivid colour can be produced even from a small amount of dye in a significant quantity. Quantification of the colour can be done by chromatography (HPLC), high performance capillary electrophoresis and spectrophotometry (visible spectra) (Wang et al., 2007).

Dye Applications

Approximately, 450,000 tons of the dyestuffs are being manufactured in the industries worldwide from 40,000 of the diverse variety of the synthetic dyes. The most versatile class of dyes is the Azo dyes and accounts for one of the largest production up to 50% in comparison to the other dyes annually (Zollinger, 1987). Azo dyes are being utilized widely in multiple disciplines of modern technology, in e.g. in leather tanning industry, paper production, textile industry, cosmetic, medicine, pharmaceuticals, food industry, wood staining, hair dyes, colour photography, light-harvesting arrays in biological and chemical research, photo electrochemical cells and agricultural industry (Kuhad et al., 2004; Couto, 2009). Textile industry is considered to be one of the largest consumer of these dyes is as it accounts for two-third of its market. Dyes are categorized into different classes and similarly, they are exploited according to the type of fibre for the dyeing of that fabric. Reactive dyes are also being employed in both natural and synthetic dyes due to which they are most commonly used as compared to the other dyes (O'Neill et al., 1999). A covalent bond is formed between the reactive dyes with the fibre group that has the compatibility for that respective reactive dye as they consist of one or more reactive groups. This property of the reactive dyes makes it different as compared to the other class of dyes. They have been largely accepted by the industries as their consumption has been increased due to their abundance brilliance, range of hues and high wet-fastness. All natural/organic fibres such as silk, wool, cotton and some of the synthetics fibers such as acrylic, rayon and polyesters are being dyed by acid and basic dyes. Some of the fibers such as cellulose fibers required the applicability of the dyes directly due to which they are classified as direct dyes. Moreover, they are also being utilized for coloring paper, to some extent nylon leather and rayon. Solvent dyes are consumed for coloring plastics, wax, inks, minerals, oil and fat products. Mordant dyes can only be employed for the coloring of leather, furs, anodized aluminum and wool (Wang et al., 2007).

Textile Dyeing Wastewater Risk

Industrial effluents reduce the penetration of light in rivers, simultaneously affecting aquatic flora and their photosynthetic activities due to the presence of synthetic dyes. Therefore, the food source of aquatic organisms is being affected severely. Hence, the amount of dissolved oxygen also decreases due to formation of the thin layer that makes the dyes to be discharged over the surfaces of water, affecting the aquatic fauna as well. In addition, biochemical oxygen demand also increases in the wastewater consisting of dye in the effluents. Dyes persist in the environment as they are the general stable organic pollutants due to which they are being considered as xenobiotics. As a result, they show resistance to degradation methods. Therefore, for their proper degradation, several methods have been explored and developed. Regardless of the number of successful methods such as biological and physicochemical processes, degradation of the textile industry effluents cost effectively remains a major problem. Therefore, this review has focused onto the environmental pollution caused by the textile industrial wastewater effluents and the best available environmentally friendly treatment technologies including physical, chemical and biological methods.

Environmental Impact

The first contaminant to be documented from wastewater (< 1 ppm) is the synthetic dyes as they are highly visible due to their transparency thus, affecting the solubility of gases and aesthetic merit. Thereby, the sunlight is reflected while it is entering into the water. Hence, hindering photosynthesis and interferes with the growth of the aquatic species. Moreover, living organisms can have chronic and/ or acute effects due to their concentration and length of exposure,. The first and major concern is not only to removal the colour from wastewater containing dyes but it needs to significantly decreased the toxicity and to eliminated permanently as well. In effluents of textile industry wastewater, a diverse form of dyes can be found. It has been estimated that 40,000 tons of textile wastewater of the total amount i.e.450, 000 tons is being discharged in the water bodies due to the production of dyestuffs at a large scale (O'Neill et al., 1999). The dyes are being produced in industries according to their compatible fibers i.e. resistance to microbial attack, high stability in light and washing .In fact, these dyes are synthesized in such a way so that the dyes could be able to resist the harsh conditions causing their degradation to be resistant and having difficulty in the colour removal by the conventional wastewater treatments from textile wastewaters. Dye fixation rate values provides an estimate of amount released as the fixation of a dye varies according to the parameters of dyeing procedure such as shade and fibre (Al-Degs et al., 2000). During hydrolysis, the reactive dyes do not react with the fiber as compare to the other types of dyes due to which nowadays, reactive dyes are being used most commonly in the textile industry. Therefore, an efficient method has to be investigated for the removal/ degradation of this reactive dye as this class is highly reactive. Furthermore, they remain for a longer period of time due to their stability and complex structure integrity. Due to the commercial importance of these dyes as they are being exploited at a large scale but unfortunately they are posing detrimental effects. Therefore, extensive studied has been carried out due to the hazardous environmental impact of these dyes (Pinheiro et al., 2004; Mathur et al., 2003; Puvaneswari et al., 2006; Pereira et al., 2009a, b). It is understandable that our knowledge remains incomplete regarding the environmental hazards involved in their use due to the production and consumption of these synthetic dyes at a large scale (Forgacs et al., 2004.The most commonly used synthetic dyes are the Azo dyes; the largest group of highly toxic dyes that are being released into the environment in the water bodies (Zhao and Hardin, 2007). Indeed, some detrimental effects have been associated to splenic sarcomas and bladder cancer as well.

Wastewater Remediation

The textile industry is considered to be one of the major industries for polluting the water bodies due which it has been pressurized immensely for the remediation of harmful effects of the dyes, particularly their allergenic, and mutagenic carcinogenic effects. There are regulations vary in different countries concerning the colour limits in the textile industrial effluents. Bioremediation targets both the Textile dye wastewater treatment and dye degradation and its mineralization both. In fact, when the bond is broken during decolourisation but still the molecules remain intact. Thus, the absorption of the visible light of the electromagnetic spectrum shifts to the ultraviolet or infrared region by the associated molecules. Therefore, for the wastewaters treatment, a wide range of technologies has been developed for the removal and degradation of synthetic dyes to decrease or eliminate their detrimental effects on the environment. These methods involve physical methods such as reverse osmosis, sorption techniques, nanofiltration, electro dialysis, and membrane-filtration processes; chemical methods such as flocculation or coagulation combined with filtration and flotation, electroflotation, precipitation flocculation, electro kinetic coagulation, irradiation or electrochemical processes and conventional oxidation methods; and biological methods particularly, the use of pure enzymes, anaerobic and aerobic microbial degradation. The conventional wastewater treatment methods were inefficient for the remediation of textile dyes due to their chemical stability which leads to the complexity in the structures (Forgacs et al., 2004). Additionally, the water recycling issue was also not addressed by the traditional methods (Soares et al., 2004). Recently, the most advanced emerging oxidation process relies on the generation of oxidizing agents such as hydroxyl radicals. This method has shown the successful degradation of the pollutants (Arslan and Balcioğlu, 1999; Zhao and Hardin, 2007).Though, these methods are efficient but they consume electrical energy and chemical reagents at a large scale which makes these methods costly and unappealing for the consumers commercially for the remediation of toxic pollutants. Therefore, an efficient and cost effective, eco-friendly and environmentally friendly method has to be developed for the degradation of the dyes present textile industrial wastewater (Couto, 2009). Hence, there are some of physical, biological and chemical methods that are generally considered environmentally friendly and cost effective as the pollutant degradation goal can be achieved for the complete remediation of these dyes (Pandey et al., 2007). They also remove suspended solids, COD and BOD. Indeed, the treatment method for the removal of dyes is selected on the basis of their chemical and physical characteristics. The technologies being used for the dye removal and those in development have been mentioned in this review (Vandevivere et al., 1998; Forgacs et al., 2004; Anjaneyulu et al., 2005).

Strategies to Remove Different Types of Dyes from Textile Effluents

There are different methods to achieve effective color removal, such as: physical, chemical, electrochemical and biological treatments**.**

1) Physical Methods

a) Adsorption

Adsorption is most frequently used procedure in textile industry in which activated carbon is used as excellent adsorbent for many dyes, but the factors that limit its implication in decolonization are high price and regeneration capacity (Galan et al., 2013). Low-cost adsorbent materials such as peat, clay, fly ash, zeolites, bentonite clay, agriculture wastes, wood chip, pumice and silica gel were used by some researchers (Holkar et al., 2016; Hayelomet al., 2014; Rehman et al., 2013)

b) Flocculation-coagulation

This physical method was used for decolorization of textile industry wastewater effluents contaminated with dyes. One of its drawbacks is the low decolorization efficacy of reactive dyes for the wastewater treatment. Therefore, the inefficiency and the production of resultant sludge at a large scale limit the use of these techniques.

c) Membranes Filtration

Membrane filtration has the ability to clarify, concentrate and separate dyes from the effluent. The function of these membranes was to give an exciting potential for the recycling of hydrolyzed reactive dyes (Chollom et al.,2015).

Some aspects that need to be taken into account concerned with membrane-based treatments are: investment cost; possible fouling and the production of other wastes having insoluble dyes (e.g. indigo); and starch that needs further treatment (Koyucu and Guney, 2013).

d) Irradiation and Ion exchange

The irradiation technique has the potential in treating different colored water of small volume, but requires high amount of dissolved oxygen.Whereas, the ion exchange methods manifest more deteriorating results in treating different dyes and show inadequate response in the presence of other additives in the same wastewater (Abu-Saied et al., 2013).

e) Nanofiltration

Nanofiltration is upcoming technique for the removal of pollutants in textile industry. By nanofiltration many reactive dyes can be separated from waste matter (Stoykoand Pencho, 2003). Percentage of dyes that can be treated by this processs is 85-90%, by recycling (Muthumareeswaran et al., 2017). It includes treatment of solutions (Chollom et al., 2015) that are complex and highly concentrated, in dyeing processs (Li et al., 2016; Malekian et al., 2016).

2) Chemical methods

a) Ozonation Advanced

Ozonation plays an important role in decolorization of synthetic dyes. Ozone encounters different dyes effluent according to their composition (Litter and Quici, 2010). Researchers had found that ozone effectively decolorizes azo dyes in textile effluent. Dyes photo-degradation speed by ozonation depends on its chemical structure (Zaharia et al., 2009). This method has advantages that it increases neither the amount of wastewater nor its mix sludge (Litter and Quici, 2010). The disadvantage is that it produces carcinogenic nitrogenous compounds and some harmful molecules, so not recommended for use (Deepa et al., 2014).

b) Oxidation Processes

Advanced Oxidation treatment is one of the traditional processes to remove organic or inorganic industrial effluents. Its effectiveness is based on the production of oxidizing reagent (OH) radicals becausethey attack on the chromogenic groups, and ultimately release organic peroxide radicals that contered into CO_2, H_2O and inorganic salts (Antoniadis et al., 2010).

c) Sodium Hypochlorite

The sodium hypochorite treatment was used to control industrial pollutants being produced by dyes. The Cl^{-1} produced from NaOCl action destroys the amino groups, that ultimately results in breaking of azo bond (Quader, 2010). Its disadvantage is that sodium hypochorite is a strong corrosive agent that produces poisonous chlorine gas when mixed with acids (Fukuzaki, 2006).

3) Biological Methods

In textile wastewater, the dissolved organic matter is separated by the help of biological process. The ratio of organic load/dye and the particular microbe (bacteria, fungi, algae etc.), its temperature and the oxygen concentration present in the system affects the removal efficiency. Biological methods are categorized into anaerobic, aerobic and facultative methods on the basis of oxygen requirements (Holkar et al., 2016).

a) Bacterial Degradation

In bioremediation, microbes were used to remediate the organic contaminants and used as pollution indicators for various toxicants in wastewater needs further research (Ngulubeet al., 2017). The main advantage to work with bacteria is that they are easy to culture and can easily grow as compared to other microbes. Bacteria are able to catabolize chlorinated and aromatic hydrocarbon based organic pollutants, which can be decomposed by using them as an energy source (carbon source) (Hruby et al., 2016) and have the ability to oxidize sulfur based textile dyes (Sulphur blue 15) to sulphuric acid. (Yang et al., 2014). Many studies have shown favorable results in identifying bacteria which can degrade different azo based dyes at a faster rate (Nguyen et al., 2016).

The metabolites formed as a result of dye reduction can further be catabolized either by aerobic or anaerobic processes. The intermediate products synthesized during dye decolorization can also be reduced by other enzymes such as hydroxylase and oxygenase that are also produced by the bacteria (Wang X et al., 2014). For examples gram positive bacteria; *Bacillus subtilis* and gram negative bacteria; *Escherichia coli* were used to decolorize various dyes.

b) Fungal Degradation

The fungi have potential for the production of both the extracellular and intracellular enzymes that are involved in the metabolic processes and pathways. These enzymes were exploited for the degradation of many dyes present within the textile effluent. White rot fungi e.g *Coriolopsissp* (Chen and Yien, 2015a), *Penicillium simplicissimum (*Chen and Yien, 2015b) and white rot fungus *Pleurotuseryngii* (Hadibarata et al., 2013; Anastasi et al., 2011).

c) Algae

In textile effluent, the dye's degradation by algae takes place in three steps such as isolation of the potential algae, alteration of these dyes to colorless intermediates and adsorption on algae with the help of chromophores. Green macroalgae *Cladophora sp. is capable for the* degradation of mainly azo dyes due to the presence of the enzymes named as azoreductase enzyme (acid red 27) and the algae *Shewanella* converts the toxic pollutants to the less toxic form (Meng et al., 2014). The biodegradation of the Basic Red 46 (BR46) takes place by exploiting the green macroalg*ae Enteromorpha sp*. (Khataee et al., 2013). However, algal biomass used for the bio-sorption of the pollutants present in the textile wastewater can also be exploited for the bioremediation of pollution being produced in textile industry instead of using the expensive activated carbon (Kumar et al., 2015).

d) Microbial Fuel cells (MFC):

In a MFC system, the electrochemically active microbes were used to oxidize many organic compounds present in textile effluent to reduce oxygen content to water. The membranes were present in MFCs to separate the anode and cathode according to their compartments of (Li et al., 2014). The drawback of MFC method is the higher generation cost of MFC which makes this method unappealing for the consumers; though it is having a higher degradation rate as compare to the other methods. MFCs with high power output, low cost electrodesand membrane materials and good scalability should be developed to treat different pollution causing effluents like dyeing, printing and bleaching.

4) Electrochemical Methods:

a) Electro-coagulation

Electro-coagulation has been considered to be an effective method for dye removal as it has some advantages. It causes the dissolution of metal plates into wastewater, when current is applied between metal electrodes placed in effluent, as a result dyes was removed by flotation or precipitation (Aoudj et al., 2010). The advantage of this technique was that it showed high efficiency of color removal and degradation of recalcitrant contaminants. While flocculation and filtration generates high amount of sludge that is one its draw back (Dawood et al., 2014).

CONCLUSION

The structural complexity of the dyes present in the textile industrial effluents makes the management of this waste to be a challenging task. However, the numerous methods have been developed and exploited for the recycling and valorization of wastewater. Researchers are searching and recommending the cost effective promising technologies as per the requirement due to the emerging hazards. Therefore, for commercialization, these recently developed technologies are being tested to assure its safe usage. The traditional physicochemical methods for the wastewater treatment were neither efficient nor eco-friendly. The latest green technology suggests bioremediation as an attractive solution for the textile industrial wastewater effluents as they this method is not only cost effective, it is an efficient technology as well providing sustainability within the environment. The mechanism requires the isolation/growth of the potential microorganisms for the production of enzymes for the degradation of textile industrial wastewater effluents. Previously, many attempts have been made for the isolation of potential microorganisms and their enzymes which have been investigated for their capability degrade dyes but they were not that much efficient but now the microorganisms have been genetically modified in order to make them "super and faster degraders". The bioremediation of the dyes involved two steps especially for azo dyes for the degradation within the textile effluents. In first anaerobic step, reduction of the dyes takes place and they are reduced to aromatic amines. Then, in the second final aerobic step, they get mineralized and oxidized. Several processes have been carried out with the combination of physical and biological methods such as filtration or adsorption or oxidation /coagulation. These combinations results in the efficient degradation processes to attain the goal for the valorization of these toxic dyes. The present study and the implementation of the newly developed technologies are not only concerned with the pollution reduction rather but wastewater can be recycled as well. Furthermore, after their degradation, the value added by-products can be exploited for the industrial applications.

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