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REVIEW ARTICLE OF EFFICIENT DEGRADATION OF DYES IN TEXTILE INDUSTRY EFFLUENTS

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ABSTRACT

This review article aims to highlight the efficient degradation of dyes in textile industry effluents and the associated toxicological effects. It provides an overview of the different types of dyes used in the textile industry and the challenges associated with their degradation. The article also covers various methods used for dye degradation, such as physical, chemical, and biological methods. Additionally, the review discusses the toxicological effects of untreated effluents and the need for efficient degradation methods to reduce environmental pollution. The challenges and opportunities associated with these methods are also highlighted. This article emphasizes the need for sustainable and eco-friendly dye degradation methods that can efficiently remove dyes from effluents while reducing the toxicological impact on the environment.

1. INTRODUCTION

The dyes during the early 1900s were obtained from natural sources for the purpose of colouring textile fabrics but before the 1900s the dyes were obtained from vegetable or animal origin. Those naturally obtained dyes belong to chemical types such as flavonoids, anthraquinones, etc [1]. In the late 1800s, the first man-made synthetic dye named Mauveine was synthesized [2]. It is a well-known fact that dyes are aromatic organic compounds that are used as colouring agents. One of the major consumers of synthetic dyes are textile industry which boosts the economic growth of the country. There is a significant loss in dye materials during industrial processes and these dyes are delivered directly into the water bodies as wastewater which in turn causes pollution to the environment [3]. The Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) levels of wastewater are known to be extremely high [4]. The dyes and their by-products from industries possess characteristics such as carcinogenicity and toxicity, leading to a negative impact on the ecological system [5].

This paper presents advanced techniques in the scientific development of dye wastewater treatments. The main focus of the current study is on suggesting and seeking improvement in already existing dye removal techniques to succeed in the removal of synthetic dyes by adopting an advanced enzymatic route.

2. CHARACTERISTICS OF INDUSTRIAL DYES

The effluents that are released from cottage industries consist of dye wastes. Liquid dye waste excreted from industries contains toxic contaminants that are responsible for causing danger to environmental surroundings [1]. Several thousand commercial dyes are produced per annum [2]. Synthetic dyes became a crucial part of textile industries and the production of these dyes is estimated at around 100,000 metric tons per annum [3].

Dyes are known to be colouring agents which are organic compounds with properties of absorbing visible luminescence. They do have the ability to get attached strongly to fabric through physical and chemical bonding with fiber [4]. The auxochromes and chromophores are the components of dye molecules. Chromophores present in dye structure help in the formation of colour and auxochromes are responsible for the strong bond formation between dye and the fiber [5,6,7]. The fundamental chemical structure of chromophores contains –C=C–, –C=O, –N=N–, $–NO_2$, –C=N, and quinonoid structural rings which are authentic for light absorption in visible range wavelengths. Another fundamental structure which is known as auxochromes comprises halogens, $–CO_2H$, –COR, $–SO_3H$, $–CH_3CO–$, $–CH_3$, and $–NH_2$ present in some synthetic dyes [8]. The classification of dyes falls into two categories such as natural dyes and synthetic dyes. The dyes mostly used in industries are synthetic because they are easily produced in multiple colours and have the character to attach fast to the fiber in comparison to natural dyes. Synthetic dyes are classified based on the mode of application and their chemical structure. The most frequently used dyes comprise anthraquinone, azo, etc [9].

3. TOXICOLOGICAL EFFECTS OF DYE

Dye is one of the hazardous pollutants released by the textile industries which is authoritative for carcinogenicity and toxicity [10]. Hence, they cause severe effects on the environment and various diseases in the biological system [11]. The effluents from dye industries when mixed with the clean aquatic system it tends to cause unbalance in the ecosystem. When this colouring substance mixes with clean water it makes it difficult for the sunlight to penetrate deep into the water and affects the aquatic system. The fish absorbs the toxic synthetic dyes from water and becomes poisonous to eat. Humans consuming these fish obtained from such an environment get afflicted by

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hypertension, muscular cramps, etc. The xenobiotic nature of synthetic dyes causes allergy, cancer, and irritations in humans [12].

4. DIFFERENT DYE DEGRADATION METHODS

There is a necessity for the application of treatments that ensure complete degradation of textile effluent pollutants through physical, enzymatical, or chemical methodologies or apply a coalesce of these methodologies [13].

PHYSICAL DYE DEGRADATION METHOD:

Physical dye degradation processes involve the use of physical phenomena to break down dye molecules. Here are some examples of physical dye degradation processes with multiple references:

Photodegradation: Photodegradation involves the use of light to break down dye molecules. This process is typically achieved by exposing the dye to ultraviolet (UV) radiation. Photodegradation has been shown to be effective in degrading a wide range of dyes, including azo dyes and anthraquinone dyes [14].

Sonication: Sonication involves the use of high-frequency sound waves to break down dye molecules. This process is typically achieved by immersing the dye in a liquid and subjecting it to ultrasonic waves. Sonication has been shown to be effective in degrading a wide range of dyes, including acid dyes and reactive dyes [15].

Heat treatment: Heat treatment involves the use of high temperatures to break down dye molecules. This process is typically achieved by heating the dye to a temperature above its boiling point. Heat treatment has been shown to be effective in degrading a wide range of dyes, including direct dyes and vat dyes [16].

Ozonation: Ozonation involves the use of ozone gas to break down dye molecules. This process is typically achieved by bubbling ozone gas through a liquid containing the dye. Ozonation has been shown to be effective in degrading a wide range of dyes, including acid dyes and reactive dyes [17].

Overall, physical dye degradation processes are attractive due to their simplicity and low environmental impact. However, they may not be as effective as chemical or biological processes in degrading certain types of dyes.

CHEMICAL DYE DEGRADATION:

Chemical dye degradation methods involve the use of chemicals to break down dye molecules. Here are some examples of chemical dye degradation methods with multiple references:

Fenton process: The Fenton process involves the use of hydrogen peroxide and iron catalysts to generate highly reactive hydroxyl radicals that can break down dye molecules. This process has been shown to be effective in degrading a wide range of dyes, including azo dyes and anthraquinone dyes [18].

Advanced oxidation processes (AOPs): AOPs involve the use of highly reactive oxidants, such as ozone or hydrogen peroxide, in combination with a catalyst to break down dye molecules. AOPs have been shown to be effective in degrading a wide range of dyes, including azo dyes and anthraquinone dyes [19].

Redox reactions: Redox reactions involve the transfer of electrons from one molecule to another, resulting in the formation of free radicals that can break down dye molecules. This process has been shown to be effective in degrading a wide range of dyes, including azo dyes and anthraquinone dyes [20].

Overall, chemical dye degradation methods are often effective in breaking down dye molecules and can be applied to a wide range of dyes. However, they may require careful handling and disposal of chemicals and generate by products that need to be properly managed [21].

ENZYMATIC DYE DEGRADATION:

Enzymatic dye degradation is a process where enzymes are used to break down dye molecules into simpler and less harmful substances. This process is widely used in the textile industry to treat the wastewater generated during the dyeing process, as the dyes can cause environmental pollution if discharged into water bodies without proper treatment. The enzymatic degradation of dyes involves the use of enzymes such as peroxidases, laccases, and azoreductases, which are capable of breaking down dye molecules into smaller and less toxic compounds. For example, peroxidases catalyze the oxidation of dyes to form free radicals, which can then react with other molecules to form simpler compounds such as carbon dioxide and water [22]. One example of an enzymatic dye degradation process is the use of laccase to degrade azo dyes. Azo dyes are widely used in the textile industry but are known to be highly toxic and carcinogenic. Laccase is an enzyme that can oxidize the azo bond in azo dyes, which breaks down the dye into smaller, less toxic compounds. The enzymatic dye degradation process is an environmentally friendly and sustainable approach to treating dye wastewater, as it avoids the use of harsh chemicals and reduces the amount of hazardous waste generated. Moreover, the use of enzymes in dye degradation is highly specific, which means that only the target compounds are broken down, while the other components of the wastewater are left intact.

The mechanism of enzymatic dye degradation involves the use of enzymes to catalyze the breakdown of dye molecules into simpler and less harmful compounds. The specific mechanism of action depends on the type of enzyme used and the structure of the dye molecule. Here are some examples of enzymatic dye degradation mechanisms:

Peroxidase-mediated dye degradation:

Peroxidases catalyze the oxidation of dyes by using hydrogen peroxide as a co-substrate. The peroxidase enzyme converts the dye molecule into a free radical, which can then react with other molecules to form simpler compounds such as carbon dioxide and water [22].

Laccase-mediated dye degradation:

Laccases are oxidoreductase enzymes that can oxidize a wide range of substrates, including phenolic compounds and aromatic amines. Laccases can also break down azo dyes by oxidizing the azo bond, which results in the formation of smaller, less toxic compounds [23].

Azoreductase-mediated dye degradation:

Azoreductases are enzymes that can reduce the azo bond in azo dyes, which breaks down the dye into smaller, less toxic compounds. The reduction reaction involves the transfer of electrons from the azo bond to the azoreductase enzyme.

Xylanase-mediated dye degradation:

Xylanases are enzymes that can break down the hemicellulose component of plant materials that may be present in textile wastewater. This can result in the release of bound dyes from the plant material, making them more accessible for further degradation by other enzymes [24].

Protease-mediated dye degradation:

proteases are enzymes that can degrade proteins that may be present in textile wastewater. Some dyes can be bound to proteins, and the degradation of the protein component can release the dye for further degradation by other enzymes.

Lipase-mediated dye degradation:

Lipases are enzymes that can degrade fats and oils that may be present in textile wastewater. Some dyes can be bound to fats and oils, and the degradation of these components can release the dye for further degradation by other enzymes.

Overall, enzymatic dye degradation is a complex process that involves the use of different types of enzymes to catalyze the breakdown of dye molecules into simpler and less harmful compounds. The specific mechanism of action depends on the type of enzyme used and the structure of the dye molecule.

5. ENGINEERING ASPECTS OF DYE DEGRADATION

The engineering aspects of dye degradation refer to the practical application of various dye degradation methods in the textile industry. Here are some examples of the engineering aspects of dye degradation with multiple references:

Reactor design: The design of the reactor is an important aspect of dye degradation because it affects the efficiency and cost of the process. Different reactor designs, such as batch reactors, continuous-flow reactors, and packed-bed reactors, have been used for dye degradation. The choice of reactor design depends on the specific dye degradation method and the characteristics of the effluent [25].

Process optimization: Process optimization involves adjusting the operating parameters of the dye degradation process to maximize its efficiency and minimize its cost. The operating parameters include the concentration of reactants, pH, temperature, and reaction time. Optimization techniques, such as response surface methodology and artificial neural networks, have been used to determine the optimal operating conditions for dye degradation [26].

Scale-up: Scale-up refers to the process of transferring a laboratory-scale dye degradation process to a larger industrial scale. Scale-up requires careful consideration of the reactor design, operating parameters, and cost analysis. Pilot-scale studies are often conducted to evaluate the feasibility of scale-up [27].

Integration with other treatment processes: Dye degradation can be integrated with other treatment processes, such as biological treatment, to achieve better overall treatment efficiency. Integration of dye degradation with biological treatment has been shown to be effective in reducing the toxicity and colour of textile effluent [28].

Overall, the engineering aspects of dye degradation involve the design, optimization, scale-up, and integration of dye degradation processes with other treatment processes to achieve effective and efficient treatment of textile effluent.

6. CHALLENGES IN DYE DEGRADATION

Although dye degradation methods have shown great promise in treating textile effluent, there are still some challenges that need to be addressed. Here are some examples of challenges in dye degradation with multiple references:

Dye stability and degradation efficiency: Some dyes are highly stable and difficult to degrade, which can lead to incomplete degradation and the formation of by products that may be more toxic than the original dye. Therefore, it is important to develop effective degradation methods that can efficiently degrade stable dyes [29].

Toxicity of by products: Some degradation methods can produce toxic by-products, which can negate the benefits of the treatment process. Therefore, it is important to identify and characterize the by products produced during dye degradation to ensure that they are not more toxic than the original dye [30].

High operating cost: Some dye degradation methods require expensive equipment, chemicals, or energy sources, which can increase the operating cost of the treatment process. Therefore, it is important to develop cost-effective dye degradation methods that can be implemented on a large scale [31].

Dye mixtures: Textile effluent often contains a mixture of different dyes, which can complicate the treatment process. Some dyes may be more easily degraded than others, and the presence of one dye may affect the degradation of another dye. Therefore, it is important to develop degradation methods that can efficiently degrade mixtures of different dyes [32].

Overall, the challenges in dye degradation include the stability and toxicity of dyes and their by-products, the high operating cost of some degradation methods, and the presence of dye mixtures in textile effluent. Addressing these challenges will require the development of more effective and cost-efficient dye degradation methods that can efficiently degrade different types of dyes and their mixtures while minimizing their toxicity and cost.

7. CONCLUSION

In conclusion, the efficient degradation of dyes in textile industry effluents is an important issue that needs to be addressed to minimize the environmental impact of textile manufacturing. There are various physical and chemical methods available for dye degradation, each with its own advantages and limitations. Although these methods have shown great potential for treating textile effluent, there are still some challenges that need to be addressed, such as the stability and toxicity of dyes and their by-products, the high operating cost of some degradation methods, and the presence of dye mixtures in textile effluent. To overcome these challenges, researchers need to focus on developing more effective, cost-efficient, and environmentally friendly methods for dye degradation. This can be achieved through the use of advanced technologies such as nanotechnology, biotechnology, and photocatalysis. Additionally, it is important to conduct thorough toxicity testing to ensure that the by-products of the degradation process are not more harmful than the original dye. Efficient dye degradation is essential for the sustainability of the textile industry and the protection of our environment. Continued research and development in this field will lead to the implementation of more effective and sustainable treatment methods that can be used by textile manufacturers to minimize their environmental impact.

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