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Challenges in Effluents Treatment Containing Dyes

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Abstract

The textile industry uses various types of synthetic dyes and releases a number of hazardous industrial pollutants which are highly coloured, toxic and carcinogenic. Wastewater containing such pollutants leads to an increase in the biochemical and chemical oxygen demand of the wastewater bodies and causes various diseases in humans, animals and plants. Different wastewater treatment techniques such as physical, chemical and biological processes are in vogue. The different dyes used in textile industries and their removal techniques from wastewater streams are broadly reviewed in this monograph.

Introduction

Industrial development is very important for the economic growth of a country. Improper treatment of wastewater from industries before disposal poses severe environmental as well as health issues to the surrounding communities [1,2]. Most pharmaceutical, textile, food, paper & pulp and cosmetic industries use synthetic dyes for colour [3].

Textile dyeing is as old as the civilization itself. With the advent of the modern textile industry, this field has developed into a separate area of study. Water is principally used in dyeing and product finishing procedures [4]. One of the biggest challenges that the textile industry is facing is that of effective and low-cost treatment of the large number of coloured effluents that the industry produces. Discharge of these effluents without effective treatment, into the environment, poses a serious threat to human health as well as to other living organisms [5,6,7]. Apart from dyes effluent is loaded with various detergents, chlorides, nitrates, suspended solid materials, organic and inorganic pollutants, acid, bases, mordants and heavy metal ions which are highly polluting [8,9].

Classification of Dyes

Dyes can be defined as complex unsaturated organic compounds which have diverse chemical structures. The dyes which are generally used in textile industries may be categorized into a number of classes such as Direct dye, Acid dye, Basic dye, Mordant dye, Azo dye, Reactive dye, Disperse dye, Sulphur dye and vat dye [10,11]. Non-biodegradable, toxic and carcinogenic nature of some of these dyes makes them harmful, even in small concentrations. Discharge of dyes contaminated water in the environment causes substantial health concerns such as skin rashes, headaches, dizziness, breathing difficulty, nausea, body fatigue, lack of concentration, irregular heartbeat, seizures and it may even lead to cancer [12].

There are three different types of fibers used in the manufacture of various textile products: cellulose fibers, protein fibers and synthetic fibers. Each type of fiber is dyed with different types of dyes. Cellulose fibers are used to dye fabrics such as cotton, rayon, linen, hemp and lyocell and the dyes used are Reactive dyes, direct dyes, naphthol dyes and indigo dyes. Protein fibers include fabrics such as wool, angora, cashmere, silk and mohair and the dyes used for such fibers are Acid dyes and Lanaset dyes. Fabrics such as nylon, acrylic, acetate, Ingeo, polyester, spandex and polypropylene come under the class of synthetic fibers and these are dyed using Disperse dyes, Basic dyes and Direct dyes.

Techniques for Colour Removal

To reduce the environmental impact of dyes, a variety of methods to treat wastewater has been established and are currently in use. Based on the mode of dye removal and the types of dye to be removed, the techniques may be broadly categorized as physical, chemical and biological methods (including the use of algae, bacteria and fungi species) [22,23]. All technologies have their own merits and demerits.

Physical Methods

Various dye removal methods such as adsorption, membrane filtration, nanofiltration, ultrafiltration or microfiltration, ion exchange, irradiation electrokinetic, coagulation-flocculation and reverse osmosis are included in the physical category of classification. Adsorption is considered one of the most efficient and frequently used decontamination methods for the treatment of effluent-containing wastewater [24]. The process of adsorption due to its cost-effectiveness, and eco-friendly nature applies to a number of dyes. Different materials like activated carbon, fly ash, red mud, rice husk, clay, ground nut shells charcoal, sawdust, bentonite, zeolite and siliceous materials can act as adsorbents [25,26]. Membrane filtration is one of the physical methods which are applicable for wastewater treatment due to its low space requirement. Processes like reverse osmosis, nanofiltration, ultra-filtration or microfiltration are also based on membrane processes [27].

Chemical Methods

Chemical dye removal methods involve the use of chemicals in the dye removal processes. Methods like electrochemical destruction, electro floatation, use of Fenton reagent, Ozonation, advanced oxidation, electrokinetic coagulation, photochemical and ultraviolet irradiation are some of the examples of chemical methods. These techniques are efficient in dye removal however, high running cost, use of chemicals, secondary pollution, the requirement of proper equipment, high electricity consumption in some of the processes and sludge disposal are some of the drawbacks of these techniques [28,29,30].

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Different types of Dyes used in textile industries

Dye	Application	Characteristic	Examples (name of dyes)	Ref.
Acid Dyes	Silk, Wool, Nylon and Modified acrylic fibers	Water-soluble anionic dye	Tartrazine, Acid Brown 14, Fuchsin Acid, Acid Chrome Blue K, Orange 4, Eosin Y, Acid Yellow 42, Acid Brown 4	[13]
Basicdyes	Leather, Paper, Wood, Wool, Silk, Linen, Hemp, Cotton, Rayon and Straw	Cationic dyes, water soluble	Methylene Blue, Crystal Violet, Bismarck Brown, Methyl Green, Rhodamine 110, Basic Blue 17, Magenta Green Crystal	[14]
Direct Dyes	Cotton, Linen, Rayon, Wool, Silk and Nylon	Water soluble	Sirius Yellow GC, Direct Yellow 50, Direct Violet R, Direct Red 26, Direct Blue 86, Direct Green 1	[15]
Disperse Dyes	Polyester, Nylon, Acetate and Triacetate fibers	Sparinglysoluble in water	Disperse Orange 1, Disperse Blue 77, Disperse Violet 33, Disperse Blue BGL, Disperse Black JW, Disperse Violet RN	[16]
Vat Dyes	Cotton, Linen, Rayon, Wool, Silk and Nylon	Water insoluble	Indigo, Vat Red 32, Vat Brown GG, Flavanthrone, Pigment Red 195, Vat Orange 15, Indanthrene Black BBN, 9 Brown 9	[17]
Mordant Dyes	Cotton, Wool or Other protein fiber	Water soluble	Alizarin, Mordant Orange 10, Mordant Red 9, Mordant Black 11	[18]
Reactive Dyes	Cotton, Wool or Silk	Water soluble	Monochlorotriazine, Anthraquinone, Reactive Brown 2, Procion Yellow H-E3G, Cibacron Brilliant Yellow 3G-P Etc	[19]
Solvent Dyes	Plastics, gasoline, Oils and Waxes	Insoluble in water	Solvent Red 24, Solvent Red 26, Solvent Red 164, Solvent Yellow 124, Azo Anthraquinone, Phthalocyanine	[20]
Sulphur Dyes	Cotton, Linen, and Rayon	Insoluble in water	Sulphur Yellow 9, Sulphur Blue CV, Indophenol, Sulfur Black, Sulphur Yellow 9, Sulphur Red 6, Sulfur Brilliant Green, Sulphur Blue CV	[21]

Technique	Advantages	Disadvantages	Ref.
Ion Exchange	Easy regeneration and no loss of adsorbent	Only applicable for ionic dyes	[37]
Fenton Reagent Technique	No energy required to activate H_2O_2	Difficulty in sludge disposal	[38]
Ozonisation	O_3 can be applied in its gaseous state and it does not increase the volume of wastewater and sludge	Short half-life period	[39]
Enzyme Degradation	Cheap, high efficiency, reusable, less toxic and able to degrade dyes using enzymes	Low stability, less effective in harsh industrial conditions	[40]
Microbial Cultures	maximum of 30 hours to decolourise dye which is considered fast	Applicable to limited number of dyes	[41]
Fungal Degradation	Fungus breaks down dye molecules and consumes them for self-growth, applicable to numerous dyes, flexible method	Unstable system, large reactors and nitrogen requirement, lengthy growth phase	[42]
Anaerobic Degradation	Applicable to azo and other water-soluble dyes	Release of harmful gases like CH_4 and H_2S	[43]
Electrokinetic Coagulation	Efficiently feasible, economical	Sludge production	[44]
Oxidation	Break dye moleculesto CO_2 and H_2O, use of catalyst, complete degradation of dyes, short reaction time	Costly, difficultoxidizing agent activation, H_2O_2 handling, pH dependent, catalyst requirement	[45]
Photochemical	Minimum sludge production, no foul smell	Large number of by-products	[46]
Adsorption	Widely used dye removal method, re-generable adsorbent.	Some of adsorbent may have low surface area and may have high cost	[47]

Biological Methods

Biological removal methods are generally known as conventional methods of wastewater treatment. This is a low-cost, environmentally safe method which generates less amount of secondary pollutants as compared to other techniques. Biological techniques involve the degradation of dyes into less toxic compounds using biological materials like algae, bacteria, yeast as well as fungi [29]. The ability of bacteria to survive in both aerobic and anaerobic conditions helps to break down the bonds present in complex dye molecules (e.g-N=N-). Bacterial species like *Bacillus subtilis, Clostridium perfringens, Pseudomonas aeruginosa, Klebsiella pneumonia, and Escherichia coli* can degrade harmful dyes. Algae species such as *Chlorella pyrenoidosa, Spirogyra Rhizopus, Cosmarium sp., Nostoc muscorum* (blue green algae), *Ulva lactuca, Sargassum*, are effective degradation of azo dyes and compounds containing -OH, RCOO, $-NH_2$, and PO_4^{3-} into simple compounds [31,32,33]. Some studies reported that biological methods perform well in reducing the chemical oxygen demand and turbidity of the solution but are less efficient to remove colour [34].

Among different methods, physical methods due to their least usage of chemicals, simplicity and efficiency are most used for wastewater treatment when compared with chemical and biological methods.

Factors Affecting the Removal Process

The applicability of each pollutant removal technique is always governed by several factors. A number of factors like pH, time, polarity, suspended solids, chemical oxygen demand, biochemical oxygen demand, adsorbent/adsorptive interaction, particle size and temperature are there which determine the technical and economic feasibility of any dye removal technique. Therefore, it is crucial to observe and compare reaction factors with the standard parameters as many chemicals used in the textile industry cause problems with the ecosystem and human health [35,36].

Each pollution removal method has its limitations. Complete dye decolourization cannot be sufficiently achieved by one single process. A dye removal method should be simple, low cost, and easy to operate with fewer chemical requirements. The dye removal method must be able to efficiently remove a number of dyes from wastewater in a short period without producing secondary pollution. Therefore, to overcome these problems, dye removal strategies in industrial settings essentially consist of a combination of diverse techniques [48,49,50].

Conclusion

The purpose of different treatment methods used in the textile industry is to give the lowest water pollution and enhance environmental safety. Since there is no single technique which is fully capable or can be completely adaptable for all types of textile effluents containing dyes. Therefore, a combination of different methods like physical, chemical and biological methods are used to treat pollution-loaded water. Treatment of textile effluent containing a small volume of pollutants is effective using physical and oxidation methods. Due to low cost and less sludge production, biological methods have more preference than chemical methods. Therefore, to reduce the effect of toxic compounds, the research on pollution control should also focus on quantitative description of combination processes instead of only qualitative discussion.

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