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Textile Dye Effluent Treatment: Conventional And Promising Process, An Updated 20-Year Review

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Abstract

Massive environmental issues have been brought on by the improper handling of different wastes, particularly dye effluents from textile industry, which has ultimately affected human health. Even with ongoing efforts, terminal treatment remains the most common method for minimizing the pollution caused by dye effluents. This study summarized research on textile dye effluent treatment from 2000 to 2024 and briefly reviewed key techniques such as AOPs, Coagulation, flocculation, membrane, adsorption, electrocoagulation, photochemical treatment and Fenton process. Since biological treatment has great performance, including high efficiency and environmental friendliness, it has garnered increasing attention from researchers in the past few years. Comprehensive investigations on the optimisation of techniques and cost-effectiveness were necessary, though given by severe physiochemical circumstances of dye effluent. Integrated or combined treatment approaches are therefore advised, with improved performance and multi-function. This article presented some of the problems strategies such as Genetically engineered micro- organisms, biosorbents and bioremediation by nanoparticles residuals in the treatment and the high salinity in the effluent and offered suggestions for possible fixes. This review also advanced the idea that the future path of TDE treatment should be focused on achieving multi-function, recycling, and intensification. The objective of this review is to give scholars a diversified overview of the approaches used in this field and a means of improving TDE pollution problems.

Keywords: Dye effluent, pollutants, textile industry, treatment methods, microbial bioremediation

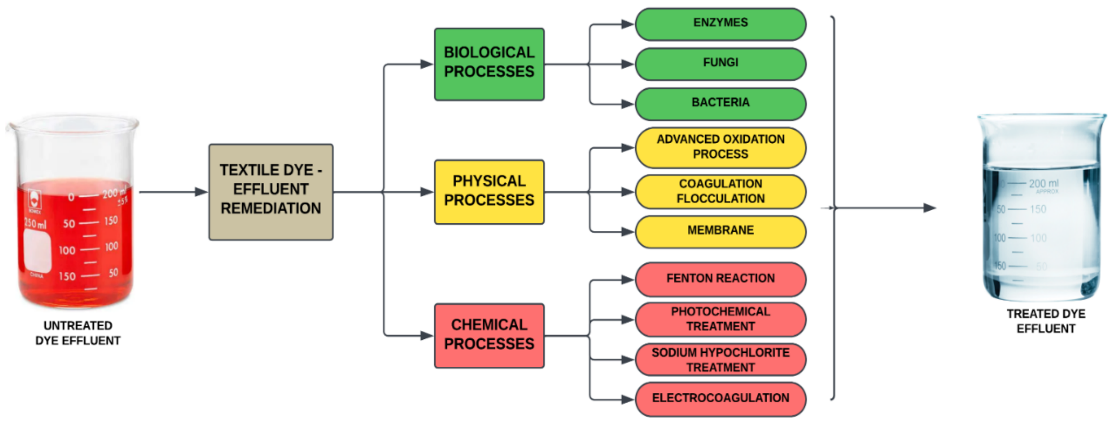
Introduction

Textile effluent has several negative effects on the ecosystem and is quite detrimental to our environment. Interestingly, the textile sector is the biggest source of dye effluent, producing a significant two-thirds of all dye waste produced[1]. The textile sector has been using dyes more frequently lately, which has increased environmental problems[2]. The procedure uses wastewater textile colors, which are carcinogenic, poisonous, and resistant to microbial breakdown[3]. They also promote the development of carcinogens during anaerobic degradation[4]. Thus, it has negative effects on the environment by upsetting aquatic life and preventing aquatic plants from photosynthesizing [5]. It also has negative effects on human health by producing respiratory problems, abnormal heartbeats, rashes on the skin, lightheadedness, and cancer(Tripathi et al., 2023a;Deng et al., 2020).

Objectives

In this review an overview of present state of competence, about the characteristics, treatment (Photodegradation, Advanced oxidation processes (AOPs), Coagulation-flocculation, Membrane, Adsorption, Sonication, Various/combined, Enzymes, Yeasts, Fungi, Algae, Bacteria and combined processes) for bioremediation possibilities. We also include the contaminants treated by microbes for bioremediation. We enfold with a quick talk about the difficulties, recent strategies and future perspective for bioremediation.

TREATMENT METHOD FOR TEXTILE DYE EFFLUENT



Physical treatment methods

Advanced oxidation processes (AOPs)

Reviewed a number of research that treated textile effluent with an enhanced oxidation technique [8]. In textile effluent treatment, they proposed that the most promising treatment technologies are advanced oxidation techniques as depicted. The Fenton reaction, which combines hydrogen peroxide with zero-valent iron, was used in a textile dye treatment study given by[9] . H2O2 = 24.3 mM, and SZVI = 2,000 mg/L. It has achieved removal efficiency of 76%, 71%, and 96% of COD, TOC, and color, respectively. Overall, effluent toxicity has dropped substantially (from 60% to 20%) and biodegradability has gone up (from 0.22 to 0.40) as a result of this research. Catalytic ozonation was suggested by(Nakhate et al., 2019a) as a technique for breaking down textile effluent. To improve oxidation activities, the authors added Cu to ZnO. According to the data, 89% of the COD was removed at a pH of 7 in 30 minutes. Additionally, the scientists have noted synergistic effects when ozonation and coupled Cu doped with ZnO are used.

Coagulation-flocculation

The investigation of (Dotto et al., 2019a)examined the efficacy of several coagulants in the remediation of textile effluent. In comparison to aluminum sulfate, the study's findings indicated that the organic coagulant MO produced a greater removal efficiency (COD of 83% and color of 90% for OP-HER dyes). Additionally, this study discovered that coagulation efficiency is significantly influenced by ph. [12]looked into the removal of Sb(V) from textile effluent in another study. Based on the experimental results, the authors stated that at pH 5–6, aerated PFS+$FeSO^{-4}$ had the maximum Sb(V) removal effectiveness of 94%. Phosphate has caused Sb(V) to be reduced more effectively through the formation of a compound called phosphate-Sb(V). The inner-sphere surface complex generated during the aerated PFS+$FeSO^{-4}$ adsorption of Sb(V) significantly improved the removal effectiveness, according to the authors' assessment.

Membrane

The scientist Leaper[13] used the air gap membrane distillation (AGMD) method to investigate the removal efficiency of rose Bengal (RB), yellow dyes (SY), and sodium dodecyl sulfate (SDS) surfactant present in synthetic textile effluent. Additionally, according to the authors, this one-step procedure employed by AGMD technology eliminated all color surfactants and salts. With a lower flux decline and higher thermal efficiency, this technique is regarded as one of the most promising for the application of effluent.

Biological process

Enzymes

As shown, enzymes are also a key aspect in biological treatment method. Further, the researcher(Darwesh et al., 2019a) used co-precipitation with glutaraldehyde to remove dyes present in industrial textile effluent by using an immobilized peroxidase enzyme embedded on modified Fe_3O_4 magnetic nanoparticles. In addition, the study discovered that, in a variety of environmental environments, the immobilized peroxidase enzyme exhibited substantially greater stability than the free form of the enzyme. The immobilized enzyme is not significantly affected by pH or temperature, according to the authors' findings. As a result, more laccase also improved the dye decomposition. At 30°C and pH of 5, the highest levels of laccase activity and dye elimination (COD of 67% and BOD of 47%) were reported.

Fungal process

The research by[15] employed the fungal strain *Aspergillus Niger* as an ecologically favorable biosorbent to remediate textile effluent. Researchers have conducted both in vitro and in vivo investigations. As a result, the scientists came to the conclusion that the fungus can function as a viable biosorbent for treating effluent, and that modifying the dye solution's pH can improve performance even more. *Aspergillus carbonarius M333* (AC) and *Penicillium labrum Pg1* (PG) filamentous fungi were used by(Arikan et al., 2019a)to decolorize and eliminate organics from effluent from the sincere textile industry. The continuous flow bioreactor achieved 79% decolorization and 68% COD removal effectiveness, judging by the data. Researchers processed real textile effluent with the filamentous fungus in an attempt to construct an ultrafiltration membrane. The researchers have measured fungal growth using 3, 5, and 9-day growth periods. A 73% decrease in COD and a 91% decolorization were obtained by research using the fungus-derived ultrafiltration membrane.

Bacteria or bacterial processes

The scientist(Rathour et al., 2019a) used a novel microaerophilic bacterial community called DR4 to remediate raw textile effluent containing 27 different dyes. The scientists came to the conclusion that *Comamonas* was the most prevalent genus amongst the bacteria. During bacterial growth, optimum electron donors and nitrogen sources are two important elements to attain optimal dye breakdown efficiency. The outcome showed that a 32-hour reaction time at 37°C was adequate to achieve 98% COD reduction and 88% dye elimination. The researcher(Hossen et al., 2019a) used three isolates of bacteria (*Bacillus sp, Bacillus cereus AZ27, and Alcaligenes faecalis AZ26*) from textile effluent for evaluating the remediation. The results further demonstrated that the addition of 500 mg/L of NSB-G dye was essential to guarantee the bacteria's optimal development.

Chemical method

Fenton Reaction

Fenton response involves treating the colored effluent with a combination of hydrogen peroxide, iron catalyst, and Fenton's reagent. This substance has more power than hydrogen peroxide. Certain dyes, like dispersion and vat dyes, are very resistant to Fenton's reagent. Fenton's reagent, however, has significantly darkened the color of a number of dyes, like irgalan blue FGL, helizarin blue BGT, indanthrene blue GCD, and remazol brilliant blue B(Senthil Kumar et al., 2019a). When treating effluent that is harmful to living things or cannot be treated biologically. A significant disadvantage of this process is the chemicals' potential to produce sludge and the flocculation of color molecules (Senthil Kumar et al., 2019a)(Robinson et al., n.d.-a).

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Photochemical treatment

In the presence of H2O, this mechanism uses UV light to change dye molecules into CO_2 and H2O. The primary reason for the degradation is the high production of hydroxyl radicals. UV lamps have the ability to activate chemicals such as H_2O_2. The amount of UV light, pH, dye structure, and solution composition are the variables affecting the rate of dye elimination. Benefits of photochemical treatment of colored effluent includes a notable decrease in odor and the elimination of sludge(Senthil Kumar et al., 2019a)

Sodium hypochlorite (NaOCl)

Effluent which has been tinted can be produced by adding chlorine chemicals, which can break down the nitrogenous bridge more quickly and eliminate the amine group found in dye molecules like. This explains why dyes containing sulfonic acids and amino groups in their chemical structure are more susceptible to chlorine's attack. Chlorine (Cl) is a chemical element that may be a solid, gaseous, or liquid. When chlorine gets added to water, HClO is created.Reactive dyes need longer contact times and are more difficult to remove with this technique. It initiates and accelerates the azo bond breakage process. This approach cannot break down dispersed dyes. Cl is used less frequently to remove colors because it creates aromatic amines and has negative effects when thrown into waterways(Senthil Kumar et al., 2019a)(Robinson et al., n.d.-a) as mentioned.

Electrocoagulation

This method is used to eliminate organic pollutants from effluent. The technique involves immersing two metal electrodes in effluent; the cathode emits hydrogen gas, while the aluminum iron anodes act as coagulants and catalysts. The flocculated species is helped to ascend into the atmosphere by hydrogen gas as shown. On the site, coagulant particles form. There are three stages to this procedure. Following the oxidation of sacrificial anodic electrodes, coagulants are produced in stage 1 of the process. The second phase includes the destabilization of contaminants and the formation of emulsions[21]. The third step, floc formation, is the last one. 99.60% of the dye was successfully removed under these circumstances(Senthil Kumar et al., 2019a). The main disadvantages include the high cost of electricity, the production of sludge, the pollution caused by chlorinated organics, and the heavy metal intoxication resulting from indirect oxidation. Here the table 2 summarizes dye effluent treatment methods

Execution of Diverse Dye effluent Treatment Solutions			
Treatment Methods	**Dye**	**Results**	**Reference**
Physical			
Adsorption			
laccase, *Aspergillus niger*, peanut shell, and activated carbonrice processing waste	Blue dye	Maximum dye removal employing activated carbon 60°C, adsorbent dosage, 10 minutes of contact.	[22]
Adsorption by metal-organic frameworks based on iron (Fe-MOFs)	Congo	Five hrs of 15°C, 23. 39, 24. 74 mg/L, 17. 99 mg/L extracted in a 200 ml solution.	[23]
Coagulation/flocculation			

flocculation and coagulation	Acid red	236. 68 mg for dye all had been optimized via surface methodology (RSM).	[24]
Using polydiallyl dimethyl ammonium chloride and polyaluminum chloride for flocculation and coagulation	Multiple dyes effluent	dye elimination at pH>3 and PAC/PDDA=400/200 ppm, the ideal dosage	[23]
Biological			
Enzymatic degradation			
Luffa acutangula	methyl orange	The highest level of dye decolorization was reached. 30 mg L−1 dye at pH 5. 0.	[25]
Enzymatic breakdown caused by *Datronia sp. KAPI0039*, a white rot fungus	Reactive blue	Decolorization of 600 mg/l *Datronia sp*. at pH 5	[26]
Adsorption by microbial biomass			
Enterobacter	Acid Maroon	Maximum absorption 6 h of contact	[27]
Budget-friendly	Textile dye	pH 4.3, 45 °C	[28]
Chemical			
Fenton reaction			
H_2O_2	Red	20 mg , 90-minute	[29]
Fenton's oxidation	Blue	elimination of 20 minutes.	[30]

Table 2 Dye effluent Treatment Methods

Microbial Bioremediation (Bacteria)

Naturally occurring dye-resistant strains of microorganisms (Cepoi et al., 2016a)(Chen et al., 2018a). adapt to the hazardous chemical environment and change different highly toxic compounds into less or non-toxic forms(Saratale et al., 2011a).Under certain environmental conditions, microorganisms have the innate capacity to degrade, detoxify, and mineralize synthetic dyes(Sathishkumar et al., 2018a)[35].The isolated strain performed better in decolorizing colors than strains that were sold commercially[36]. A pure bacterial culture or mixed cultures, sometimes referred to as a "consortium," can be used to carry out dye degradation[35]. The latter utilizes synergistic metabolic effects, which has been specifically demonstrated to facilitate efficient dye degradation [37].

A pure culture may not exhibit the same range of activities as a bacterial consortium. In certain cases, a single strain of marine cyanobacterium *P. valderianum* can also biologically remove numerous chemicals. This species effectively decolorized >90% of various dyes by adsorption[38].In the experiment conducted by[39], It was reported that *Paracoccus sp. GSM2* was demonstrated to be the optimal strain for the remediation of textile effluent that contained reactive azo dyes. Reactive violet was not the only azo dye that could decolorize more than 70% of a mixture in 38 hours. It illustrates how microbial strains can be used for a wide range of purposes when treating textile effluent [40]

RECENT STRATEGIES FOR BIOREMEDIATION OF TEXTILE DYE EFFLUENTS

Environmental sustainability is becoming more and more of a public issue because to the rising costs of waste effluent management and dye treatment facility management. Achieving environmental sustainability and promoting economic growth are two goals that can be achieved through the efficient dye management using bioremediation[41][12].Specifically, genetic engineering is used with molecular tools on altered microbes (such as yeast, fungus, and bacteria). Environmental contaminants can be bioremediated using GEMs[42][12]. The [43] work used wild-type laccase, *D500G,* and mutant *laccase Lacep69* to conduct dye decolorization studies. They discovered that, at 78% decolorization for acid violet, D500G's decolorization rate outperformed that of wild-type laccase. Biosorption is a method that doesn't require energy and uses biological molecules to help with sorption[44]. Microbial biosorbents extract or adsorb xenobiotics, including metals, dyes, carcinogens, and medications, from water or soil[45][46]. An effective and environmentally acceptable substitute for removing dyes from the environment is nano-bioremediation. The production of nanoparticles by eco-friendly bacteria aids in the cleanup of pollutants through nano-bioremediation. Because of their unique structural characteristics, nanoparticles (NPs) are a popular choice for treating effluent from textile industries. For the effective removal of dyes, these NPs function as adsorbents. It was found that eosin yellowish was effectively removed (95%) at 75 ppm using Fe2O3 nanoparticles at pH 6 after 15 minutes of treatment. CuO-NPs produced by the *F. oxysporum OSF18 strain* and immobilized in alginate beads were reported by in a different investigation, showing a 90% dye remediation efficiency[47].

FUTURE PROSPECTS

The chemical, physical, and biological treatments are the most often utilized techniques for color removal. Although the physicochemical methods have been shown to be effective, their cost is high. Therefore, biological dye removal techniques hold some promise as a practical substitute for physicochemical techniques. These days, innovative dye remediation techniques are receiving more attention from researchers. They have a better removal potential and may generate power for pollutant cleanup, microbial fuel cells have become an important and useful technique. Additional methods include the remediation of dyes by yeast, phytoremediation, myco remediation, microbial remediation, enzyme-mediated procedures, and nanotechnology. The efficacy and success rate of these techniques present significant difficulties. The combination of these cutting-edge techniques could offer a comprehensive approach to reducing dye pollution. Future research should examine decolorization methods mediated by both pure and mixed cultures, wherein microbial strains should be enhanced through genetic engineering. The accumulation of dye waste and dye effluent presents health and aesthetic issues in addition to environmental pollution. Future research should concentrate on creating pure and mixed culture bioremediation systems, wherein microbial strains are genetically modified to exhibit certain features through the use of tools and methodologies from proteomics, metabolic studies, and genetic engineering. This strategy has the potential to provide long-lasting and practical solutions to address environmental issues associated to dyes. Phytoremediation is one of the most important biological methods for eliminating the vibrant dyes present in textile effluent.

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Jaresh. R, Guhan. T. S, Sundeep.R - Investigation, Review of literature, Writing - original draft, Supervision - K.J. Sharmila, review and editing –J. Raveena Jayam.

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DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study area available within the article.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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