

An overview of the use of photocatalysis in the environmental control of textile effluent

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Abstract. This study offers a thorough examination of the use of photocatalysts in textile effluent management for environmental goals. Textiles are produced on a big scale to fulfil human requirements and have become an essential part of daily life. Clothes and textiles are essential components of contemporary civilisation and human existence. As the market for textile products has grown, so too has the number of textile mills and the waste they produce, creating a significant global pollution problem. Numerous materials used in the textile industry provide serious risks to human health and the environment. A vast array of speciality chemicals, like as softeners, stain-releasing agents, saturating agents, fixing agents, and different organic dyes, are used in the textile industry. This technique has resulted in the discharge of colourants and other dye-laden effluents into river systems. This research focusses on three key areas: (i) the definition and operation of textile wastewater; (ii) the use of photocatalysts in textile wastewater treatment; and (iii) the impact of nanophotocatalysts and irradiation absorption rate on the treatment efficiency of textile wastewater. One effective way to lower the number of pollutants in textile effluent before releasing it into aquatic bodies is by photocatalytic treatment. This tactic aids in achieving the main objectives of preserving the integrity of water resources and lessening the negative environmental effects of waste from the textile sector.

1 Introduction

Environmental management carries out studies and offers professional advice on hazardous particle control, ecosystem preservation, and the sustainable use and conservation of natural resources. Environmental management is to implement programs to safeguard and maintain the local plant and animal life as well as control and avoid pollution, such as the release of garbage into rivers [1]. One major environmental problem on a worldwide scale is water contamination. The production of paper, dyes, textiles, cosmetics, and food releases large volumes of various colours into the sky [2]. The textile industry employs a variety of basic materials, compounds, pigments, processes, and apparatus to produce a wide range of

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threads, including materials such as nylon, polyester [3]. These effluents damage public and environmental health. Textile wastewater contains too much salt. Textile dyeing effluent contains toxic, mutagenic, and carcinogenic substances, making treatment difficult. Anaerobic-advanced treatment is used for textile dyeing wastewater. [18]. Many procedures have been explored to remove the tint. Traditional textile wastewater treatment does not fulfil Environmental Standard standards, hence highly effective and creative treatment methods must be investigated. The accelerated oxidation process is crucial to current wastewater treatment. The study tested hybrid nanocomposites' photocatalytic ability to remove methyl orange (MO) and methylene blue (MB) colours from textiles using visible and ultraviolet light. The best visible and UV active photocatalyst. Wastewater cleanup is costly; thus, firms avoid it. Textile wastewater was untreated [4].

It is crucial to guarantee that the water used in the manufacturing of textiles is clean. It is difficult to totally prevent wastewater generation, nevertheless. Thus, before the textile industry's effluent is discharged into the environment, it must be thoroughly studied and treated scientifically [3]. We thus made the decision to write a succinct review article on methods for handling wastewater from textiles. The review article seeks to provide readers with a greater knowledge of the fundamental ideas behind a particular topic based on our current understanding of the subject.

2 Textile wastewater

2.1 Process in textile industry

Economies worldwide are substantially impacted by the textile sector; however, China, India, Pakistan, Bangladesh, and Malaysia are the most susceptible. Malaysia's textile sector was historically one of its biggest three producers of foreign revenue. Nevertheless, it currently holds the distinction of the industry with the most rapid rate of growth. Figure 1 illustrates the textile exports' expansion rate from 2013 to 2021. This statistic suggests that the wastewater from the textile industry will increase, given the significance that water plays in the manufacture of textiles. The moist technique for textile processing employs water as an agent for colouring, printing, and additional finishing steps. The fundamental flowchart that shows how wastewater from industrial textile processes is treated is shown in Figure 2. Water is used extensively in textile factories throughout the manufacturing process; a kilogramme of textiles typically needs between 100 and 200 litres of water [6]. Twenty percent of water pollution comes from wastewater discharged by the textile industry, which also significantly contributes to environmental damage. Every year, 50,000 metric tonnes of dyes are thought to be released into the environment [7]. Figure 2 illustrates the precise procedure for waste creation from the textile industry.

The textile business uses natural fibres, such as cotton, flax, and wool, as well as synthetic fibres, including polyester and polyamide, derived from petroleum. Natural fibres are derived from fibres such as wool flax, and cotton. The threads undergo many procedures, including cleaning, whitening, mercerising, colouring, coating, the printing process, and finishing, to produce the final textile material. A diverse array of dyes, such as azo, vat, reactive, acid, basic, sulphur, direct, and metal complex colours, is used to colour threads [3]. Surface water and groundwater sources in the vicinity get contaminated when textile effluent is released into the environment. According to research, textile dyeing industry effluent (TDE) is a term used to describe wastewater from the textile industry [8].

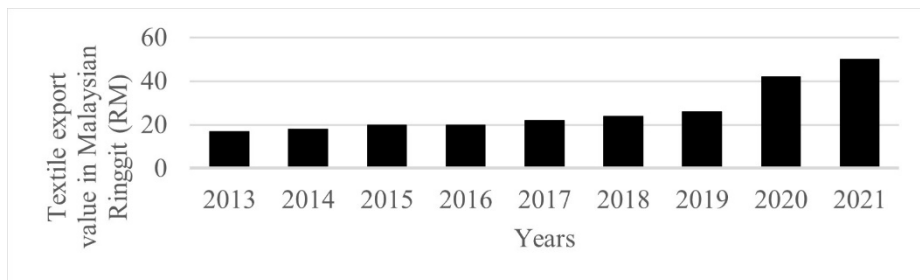


Fig. 1. The growth rate of textile exports from 2013 to 2021 [5].

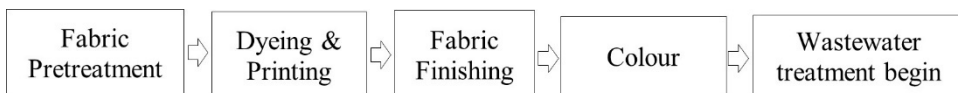


Fig. 2. The process of treating wastewater generated by the textile industry.

2.2 Pollutants in textile wastewater

Ten to fifteen percent of the pigments used end up directly in wastewater bodies. Organic molecules make up many synthetic colours, which are pollutants. These contaminants might be halogenated, non-halogenated, or therapeutic in origin. Methylene blue (MB), often known as basic blue 9, is a halogenated substance. Because it has a positive charge and can dissolve in water, this dye is cationic. It transforms into chloride ions when it meets water-based solutions. It is used in a few disciplines, including as biology, chemistry, and medicine. In the textile industry, MB is mostly used as a brightening agent for textile textiles [4]. The pollutants present in textile wastewater are listed in Table 1 of the relevant literature.

Table 1. Compilation of pollutants found in textile effluent as documented in literature.

Pollutants	Reference
Materials like colourants, salts, adsorbed organic halogens (AOX), and heavy metals	[9]
Paint, pigments, and salts with an oil basis	[10]
Significant amounts of various inorganic and organic substances, involving sodium hydroxide, sodium sulphate, calcium chloride, calcium nitrite, urea, ethyl alcohol, toluene, cyclohexane, propanoic acid, benzene, tetratriacontane, and phthalic acid solution, as well as unresolved colours, the chlorogenic waste products, phthalates, as well as toxic metals, were discovered and determined to be dangerous substances..	[3]

Many of the contaminants found in wastewater from textile industries are resistant to biological breakdown. According to research by [9], the complicated properties of textile wastewater may be partly responsible for the ineffectiveness of textile wastewater treatment facilities. Wastewater eventually becomes the primary source of pollution in the environment. It contaminates sources of groundwater as well as surface water. The content that follows offers a thorough examination of the effects brought about by textile wastewater and is supplemented by relevant references:

1. The wastewater produced by the textile industry is a complex combination of pigments and chemical compounds, including dispersion colours, that have the potential to cause birth defects, cancer, and genetic abnormalities [7].
2. Chemicals can travel across international boundaries, endure in the environment, and build up in living things at various food chain levels. This puts people's safety at danger. The health of the populace is in danger. Aquatic ecosystem disturbance, eutrophication, and aesthetic degradation are caused by the release of coloured wastewater into the environment [8].
3. The textile sector is mostly responsible for the release of hazardous and nonbiodegradable coloured dye effluents into surrounding water sources. Water that has colour prevents light from penetrating, which has an adverse effect on photosynthesis, a process that is essential to sustaining the biotic environment [4].
4. The effluent damages the aquatic ecology by obstructing light passage into the water and drastically lowering oxygen levels owing to hydrosulfides [11]. This makes it a major environmental concern. A recognised carcinogen, organically bonded chlorine makes up around 40% of colourants used worldwide. Chemicals that we breathe in or absorb via our skin volatilise into the atmosphere, causing allergic responses and perhaps harming unborn children [11].

3 Photo-catalytic treatment

Colour removal methods that are often used include chemical, biological, and physical treatment. Treatment techniques for textile wastewater often include flocculation, membrane filtration, adsorption, and sedimentation. The many types of photosynthetic oxidation processes (AOPs) include those based on hydroxyl radicals, ozone, UV light, and sulphate radicals [12]. The AOP category as it is presented in the literature is shown in Figure 3. A novel technique for breaking down dyes is photocatalytic degradation (PD), which makes use of nanophotocatalysts [7]. Compared to absorption, which just moves contaminants to other phases, they are more effective. To synthesise AOP photocatalysts, this work used UV and visible lamps that were affordable, long-lasting, and effective [2]. The material known as semiconductors consumes energies through photocatalysis, transferring electrons from the valence band (VB) to the conduction band (CB), generating positive holes. Positive holes working with electron donors such as water-based might oxidise organic pollutants or generate hydroxyl radicals. Both processes produce OH radicals. Superoxide radical is created when light-generated electrons are absorbed by the oxygen in the solution. Innocuous molecules are created when pollutants react with radicals that have generated on the catalyst [12]. Even though photocatalysis is durable, ecologically sound, and kind to the environment, there is still a need for cheap and readily available raw materials [4]. One Advanced Oxidation Process (AOP) that has the potential to eliminate hazardous pollutants is semiconductor photocatalysis. This technique is low-maintenance, renewable energy-based, and doesn't generate any secondary pollutants [13].

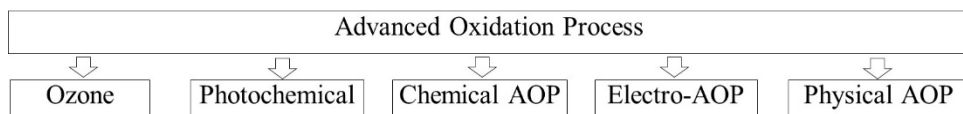


Fig. 3. Categories of Advanced Oxidation Processes.

4 Catalyst

When exposed to light, organic contaminants are broken down by photocatalysts. In photocatalytic reactions, pollutants are broken down by free radicals produced by sunshine and a catalyst [13]. Catalysts are used in photocatalysis. The photons of visible or ultraviolet light that interact with the reaction site and the crystal structure of the catalyst both affect how quickly the reaction proceeds. Catalysts with certain electronic structures work as sensitizers for redox processes triggered by light. The electrical structure is defined by the empty conduction band and full valence band. Photons become absorbed by valence band electrons whether the energy from the arriving sunlight is equivalent to or below the band gap. Electrons will travel in the conduction band. Still unresolved are gaps in the outer rings. Their significance cannot be overstated. These holes cause compounds that give electrons to oxidise. When water (H₂O) comes into contact with these pores, it produces hydroxyl, a potent oxidant. When water absorbs an electron in the conduction band, the superoxide ion is created. Redox processes are thus started by this unbound electron. Pairs of electrons and holes have the ability to oxidise and reduce molecules into the required products when they meet the catalyst's requirements.

ZnO/TiO₂ photocatalysis has been used in 70–80% of wastewater treatment studies, according to the literature. TiO₂ is used as a photocatalyst in several environmental science applications. The ability of photocatalysts to extract colour from textile effluent was found to be restricted [7]. One important drawback is UV irradiation activation, since there is only 3-5% UV radiation in the sun light spectrum [13]. With the aid of nanocatalysts composed of semiconductors such as TiO₂, SnO₂, WO₃, V₂O₅, and ZnO, organic contaminants in water may be broken down by photocatalysis [12]. Although photogenerated electrons and holes recombine quickly due to slower charge separation, nanostructures are nonetheless often utilised as photocatalysis catalysts. This problem may be resolved by doping, attaching flaws to nanocatalysts, modifying noble metals, or integrating with other semiconductors.

Catalyst composition may be changed using several techniques. As an example, introducing metal or non-metal ions into the semiconductor may raise the energy levels of impurities, reduce the band gap, and improve the absorption of visible light [14]. Electric charge separation is made easier by combining semiconductors into heterojunctions. By comparing semiconductors with various band edge locations, one may restrict recombination by encouraging charge transfer. Co-catalysts, including noble metals (Pd, Pt) or metal oxides (CoO_x, NiO_x), may enhance semiconductor performance. This process generates redox active sites and improves charge separation [15]. These methods have been used by scientists to create semiconductor heterojunctions and nanocomposites with improved visible light absorption, charge separation, and water treatment capabilities. CuFe₂O₄, a visible light photocatalyst, has been used. It breaks down organic contaminants in textile wastewater. CuFe₂O₄ photocatalytically eliminated organic colours from wastewater at high rates when exposed to visible light [16]. For instance, after 80 minutes of exposure to visible light, methylene blue (MB) was destroyed at a rate of 98.2% by a ceramic fabric photocatalyst loaded with CuFe₂O₄. In a different research, biochar and CuFe₂O₄ were used as catalysts in the presence of light to treat wastewater containing developing pollutants. The findings of the research were positive [17]. Therefore, it is necessary to research various nanophotocatalysts to increase treatment efficacy.

5 Conclusion

Degradation of the environment is the main problem worldwide. Water contamination poses a health risk to people. 20% of Earth's water is contaminated by untreated textile effluent. Technologies for treating wastewater using photocatalytic dyes are being researched to

develop more eco-friendly solutions. To summarise the components of textile wastewater, photocatalysts as a treatment for textile wastewater, and the best photocatalysts based on their benefits, this research was conducted. To find the most effective method for cleaning textile effluent, scientists are combining nanomaterials with nanofiltration. Provide novel approaches for photocatalyst renewal and more efficient photocatalytic materials. To improve the use of solar energy and raise the effectiveness of pollutant-catalyst reactions, further research is needed. This is important since our objective is to reduce the effects of pollutants while cutting costs associated with operations and putting environmentally friendly treatment methods into place. It is crucial to consider how the textile industry affects the economy and the environment, just as an energy analyst would. This industry's uncontrolled effluent discharge has negatively impacted the environment even if it has surely helped the economy expand. It is crucial for scholars to draw attention to practical solutions that may boost the economy and preserve the environment.

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References

1. P. Sewerniak et al., Environmental effects of a management method used after fire on development of temperate Scots pine ecosystem: a 15-year study from Poland. *Environmental Management*. **72**, 978–990 (2023). <https://doi.org/10.1007/s00267-023-01843-8>
2. M. Khodamorady et al., Fe₃O₄@BNPs@ZnO–ZnS as a novel, reusable and efficient photocatalyst for dye removal from synthetic and textile wastewaters. *Heliyon*. **9**, 16397 (2023). <https://doi.org/10.1016/j.heliyon.2023.e16397>
3. R. Sharma et al., Constructed wetlands for textile wastewater remediation: A review on concept, pollutant removal mechanisms, and integrated technologies for efficiency enhancement. *Chemosphere*. **290**, 133358 (2022). <https://doi.org/10.1016/j.chemosphere.2021.133358>
4. P. Manojkumar et al., Development of surface-modified galvanised steel as an immobilised photocatalyst for textile wastewater treatment. *Inorganic Chemistry Communications*. **145**, 110056 (2022). <https://doi.org/10.1016/j.inoche.2022.110056>
5. K. Farhana et al., The Scenario of Textile Industry in Malaysia: A Review for Potentiality. *Mater Circ Econ*. **4**, 20 (2022). <https://doi.org/10.1007/s42824-022-00063-5>
6. M. A. El-Liethy et al., New insights for tracking bacterial community structures in industrial wastewater from textile factories to surface water using phenotypic, 16S rRNA isolates identifications and high-throughput sequencing. *Acta Tropica*. **238**, 106806 (2023). <https://doi.org/10.1016/j.actatropica.2022.106806>
- H. R. Dihom et al., Photocatalytic degradation of disperse azo dyes in textile wastewater using green zinc oxide nanoparticles synthesized in plant extract: A critical review. *Journal of Water Process Engineering*. **47**, 102705 (2022). <https://doi.org/10.1016/j.jwpe.2022.102705>
8. S. Kalai Selvi et al., Treatment of textile dyeing wastewater using a low-cost adsorbent. *Materials Today: Proceedings*. **45**, 2214785323019272 (2023). <https://doi.org/10.1016/j.matpr.2023.04.031>
9. J. M. Bidu et al., Textile wastewater treatment in anaerobic reactor: Influence of domestic wastewater as co-substrate in color and COD removal. *South African Journal of Chemical Engineering*. **43**, 112–121 (2023). <https://doi.org/10.1016/j.sajce.2022.10.007>

10. K. Jin et al., Composite membranes with multifunctionalities for processing textile wastewater: Simultaneous oil/water separation and dye adsorption/degradation. *Separation and Purification Technology*. **320**, 124176 (2023). <https://doi.org/10.1016/j.seppur.2023.124176>
11. S. Khan et al., Environmental and Health Effects of Textile Industry Wastewater. *Environmental Deterioration and Human Health: Springer Netherlands*. **21**, 55–71 (2014). https://doi.org/10.1007/978-94-007-7890-0_4
12. Z. Al-Sharji et al., Plasmon enhanced photocatalytic degradation of 4-chlorophenol using zinc oxide nanorods decorated with gold nanoparticles as supported catalysts under natural sunlight. *Chemical Engineering and Processing - Process Intensification*. **188**, 109369 (2023). <https://doi.org/10.1016/j.ccep.2023.109369>
13. M. Antonopoulou et al., Photocatalytic degradation of organic micropollutants under UV-A and visible light irradiation by exfoliated g-C₃N₄ catalysts. *Science of The Total Environment*. **892**, 164218 (2023).
<https://doi.org/10.1016/j.scitotenv.2023.164218>
14. F. Imtiaz et al., Semiconductor Nanocomposites for Visible Light Photocatalysis of Water Pollutants in Concepts of Semiconductor Photocatalysis. *IntechOpen*. **72**, 1565 (2019). <https://doi.org/10.5772/intechopen.86542>
15. D. Zheng et al., Nanocatalysts in photocatalytic water splitting for green hydrogen generation: Challenges and opportunities. *Journal of Cleaner Production*. **414**, 137700 (2023). <https://doi.org/10.1016/j.jclepro.2023.137700>
16. D. Cheng et al., Loading CuFe₂O₄ onto ceramic fabric for photocatalytic degradation of methylene blue under visible light irradiation. *Ceramics International*. **48**, 1256–1263 (2022). <https://doi.org/10.1016/j.ceramint.2021.09.210>
17. J. Leichtweis et al., Wastewater containing emerging contaminants treated by residues from the brewing industry based on biochar as a new CuFe₂O₄/ biochar photocatalyst. *Process Safety and Environmental Protection*. **150**, 497–509 (2021). <https://doi.org/10.1016/j.psep.2021.04.041>
18. Al-Tohamy et al., A critical review on the treatment of dye-containing wastewater: Ecotoxicological and health concerns of textile dyes and possible remediation approaches for environmental safety. In *Ecotoxicology and Environmental Safety*. **231**, 113160 (2022). <https://doi.org/10.1016/j.ecoenv.2021.113160>