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Role of biological processes for treatment of textile waste water– A state of Art review

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The textile industry is one of the significant industries that every year produces vast quantities of industrial waste is a global concern due to its overall environmental impact. A high content of pigments and other additives with complex structures has been found in the discharge which is not only toxic to marine life, but also mutagenic for humans, as a major source of water pollution. The removal of the dyes is often more important because of their complex aromatic molecular structures, which are frequently synthesized to resist soap, water, light or oxidizing agents which make them more stable and less naturally degradable. Therefore, the physical and chemical methods do not often remove dyes effectively. Bioremediation of textile waste water using different microorganisms has achieved considerable prominence as a very safe, affordable and adequate solution. The emphasis of this analysis is primarily on the contribution of biological treatments using different microorganisms with their mechanism in this field from textile effluent in addition to various physico-chemical process for textile wastewater treatment. It also focuses on the different factor affecting decolorization of degradation process for different reactive dyes.

Keywords: Textile wastewater, physio-chemical methods, bioremediation, decolorization, biodegradation.

Introduction

Textile wastewater is related to one of the big issues of water contamination. It includes a mix of various dyes, subsidies, additives and other chemicals added during the manufacture of textiles which trigger serious environmental issues. In India, an average textile mill discharges around 1.5 million liters of untreated effluent each day contributing to chronic and acute toxicity[1]. Also, the untreated effluent deposited in potable water bodies, such as rivers and reservoirs which increase the concentration of color, pH, biological chemical demand (BOD) and chemical oxygen demand (COD) thus it become very difficult to treat[2]. Based on the composition of wastewater and its harmful impacts the textile sector is ranked as the most polluting industry among the all others. Dyes are the primarily complex organic molecules consists of two groups chromophores (color imparting compounds) and auxochromes (color intensifier)[3]. Depending on their groups and characterization dyes can be classified as reactive, acidic, basic, anionic, direct, azo, anthraquinone, etc. Currently, reactive dyes are most widely used dyes among all due to their wide variety of shades, excellent color, ease of application and low energy consumption etc.[1]. Various physio-chemical methods have been used to remove the color and pollutants found in textile dye wastewater such as adsorption, chemical oxidation and reduction, flocculation, photolysis, etc. Although physio-chemical treatments are successful up to some extent for the decolorization of dye but they need more energy and chemicals. With these drawbacks, the biotechnological approach has been received great attention in recent years due to its high efficiency and cost effectiveness[4]. Bioremediation is a safe, cost-effective and environmentally-friendly alternative to traditional textile waste treatment processes. Microorganisms such as bacteria, fungi and yeast are commonly used for the decolorization of dye present in wastewater[5]. In this review, the current physio-chemical methods used for the removal of reactive dyes will be discussed. Also, the biological treatment by the action of various microorganisms for the dye removal are also discussed.

Current physio-chemical method

Oxidative method:

The oxidation methods are the simpler and popular method used for the degradation of dyes. The impetus mechanism in oxidative process is the oxidative cleavage of the aromatic ring of the dye molecules[6]. Oxidation method has many different ways of approach (such as Fenton's reagent, ozonation, photochemical, sodium hypochlorite (NaOCl)) which can be adopted conventionally[5]. Jovic *et al.* in 2013 reported that the oxidation process can be capable of complete decolorization of dyes by removing the chromophore groups. However, they may have the main drawback of sludge production (toxic by-products) which is again difficult to treat except the ozonation process.

Adsorption:

Adsorption is one of the oldest wastewater purification method used for the treatment of organic pollutants from industrial wastewater including dyes[7]. A wide range of adsorbents are used or fabricated since past few decades such as activated carbon, woods chips, silica gel, fly ash, spent tea leaves etc. for the removal of dyes from wastewater at laboratory scale or industrial scale[8]. Overall, the absorptive process is a good process but still its practical adoption is limited such as synthesis and regeneration cost, ineffective towards some dyes (disperse and vat) and the overall operating cost is higher which makes this process limited.

Membrane separation:

Dye removal through membrane separation has a large potential because of its easy operation and low maintenance. It can holds great potential for the removal of color, COD, and salinity in wastewater[9]. The dye molecules are permeated at high membrane through the membrane. The mechanism is regulated by the partial difference in pressure on both sides membrane (permeate and feed). Despite many advantages, this method has several drawbacks such as large operating cost (higher cost of membrane), blockage of membrane, the left filtrate residue makes disposal problems, and the not effectiveness for large volume and high pressure[10].

Ion-exchange:

Ion-exchange process is one of the commonly used method used for the removal of dyes from wastewater. This method had several advantages such as no sludge production, recovery of solvent, effective removal of soluble dyes[11]. Still the higher cost, ineffectiveness for higher concentration of dyes, not suitable for disperse dyes etc. are the factors that make this process limited in use[6].

Electrocoagulation:

Electrocoagulation (EC) is an important method for wastewater treatment and the regaining of various chemicals from wastewater. This method was some advantages i.e. low sludge production, less chemicals use, easily operated[12]. But, still this process has also several drawbacks such as high conductivity of wastewater is required, high energy consumption cost, electrode replacement cost, sludge production (disposal) may increase the operating cost.

Biological treatment/Bioremediation of reactive dyes

Bioremediation is a treatment process used to break or degrade hazardous substances into less toxic or nontoxic substances using naturally occurring micro-organisms (bacteria, yeast or fungi). Biological methods are known for being environmentally friendly, as they contribute to the full mineralization of organic contaminants at low costs and to the creation of low sludge. The techniques of bioremediation are known *in situ* (applied at the site of contamination), ex situ (contaminants are removed by biology from the environment), using pure microbes and mixing/mixing microbial micro-organisms, including plant processing (i.e. phytoremediation)[13].

Bacterial degradation of dyes:

It's a well-known and cost-effective method for the industrial applications because bacterial growth was easy and therefore bacteria for degradation purposes can be cultured very conveniently. The breakdown of the azo bond through bacterial action between the dye and the fibers by anaerobic degradation resulting in formation of amines of aromatic mixed bacterial groups[14]. After that, under aerobic conditions the resulting aromatic amines can be further metabolized. One advantage of getting bacteria from real wastewater depletion sites is that they are more likely to have activated enzymes which help the enzymes to decompose the dye[5].

Degradation of dye by the use of fungi:

Fungal species can decolorize a wide variety of dyes most effectively. They are the species not below plants or animals. They can get their nutrients through absorbing dead organic matter or waste. Fungal species may degrade biomass pollutants or non-biodegradable ones that cannot be done with bacteria on their own[15]. The single most productive class of microorganisms is white rot fungi. White rot fungi can produce various different oxidoreductases enzymes that can degrade various dyes under aerobic conditions. The oxidation of various organic pollutants including reactive dyes by ligninolytic fungi is due to a non-specific and non-stereo-selective system extracellular enzyme consisting of (lignin peroxidase, manganese peroxidase and laccase etc.).

Degradation of dye by the use of algae:

Algae is a photosynthetic microorganism with different factors depends on its natural habitat such as hydrophytes, benthophytes, epiphytes, epizophytes etc. It is widely used to degrade reactive dyes through azo-reductase enzymes due to its large surface area and binding ability. Different studies have shown that several contaminants in wastewater OH, $RCOO^-$, $-NH_2$, and PO_4^{3-} have been absorbed on the surface of algal surfaces. Many species of Chlorella and Oscillatoria will degrade azo dyes to aromatic amines which further metabolize into simpler organic compounds or CO_2 of aromatic amines[16].

Degradation of dye under aerobic conditions:

Many bacteria that degrade dyes under aerobic conditions cannot use the dye as a source of carbon but need a supplementary source of carbon source. As the sole source of carbon, very few bacteria are able to grow on azo compounds. Such bacteria, for example *Pigmentiphaga kullae* K 24 and *Xenophilus azovorans* KF 46, can cleave -N=N- bonds and use amines for their development[11,18]. Aerobic bacteria have oxidoreductive enzymes, which may break symmetrically or asymmetrically the dye molecules. Aerobic bacteria can also cause deamination, desulfonation, hydroxylation, etc. Various studies on the biodegradation of some most widely used textile dyes using different microbial strain under different conditions are given in Table 1.

Table 1. Various studies on the biodegradation of different used textile dyes using different microbial strain

Name of dye	Microbial strain	Methodology	Major findings	Ref.
Reactive black 5	*Bacillus cereus* strain KM201428	Batch study by varying parameters (contact time, dye concentration and pH)	Decolorization was up to 92% in 120 h at pH 9 and temp. 25°C	21
Reactive blue 4	*Staphylococcus hominis* subsp. hominis DSM 20328	Optimization study with varying parameters pH, temp., conc. of carbon source and dye, salt, and glucose incubated at 37°C	Decolorization of 97% at pH 7 was observed in the presence of 10% glucose	22
Reactive red 120	*Tistrella mobilis*	Fresh bacterial inoculums (5 ml) in MSM inoculated into 100 ml (v/v) of dye containing under static condition	Decolorization of 92% in 10 days under static condition at pH 7 and temp. 30°C	23
Reactive orange 16	*Nocardiosis* sp.	Optimum parameters for degradation of RO-16 such as pH, temperature, dye conc. were analyzed	85.6% of decolorization within 24 h at pH 8, temp. 35°C	24
Reactive yellow 145	*Pseudomonas aeruginosa* and *Thiosphaera pantotropha* ATCC	Degradation and decolorization of RY145 under the effect of both static and shaken conditions	100% decolorization of 50 mg/L RY 145 within 96 h and 72 h	25
Reactive blue 19	*Klebsiella* sp. C NCIM 5546	Optimum parameters investigation such as pH, temperature, glucose concentration etc.	90% decolorization of RB19 within 24 h at pH 7, temp. of 37°C, 6 g/L	26
Novacron orange FN-R, Novacron Super Black G, Bezema Yellow S8-G	*Vibrio* sp., *Neisseria* sp., *Bacillus* sp.	Experimentally optimized the decolorization of dyes through different bacterial culture under static condition at 37°C	Novacron Brilliant Blue FN-R and Novacron Super Black G can decolorize up to 90% in 6 days	27
Methylene blue	Mixed bacterial culture	RSM (CCD) optimization of process time, dye concentration and pH	78.2% of decolorization of Methylene blue (50 mg/L) in 4 days at pH 7	28
Synazol red 6HBN	*Alcaligenes aquatilis*	Decolorization study using saw dust and yeast extract as nutrient source	82% of decolorization of dye in 4 days at 37°C and pH 7	29
Crystal violet	*Enterobacter* sp. CV-S1	pH, temperature, initial dye concentration and inoculum size were optimized	100% removal of CV dye 10% (v/v) under 72 h at temp. 35°C and pH 6.5	30

Table 2. Major factors affecting the biodegradation and decolorization of reactive dyes

Major factors	Descriptions
pH	The pH has a significant influence on dye decolorization efficiency, and the optimal pH for color removal in bacteria is always between 6.0 and 10.0. Tolerance to high pH is especially important for industrial processes using reactive azo dyes, normally conducted under alkaline conditions
Temperature	Temperature is also a very important factor for all microbial vitality processes, including remediation of water and soil. Furthermore, the decolorization rate of reactive dyes increases up to the optimal temperature and then there is a decrease in the decolorization due to the denature of the activity of enzymes
Dye concentration	It may report that increasing the concentration of dye decrease the decolorization of dye due to the enhanced toxicity of dyes through which active sites of the azoreductase enzymes should be blocked by dye molecules at different concentration
Oxygen/agitation	Biological factors can directly impact the process of degradation and decoloration of azo dyes, depending on the biological reduction or oxidative status, and indirectly influence the microbial metabolism. However, small amounts of oxygen are also needed for oxidative enzymes that degrade azo dyes
Dye structure	The decolorization rates for dye removal should be higher for dye with simplified structures and less molecular weights while the dye with complex structures having electron withdrawing groups such as $-SO_3H$, $-SO_2NH_2$ in the *para* position of the phenyl ring have high molecular weight hence less decolorization rate

Many bacteria that degrade dyes under aerobic conditions cannot use the dye as a source of carbon but need a supplementary source of carbon source. As the sole source of carbon, very few bacteria are able to grow on azo compounds. Aerobic bacteria have oxidoreductive enzymes, which may break symmetrically or asymmetrically the dye molecules. Aerobic bacteria can also cause deamination, desulfonation, hydroxylation, etc. Also, the degradation of dye has will be affected by several factors as given in Table 2.

The azo dyes are often reduced to colorless aromatic amines under anaerobic conditions. Decolorization of dye under anaerobic conditions relies on the additional source of organic carbon and the composition of the dye. The reducing agents are nicotinamide adenine dinucleotides (NADH), and flavin adenine dinucleotide (FADH)[19]. During the degradation process the intermediates formed can be degraded aerobically or anaerobically. It may be reported in several studies that the azo bond reduction can be inhibited by oxygen as aerobial respiration requires NADH, thus preventing movement of electrons from NADH to azo bond.

Mechanism of biodegradation of dyes

The process of degrading the synthetic dyes occurs in two stages both under aerobic and anaerobic conditions. The first stage involves reductive cleavage of the azo bond (-N=N-) leads to the formation of aromatic amines which are usually colorless but potentially harmful. In second stage aromatic amines being degraded under aerobic conditions[30]. However, reduction of azo bond with the aid of azo reductase enzymes under anaerobic conditions involves transferring four electrons (reduction equivalent) through two stages at the azo linkage transferring two electrons to the azo dye at each stage which serves as final electron acceptor resulting in decolorization of the dye[23]. The subsequent intermediate metabolites will be further aerobically or anaerobically degraded[20] as shown in Fig. 1.

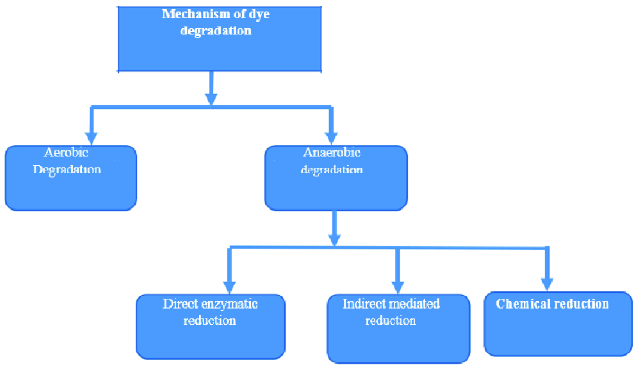

Fig. 1. Mechanism involved in dye degradation.

Conclusions and future scopes

Dyestuff accumulation and pollution contamination cause environmental and medical and aesthetic issues. Specific physio-chemical approaches for handling of wastewater dyes have been introduced. However, there are many constraints such as low performance, costly, environmentally friendly, production of sludge, etc. Bioremediation is an environmentally sustainable and inexpensive approach that utilizes microorganisms to extract wastewater. However, there is future scope on the scaling-up of newly identified bacteria in successful laboratory experiments for future implementation in the industry. Also, there is a need to measure toxicity levels alongside the decolorization rate at the laboratory scale. Furthermore, it is possible to boost the new advances in genomics and proteomics to enhance enzymatic treatment of textile wastewater.

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