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Review Article

Involvement of Microorganisms in the Biodegradation of Synthetic Dyes of Textile Waste

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Abstract

Due to its overall environmental impact, the residual dye in the wastewater from the synthetic dye manufacturing and textile industries is a global concern. The discharge is heavily pigmented and contains various chemicals with intricate structures. The dyestuff in the effluent is less sensitive to acids, bases, and oxygen as required for dyed garments. As a result, the degradation of the dyes is not always effective using traditional physical and chemical approaches. Some microbes can use the dyes as a source of carbon, nitrogen, or both when they are developing in a region that has been exposed to textile effluent. Using these bacteria for bioremediation of textile effluent has become increasingly popular as a very clean, affordable, and sufficient option. This review was focused on the role that bacteria play in this industry and the isolation of those bacteria from textile wastewater and data were searched from Scopus. PubMed, Medline, and various reputed platforms. Discussion of the variables that affect how well various bacteria perform is a secondary concern. In conclusion, it is envisaged that the removal of hazardous substances and pigments from textile wastewater will primarily be accomplished through microbial treatment.

Keywords: Textile Industry; Azo Dyes; Biodegradation; Synthetic Dye

Introduction

Before 1856, dyes were made using organic materials including flowers, vegetables, wood, roots, insects, etc. However, as needs and demands grew, businesses started to rely more and more on synthetic dyes made from petrochemicals. In comparison to natural dyes, these dyes are water soluble, readily absorbed, and color develop quickly, and they offer a wide range of hues [1]. Currently, about 800,000 tons of dyes are produced annually on a global scale. Textile industries use a lot of the dyes that are produced. The processing of textiles uses a lot of water and generates a lot of wastewaters. A significant portion of the dyestuff from an aqueous dyeing process is regrettably discharged with the wastewater due to inadequate depletion of dyes onto textile fibre [2]. Environmental pollution is significantly increased as a result of the wastewater release because it contaminates soil and water [3]. In addition, it has the potential to be poisonous and mutagenic to aquatic flora and fauna, change the pH and oxygen levels of the water, and prevent light from penetrating the water, disrupting the aquatic ecology. The remaining dyestuff is also linked to a number of negative consequences on human health, including as inflammation, respiratory issues, and immune system damage. The amount of dye in colored wastewater discharged by the textile industry can range from 10 to 200 mg/l, together with a variety of other organic and inorganic compounds and additives [4].

In fact, even after effluent treatments, it is predicted that up to 90% of these colours still end up in rivers and remain chemically unaltered. The complexity of the dye structures affects how quickly

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dye molecules break down. They can be acid dyes, azo dyes, basic dyes, disperse dyes, sulfur dyes, pigment dyes, etc. based on their chemical makeup [5]. The majority of dyes utilized in the textile industry are azo. They are the most widely used synthetic dye because they are affordable and simple to use. Degrading synthetic dyes, particularly azo dyes, can be accomplished by the employment of bacterial techniques [6]. The employment of microorganisms for biodegradation is practical due to their adaptability, dynamic metabolisms, and potential enzyme machinery. When compared to traditional procedures for the treatment of textile waste, bioremediation is a non-hazardous, affordable, environmentally friendly, and frequently more effective option. The mechanism by which synthetic dyes are broken down by microorganisms is covered in this review, along with the isolation and selection of microbes that can decolorize textile effluents [7].

Mechanism of dye degradation

At least three steps make up biodegradation: a small modification of an organic molecule that leaves the primary structure intact; fragmentation of a complex organic molecule in a way that the pieces could be put back together to produce the original structure; and complete mineralization, or the conversion of organic molecules into mineral forms like carbon dioxide or methane as well as inorganic forms of other elements that may have contained the original structures. Both the lyophilized culture and enzyme did this. It was discovered that the degradation of the dye was carried out by a well-defined lignin-degrading enzyme system, which included lignin peroxidase, Mn (II)-dependent peroxidase and glyoxal-oxidase. Decolorization is mostly caused by dyes adhering to microbial cell surfaces. It was discovered that absorption plays a significant role in the decolorization process and may even play a role in the first stages of dye degradation. 45 Microscopic investigations revealed that the fungi's spores, not their hyphae, were the ones taking up the colour. It's possible that the dye and fungus had a hydrophobic-hydrophillic interaction that caused the absorption phenomenon. When the concentration of the enzyme or the cell mass was increased, the dye's colour changed, suggesting that the dye was degraded by both enzymatic action and adsorption to the cell mass. More degradation was caused by both working together than by either acting alone [8].

Microorganisms for dye destruction from textile wastewater

Large volumes of sludge can be produced by physico-chemical treatment procedures like coagulation, precipitation, filtration, adsorption, photolysis, and oxidation with hydrogen peroxide or ozone, and these procedures frequently call for the addition of additional environmentally hazardous chemical additives.

Due to their low cost, environmental friendliness, and ability to selectively deliver a complete breakdown of organic contaminants without causing collateral damage to the site's flora or fauna, biological treatment technologies are appealing alternatives to the conventional physicochemical approaches [9].

The activity and flexibility of microorganisms determine the effectiveness of the treatment of the dyestuff. Textile dyes are decolorized by microorganisms in two major ways, either adsorption on microbial biomass or biodegradation of dyes by the cells or enzymes. The use of biomass is particularly useful if the effluent is highly toxic and does not support the growth and maintenance of microbial cells. Adsorbents can include bacteria, microalgae, and fungi, and the adsorption does not degrade the dye into fragments. In contrast to biosorption, the original dye structure is disrupted in biodegradation, often entirely decomposed. Thus, biodegradation is the more practical option [10].

Degradation of dyes by fungi

The synthesis of extracellular enzymes phenoloxidases and peroxidases by decay fungi in culture is an essential physiological trait. When added to agar plates with 0.5% (w/v) Gallic or Tannic acid, certain fungi develop brown diffusion zones as a result of the oxidation of the corresponding phenolic acid by extra- or intracellular phenoloxidases. According to Bavendamm40, the capacity of white-rot fungi to decompose lignin is closely connected with the presence of phenoloxidases in these fungi [11]. The first to apply this technique to 210 species of wood-decaying fungi was Davidson., *et al*. 96% of the white-rot fungi studied were successful on either gallic acid agar, tannic acid agar, or both media. On plates enriched with 28 different chemicals, Kaarik36 evaluated 173 wood-decaying species and discovered that the responses of different strains to certain phenolic compounds varied greatly. The basidiomycetous fungus Phanerochaete chrysosporium is known as the "white rot fungus" because it can break down lignin, a randomly connected polymer made of phenylpropane that is a component of wood [12].

In spite of the success, the fact that white-rot fungi are not naturally found in wastewater makes the enzyme production unreliable. In addition to that, some other disadvantages are associated with using white-rot fungi, i.e., long growth cycle and the dependency on nutrient limitation. The decolorization is also limited by the long hydraulic retention time required for complete decolorization [13].

Biological decolorization of azo dyes by yeasts is mediated by azoreductases in yeasts which catalyze reductive cleavage of azo groups (–N=N–). Example of such yeasts includes Candida oleophila and Candida zeylanoides. Decolorization by these strains is due to azo bond reduction, forming the corresponding amines. A study of the enzymes responsible for the biodegradation of Methyl Red by Saccharomyces cerevisiae MTCC 463 showed different levels of the activities of laccase, lignin peroxidase, NADH–DCIP reductase, azoreductase, tyrosinase, and aminopyrine N-demethylase. It is suggested by studies that these products are further degraded into aliphatic amines that might be facilitated by oxidative enzymes such as lignin peroxidase and laccase [14]. S. cerevisiae cells have also shown bioaccumulation of reactive textile dye (Remazol Blue, Remazol Black B, and Remazol Red RB) during growth in molasses. Some ascomycete yeast species, such as Candida tropicalis, Debaryomyces polymorphus, and Issatchenkia occidentalis, have been studied to decolorize azodyes. Galactomyces geotrichum MTCC 1360 can decolorize azo and reactive high exhaust textile dyes [15]. *Trichosporon beigelii* has shown to have the capability to degrade Navy blue HER up to 100%.

Degradation of dyes by algae and plants

Studies suggest that photosynthetic organisms like algae and cyanobacteria are capable of degrading azo dyes through an induced form of azoreductase. Algae are mostly used in biosorption. Several species of Chlorella and Oscillatoria are able to degrade azo dyes to their aromatic amines and to further metabolize the aromatic amines into simpler organic compounds or CO_2 [16].

Using plants for the process, better known as phytoremediation, has a major advantage, which is the limited need for nutrient supplies. Brassica juncea, Sorghum vulgare, and Phaseolus mungo have successfully decolorized textile effluents up to 79, 57, and 53%, respectively. *Blumea malcommi* and *Tagetes patula* have also given positive results in the literature. However, there are some drawbacks – the requirement of the area in order for the treatment to be functional and the impact of pollution on plants [17].

Degradation of dyes by bacteria

Bacterial oxidoreductive enzymes are the key to the degradation of synthetic dyes. This dynamic metabolism of bacteria enables them to utilize complex xenobiotic compounds of the dyestuff as a substrate. In the process, they are broken down to less complex metabolites. An advantage of obtaining bacteria from actual sites of wastewater disposal is that they are more likely to have the enzymes activated, which facilitate the decomposition of dyes [18].

Microbial decolorization and degradation of azo dyes

Mixed bacterial cultures

Isolation of pure cultures from textile wastewater can be time-consuming and laborious. In addition, it is difficult to obtain complete decolorization by a pure bacterial culture. Mixed bacterial cultures, due to their cooperation for an enhanced effect, provide better results in decolorization and mineralization. They can efficiently degrade toxic aromatic amines. Nonetheless, the fact that these results are not readily reproduced and that mixed cultures do not provide the exact view of the dye metabolism makes the process and the results hard to interpret [19].

Bacterial methods for decomposition of dyestuff

The degradation of synthetic dyes by bacteria is facilitated by their oxidases. In the case of azo dyes, azoreductase plays the most vital role in decolorization by breaking down azo bonds. Some bacteria have been studied to degrade dyes under aerobic condition. Aerobic conditions facilitate mono- and dioxygenase enzymes to catalyze the incorporation of oxygen from O2 into the aromatic ring of organic compounds [20]. Some aerobic bacteria reduce azo compounds with the help of oxygen catalyzed azoreductases.

Decolorization under Anaerobic Conditions. For azo dye degradation, the enzyme azoreductase functions under anaerobic conditions. Nicotinamide adenine dinucleotide (NADH) and flavin adenine dinucleotide (FADH) are the reducing agents. Intermediates formed in the process are degraded aerobically or anaerobically. Studies suggest that oxygen may inhibit the azo bond reduction activity, since aerobic respiration utilizes NADH, thus impeding the electron transfer from NADH to azo bonds. Alternatively, decolorization might be attributed to nonspecific extracellular reactions occurring between reduced compounds generated by the anaerobic biomass. Decolorization is mediated by methanogens and acidogenic, as well as methanogenic bacteria, under anaerobic conditions. It is a nonspecific process, depending on the carbon source and the dye structure. Some bacteria taking part in the decolorization process could grow aerobically; however, decolorization is achieved only under anaerobic conditions. Dye decolorization reactions usually follow first-order kinetics with respect to dye concentration. Zero-order kinetics has also been observed [21].

Decolorization under Anoxic Conditions. Whereas anaerobic conditions are entirely free from oxygen, anoxic conditions have less than 0.5 mg/L dissolved oxygen. Operating conditions for these are similar to aerobic treatments. Under anoxic conditions, nicotinamide adenine dinucleotide phosphate (NADPH) carries more electrons for reduction. Mixed bacterial populations of aerobic and facultative anaerobic have been shown to be useful in anoxic decolorization of various dyes [14]. This requires complex organic sources, such as yeast extract, peptone, etc., which increases the cost.

Decolorization under Aerobic Conditions. Most bacteria that degrade dyes under aerobic conditions cannot utilize the dye as a carbon source and require an additional carbon source. Very few bacteria are capable of growing on azo compounds as the sole carbon source. These bacteria are able to cleave –N=N–bonds and utilize amines for their growth, for instance, Pigmentiphaga kullae K24 and Xenophilus azovorans KF 46. Aerobic bacteria possess oxidoreductive enzymes and can break the dye molecules symmetrically or asymmetrically. They could also bring about deamination, desulfonation, hydroxylation, etc. Therefore, different dye structures can be broken down by anaerobic bacteria [22].

Factors influencing the performance by bacteria in decolorization

Biodegradation of synthetic dyes and other chemicals in textile effluent depends on the physical, chemical, and biological processes, as well as some environmental factors.

Dye structure

Dyes with simpler structures and low molecular weights exhibit higher rates of color removal. The nature of substituents on the aromatic ring has been shown to have an impact on oxidation. Studies have demonstrated that electron-donating methyl and methoxy substituents enhance the enzymatic degradation of azo phenols, while electronwithdrawing chloro, fluoro, and nitro substituents inhibit oxidation.

Dye concentration

According to a study, increasing the dye concentration gradually decreases the decolorization rate.This may be due to the toxic effect of dyes on the microorganisms. Several other possible reasons could be inadequate cell to dye ratio, as well as blockage of active sites of azoreductase by dye molecules with different structures [23].

Carbon and nitrogen sources

Most microorganisms generally cannot utilize dyes as a carbon and/or a nitrogen source for growth. Such bacterial cultures require a carbohydrate source, or complex organic sources, such as yeast extract, peptone, or a combination of both for the decomposition. Temperature and pHDecolorization rate is higher at optimal pH and decreases at a more acidic or alkaline pH. Textile industrial processes take place mostly under alkaline conditions; thus, the tolerance to high pH is important. The optimal often being between 6 and 10 [24].

Very high temperatures can be associated with denaturation of azoreductases. It is observed that increasing temperature in a certain range (optimum) increases the decolorization rate. Increasing the temperature further drastically decreases the rate. Dissolved Oxygen. Different groups of bacteria decolorize dyes under anaerobic, facultative anaerobic, and aerobic conditions. For those operating under anaerobic conditions, reductive enzyme activities are higher in anoxic conditions, which break down the structure of the synthetic dyes. Dissolved oxygen is considered an inhibitor of the azo dye reduction process, since both molecules act as electron acceptors and oxygen is a much stronger oxidant.

Conclusion

In order to maximize the decolorization produced by isolated bacterial strains, it is essential to adjust all the parameters.

Attempts should then be made to scale up and apply bacterial decolorization techniques in real industrial effluents based on the successful laboratory results. Additionally, there is a chance to improve the effectiveness of bacterial or enzymatic treatments of textile wastewater thanks to the most recent developments in genomics and proteomics. There is a possibility to enhance the performance of bacterial or enzymatic treatments of textile wastewater. with all the positive research findings and ongoing developments, microbiological treatment is hoped to predominate in the elimination of harmful compounds and pigments from textile wastewater.

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Conflict of Interest

Authors have declared for none conflict of interest.

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