

Nanotechnological Approaches for Treating Textile Effluent: Environmental Aspects and Opportunities - A Review

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Abstract

Textile industry is known for its significant contribution to the global economy; however, it poses considerable environmental challenges due to extensive water use and the generation of textile effluent as wastewater into the environment. Unregulated discharge of untreated/inadequately treated textile wastewater into water bodies and on the land leads to health hazards. Conventional wastewater technologies are quite expensive and even inefficient to treat all wastewater generated from clusters of textile units. In recent decades, advanced and innovative technologies have been explored to treat wastewater effectively with sustainable approaches including the application of nanomaterials. The present study presents a comprehensive review of the advancements in the utilization of nanomaterials for treating textile effluents. Nanomaterials are characterized by unique properties at the nanoscale and have shown great potential in improving wastewater treatment efficiency. Objective of the present review was to outline the current state-of-the-art developments in the application of nanomaterials and their corresponding treatment mechanisms in the context of textile wastewater. Present review encompasses a wide range of nanomaterials, including nanoparticles, nanocomposites, and nanocatalysts, and their diverse roles in addressing various challenges associated with textile wastewater, such as color removal, organic pollutant degradation, and disinfection for recycling and reuse of treated water. Furthermore, it also examines the challenges and opportunities of nanotechnology in its treatment processes. Finally, the review concludes with an outlook on future research directions, emphasizing the need for interdisciplinary collaborations, optimization of nanomaterial-based processes, and the development of reliable and cost-effective methods for textile effluent treatment and disposal.

Keywords

Nanotechnology, Nanomaterials, Textile effluent, Water quality, Wastewater treatment

Introduction

The idea of life without water is incredible, as water is a natural resource on earth, and the availability of water in its purest form is so important to humans and other living beings. About 70% of the Earth's surface is covered with water [1, 2]. 97.5% of all water is salt water and the remaining 2.5% is considered fresh water, of which about 68.9% is in the form of ice, snow caps, and glaciers. Furthermore, groundwater accounts for 30.8% of freshwater, of which only 0.3% is readily accessible [3, 4]. Water pollution is currently the world's biggest problem, caused by rapid population growth, industrialization, urbanization, inadequate sewage treatment, industrial waste, marine waste dumping problems, radioactive waste, and some agricultural practices vary [3-6]. Approximately 1.2

billion people worldwide do not have access to safe drinking water, 2.6 billion people struggle to provide basic sanitation, and millions of people, especially children, have unsafe and polluted water. You are at risk from the introduction [7-9]. The textile industry plays an important role in the global economy, providing employment opportunities and contributing to the national GDP. Textile wastewater is characterized by its complex composition, containing various contaminants such as dyes, surfactants, salts, heavy metals, and other chemicals used in textile production [10]. If untreated textile wastewater is released into water bodies without proper treatment, it will have serious impacts on the environment and human health [11, 12]. These wastewaters contain non-biodegradable dyes that can persist for long periods in aquatic ecosystems, causing water pollution and adverse effects on ecological balance. The presence of toxic substances in fiber wastewaters poses a risk to human health as they can enter the food chain, accumulate in aquatic organisms, and ultimately affect human consumers [11-13]. To reduce the environmental impact of textile effluent, traditional textile effluent treatment methods including physical, chemical, and biological processes have been adopted. However, these methods often reach their limits in effectively removing the complex contaminant mixtures in textile wastewater. Challenges with traditional treatment methods include high operating costs, poor removal efficiency, and the generation of secondary pollutants during the treatment process [12, 13-17].

In recent years, nanotechnology has developed as a promising approach to wastewater treatment, offering innovative solutions to overcome challenges faced by traditional methods. The emerging field of nanotechnology offers potential water purification proposals with low cost, high labor efficiency in pollutant removal, and reusability [18]. Nanomaterials possess unique properties such as strong mechanical properties, porosity properties, hydrophilicity, nanosized, large surface area, high reactivity, and strong solution mobility [19], it is therefore ideal for wastewater treatment. Various nanomaterials have been reported to successfully remove some heavy metals and various harmful microorganisms [19-22]. Currently, the World Health Organization reports that water pollution kills about 1.7 million people and that water-related diseases are reported to cause 4 billion different health problems each year. Table 1 shows various water pollutants, their sources and their adverse effects on humans and the environment.

Nanomaterials such as nano-photocatalysts, nano-motors, nano-membrane, nanoparticles, nano-adsorbents, nano-composites, and nanofibers show promising capabilities in adsorption, catalysis, advanced oxidation, membrane filtration, ion exchange, and other treatment processes [33]. These nanotechnology approaches demonstrate improved efficiency in removing various contaminants, including dyes, heavy metals, and organic contaminants, from textile wastewater [34]. The purpose of this review article is to examine in detail the opportunities, challenges, and prospects of nanotechnology approaches to textile wastewater treatment. The composition and properties of textile effluents are discussed, emphasizing their impact on the environment and human health [35, 36]. It also highlights the limitations of conventional treatments and the need for more effective alternatives. In addition, this paper explores the potential of nanotechnology in addressing challenges related to textile wastewater treatment, such as the use of different types of nanomaterials and their mechanisms for removing contaminants. By understanding the opportunities and benefits of nanotechnology, researchers, and practitioners can develop innovative and sustainable solutions for textile wastewater treatment. These solutions have the potential to reduce the environmental impact of textile industry wastewater, protect ecosystems and protect human health [37, 38].

Textile Effluent and Environmental Concerns

Textile wastewater has received a great deal of attention due to its composition and the potential environmental and health risks it poses. Textile wastewater quality is characterized by the presence of various contaminants, including dyes, which are one of the main contaminants [39, 40]. Dyes used in the manufacture of textiles are often complex organic compounds that are resistant to biodegradation [41]. As a result, these dyes can persist in water bodies for long periods, which can lead to the deterioration of water quality and the destruction of aquatic ecosystems. In addition, textile wastewater can contain surfactants, salts, heavy metals, and other chemicals used in textile processing, all of which can have negative environmental impacts [42, 43].

Wastewater quality and contaminants

Textile wastewater contains a wide range of contaminants that contribute to its complex composition. Dyes are one of

Table 1: Various water pollutants, their sources, and adverse effects.

Sources of pollutants	Effects	Ref.
Bacteria, viruses	Waterborne diseases	[23]
Agricultural chemicals	Directly affects the freshwater resources	[24]
Cultivation of land, demolition, and mining operations	Directly affects aquatic insects and fish spawning	[25]
Metal compounds, trace elements, inorganic salts, heavy metals, mineral acids	Aquatic flora and fauna, human health issues	[26]
Insecticides, herbicides	Problematic aquatic life, carcinogenic	[27]
Municipal wastewater	Caused water and air pollution	[28]
Different isotopes	Teeth, bones, and skin allergy	[29]
Different fertilizers, plant debris	Eutrophication	[30]
Marine debris	Plastic waste, water pollution	[31]
Domestic wastewater	Waterborne diseases	[32]

the main pollutants in textile wastewater [44]. These colorants are typically complex organic compounds that are resistant to biodegradation and therefore persist in the aquatic environment. Due to the variety of dyes used in the manufacture of textiles, different colors, and chemical structures enter the wastewater, making it particularly difficult to treat [44, 45]. In addition to dyes, textile wastewater may also contain surfactants, salts, heavy metals, and other chemicals used in various stages of textile processing. These pollutants can pose significant challenges in achieving effective wastewater treatment, as their properties are diverse and can adversely affect the environment and human health [46].

Effects on environment and human health

In addition to dyes, textile wastewater may also contain surfactants, salts, heavy metals, and other chemicals used in various stages of textile processing. These pollutants can pose significant challenges in achieving effective wastewater treatment, as their properties are diverse and can adversely affect the environment and human health [47, 48]. High concentrations of dyes in textile effluents can lead to dissolved oxygen depletion in the aquatic environment, adversely affecting the survival of aquatic organisms and the health of the ecosystem as a whole. Furthermore, the presence of dyes and other contaminants can interfere with the photosynthetic process of aquatic plants, impeding their growth and reducing primary productivity [49]. These changes in aquatic ecosystems can have cascading effects, leading to loss of biodiversity and disruption of ecosystem balance. The impact of textile wastewater is not confined to water bodies. Soil degradation and contamination can occur when textile wastewater spills onto the floor. Contaminants in textile wastewater can seep into the soil and endanger soil fertility and plant growth. Heavy metals in particular can accumulate in soil, persist for long periods, and enter the food chain. This pollution not only affects agricultural productivity but also poses risks to groundwater quality as pollutants can leak into aquifers and threaten drinking water sources. Regarding human health, exposure to textile wastewater can lead to a variety of health problems [50-52]. Direct contact with contaminated water can cause dermatitis, allergic reactions, and respiratory illness. Additionally, consuming seafood from bodies of water contaminated with fiber wastewater can expose humans to harmful chemicals. Toxic substances can accumulate in the body of aquatic organisms, increasing the risk of human exposure to harmful pollutants through the consumption of contaminated seafood [53, 54].

Conventional Methods of Textile Effluent Treatment and Challenges

Traditional textile wastewater treatment methods have contributed significantly to reducing the environmental impact of textile wastewater. However, these methods face several challenges that affect their efficacy in achieving comprehensive and efficient therapy [55]. Physical processes such as sedimentation, filtration, and coagulation have limitations when dealing with dissolved and colloidal contaminants such as dyes and complex organic compounds. It can remove large particles and suspended solids but may not address the wide range of

contaminants found in textile wastewater. Chemical processes such as chemical precipitation, oxidation, and disinfection are often used in combination with physical methods to improve contaminant removal. While effective in certain cases, they often produce large amounts of sludge and by-products that require proper management and disposal [55, 56]. Additionally, some chemical processes may not be effective in controlling certain refractory contaminants, creating challenges in achieving complete treatment. Biological treatment methods, such as activated sludge treatment and accumulated wetlands, use microorganisms to biodegrade organic pollutants. These methods can be used to effectively remove organic compounds. However, there may be limitations when dealing with certain stubborn contaminants such as dyes and some hazardous chemicals. Biological treatments are also sensitive to changes in wastewater composition and may require longer treatment times compared to physical and chemical methods. Additionally, traditional treatment methods face challenges in terms of cost efficiency and sustainability [56, 57]. Operating and maintenance costs can be high, especially in large processing plants. The poor removal efficiency of certain contaminants, especially complex dyes, remains a major challenge. Due to the large amount of sludge generated during processing, proper management and disposal strategies are required. There is also concern about the potential release of secondary pollutants and by-products into the environment during the treatment process. Alternative approaches, such as nanotechnology methods, are being investigated to overcome these challenges and improve the efficiency and sustainability of textile wastewater treatment [57, 58]. These approaches overcome the limitations of conventional methods and offer opportunities for more effective removal of contaminants in textile wastewater.

Nanotechnological Approach for Treating Textile Effluent

Nanotechnology has emerged as a promising and innovative approach to treating textile wastewater. It offers unique opportunities and advantages when it comes to efficiently removing contaminants, overcoming the limitations of traditional methods. The use of nanomaterials and their application in various treatment processes show great potential for improving the treatment efficiency and sustainability of textile wastewater [58, 59]. Different kinds of wastewater and its treatment by nanomaterials are shown in figure 1.

Nanotechnology offers several advantages in textile wastewater treatment. First, nanomaterials have a high surface area-to-volume ratio, which increases reactivity and adsorption capacity. This property enables efficient adsorption and removal of contaminants such as dyes and heavy metals from wastewater [59, 60]. Furthermore, nanomaterials can be functionalized or modified to selectively target specific contaminants, making them highly effective in treating complex mixtures in textile wastewater. For example, different treatment mechanisms by nanomaterials for different pollutants are shown in table 2.

Various nanomaterials have been investigated for textile wastewater treatment. These include nanoparticles, nanofi-

bers, nanocomposites, nano/micromotors, and nanocatalysts. Nanoparticles, such as titanium dioxide (TiO₂) and zerovalent iron nanoparticles, exhibit photocatalytic and adsorptive

properties and are useful in the decomposition and removal of organic pollutants [71, 72]. Nanofibers, such as carbon nanotubes and nanofiltration membranes, provide selective filtration and separation capabilities, enabling efficient removal of nanoparticles and dissolved contaminants. Nanocomposites made by combining different nanomaterials exhibit a synergistic effect and improve removal efficiency [73, 74]. Nanocatalysts, such as metal-based nanoparticles, enable advanced oxidation processes to break down stubborn pollutants. It is now believed that nano/micromotors can convert energy from various sources into mechanical power to achieve specific goals through various mechanisms. Some common examples of nanomotors and their functions as shown in table 3. Various applications of nanomembranes and their advantages and disadvantages are shown in table 4.

Figure 2 shows the different mechanisms that nano/micromotors use to deal with water contamination. Either way, these revolutionary engines are driven without fuel or fuel sources (acoustic, magnetic, or electric) and have some important and exciting applications [74].

Application of nanomaterials in textile effluent treatment

Nanomaterials are used in various treatment processes for textile wastewater. Adsorption and ion exchange processes are commonly used, where nanomaterials act as adsorbents

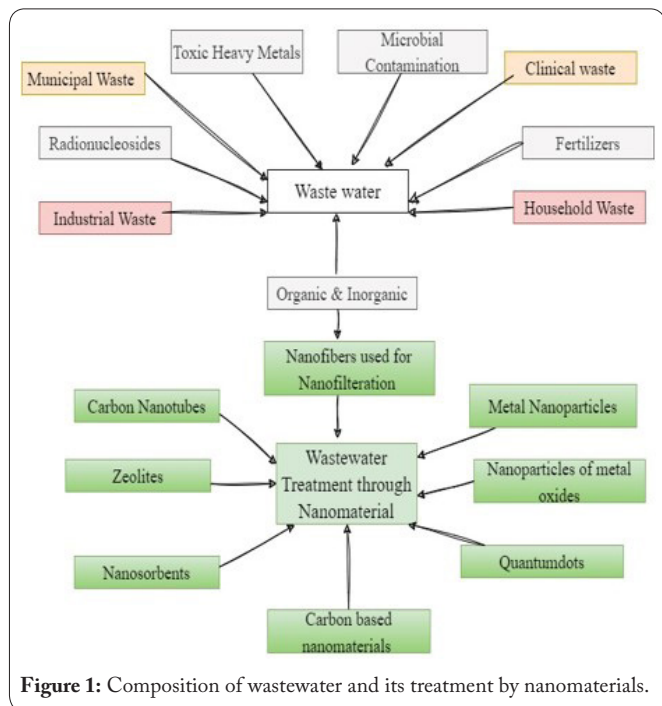


Figure 1: Composition of wastewater and its treatment by nanomaterials.

Table 2: Treatment of textile effluent by nanomaterial through different mechanisms.

Nanoparticles	Target pollutants	Mechanism of treatment	Limitation	Positive aspects	Ref.
TiO ₂	Organic pollutants	Photocatalysis	High operating cost, high sludge	Less toxic, solubility in water, photostability	[61]
Fe	Anions, heavy metals	Adsorption, reduction	High sludge production, difficult sludge disposal	<i>In-situ</i> water remediation, less operating cost	[62]
Bimetallic	Dichlorination	Adsorption, reduction	A high amount of sludge production	Higher rate of reactivity	[63]
Nanofiltration, nano-membranes	Organic and inorganic substances	Nanofiltration	High cost, membrane fouling	Low pressure	[64]
Magnetite	Heavy metals, organic compounds	Adsorption	The magnetic field required for separation	Easy to distinct, no sludge production	[65]
Metal-sorbing vesicles	Heavy metals	Adsorption	better metal affinity, reuse option, higher selective uptake profile,	Less stable	[66]
Micelles	Organic waste	Adsorption	Excellent affinity for hydrophobic, <i>In-situ</i> treatment	High cost	[67]
Dendrites	Heavy metals, organic compounds	Encapsulation	Easy to separate, renewable, high-binding capacity	High cost	[68]
Nanotube	Anionic organic pollutants	Adsorption	Good chemical, and mechanical properties, exclusive electrical properties	Low adsorption process	[69]
Nano-clay	Anionic organic pollutants	Adsorption	High surface area, high stability	Better surface and pore volume	[70]

Table 3: Different nano/micromotors and their applications.

Nanomotors	Working mechanism	Applications	Ref.
Zn/Al/Pd micromotors	speed-pH dependence	Controlling of pH	[75]
Hydrophobic agglomerates of pollutants	Highly active surface-tension	Pollutants diffusion	[76]
Polymer capsule motors	Highly active surface-tension	Oil remediation	[77]
Pt/Au nanomotors	Ag-induced acceleration	Detection of Ag ions	[78]
Ag-based Janus MIP microparticles	Molecularly imprinted polymer recognition	Solid extraction	[79]
Pt/Au nanomotors	DNA hybridization using Ag nanoparticle	DNA detection	[80]
Bubble-propelled Pt and Ag-based micro engines	High fluid efficiency	Oxidative detoxification of nerve agents	[81]
Bubble-propelled Pt and Ag-based micro engines	High diffusion, Fenton reaction	Organic pollutants degradation	[82]
SAM-modified Pt micro engines	Hydrophobic nature of oil droplets	Oil removal	[83]
Ir/SiO ₂ Janus motors	Speed dependence	Hydrazine detection	[84]
Pd nanoparticles	pH dependence	Monitoring of pH	[85]

Table 4: Different applications of nanomembranes with their advantages and disadvantages.

Types of nanomembranes	Application	Advantage	Disadvantage	Ref.
Nanofiber membranes	Water handling separate filtration devices, ultrafiltration, prefiltration, filter cartridge	Good permeate efficiency, excellent permeability, tailor-made, bactericidal	Conceivably discharge of nanofibers, pore blocking	[86]
Nanocomposite membranes	Entirely dependent on composites	The high tendency of hydrophilicity, better porosity, high catching resistance, good mechanical, and thermal stability	Oxidation of nanomaterials requires resistant substances used to release nanoparticles	[87]
Aquaporin-based membranes	Less pressure desalination	Improved ionic selectivity and better porosity	Poor mechanical stability	[88]
Self-assembling membranes	Ultrafiltration	Homogeneous nanopores membranes	Laboratory scale availability only	[89]
Nanofiltration and membranes	Color, reduction of hardness, odor	Less pressure required, charge-based repulsion, better selectivity	Membrane blocking	[90]

or ion exchangers, effectively removing contaminants through surface interactions. Catalytic decomposition and oxidation mechanisms involve the use of nanocatalysts to decompose complex organic pollutants into simpler, less hazardous substances. Photocatalysis and advanced oxidation processes use the photocatalytic properties of nanomaterials such as TiO₂ nanoparticles in combination with ultraviolet light or other energy sources to decompose organic pollutants [91, 92].

Mechanism of textile effluent treatment by nanomaterials

The mechanisms of textile wastewater treatment by nanomaterials include various processes such as physisorption, chemical reactions, and photocatalysis. Physisorption relies on the affinity of nanomaterials for contaminants and enables efficient removal of contaminants from wastewater. Chemical reactions facilitated by nanocatalysts [92, 93] include the decomposition of complex pollutants and their conversion to simpler, less toxic compounds. Photocatalysts utilize the energy of light absorbed by nanomaterials to produce reactive oxygen species that can decompose organic pollutants through oxidation processes. The use of nanotechnology in textile

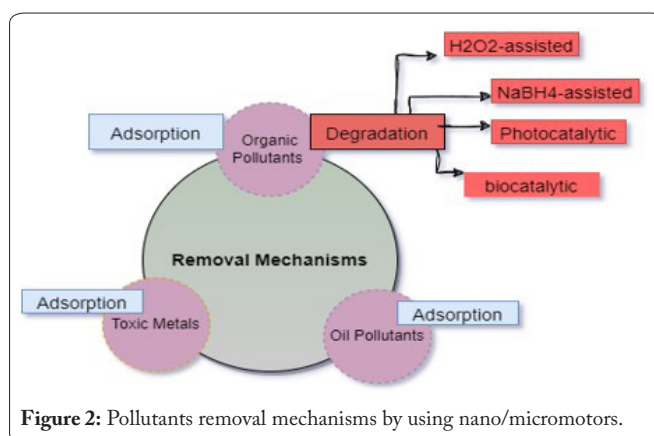


Figure 2: Pollutants removal mechanisms by using nano/micromotors.

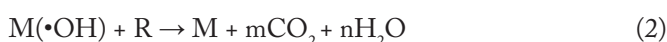
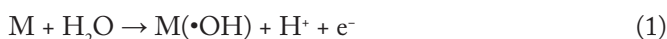
wastewater treatment offers great potential for efficient and sustainable removal of contaminants. However, there are challenges and considerations related to nanomaterial synthesis, stability, recovery, and potential environmental impacts. These challenges need to be addressed to ensure the safe and responsible application of nanotechnology approaches in textile wastewater treatment [93].

Adsorption and ion exchange process

Adsorption in textile wastewater treatment is the physical attraction and binding of contaminants to the nanomaterial surface. Activated carbon, for example, is commonly used as an adsorbent. Featuring a large surface area and porous structure, it can effectively trap contaminants such as dyes, heavy metals, and organic compounds [93, 94]. Contaminants adhere to the activated carbon surface through van der Waals interactions, electrostatic interactions, or chemical bonds and are removed from the wastewater. Ion exchange is another process used in textile wastewater treatment. Modified nanoparticles such as ion exchange resins or zeolites are used as ion exchangers. These materials have specific functional groups that selectively attract and trap certain ions from the wastewater and give other ions in return. For example, ion exchange resins can selectively remove heavy metals such as copper (Cu) and chromium (Cr) ions from wastewater by replacing them with less harmful ions such as sodium (Na) and hydrogen (H⁺) [94, 95].

Catalytic degradation and oxidation

Catalytic decomposition and oxidation use nanocatalysts to facilitate the decomposition and transformation of organic pollutants in textile wastewater. For example, nanoparticles made of palladium (Pd) and platinum (Pt) act as catalysts in these processes. In catalytic decomposition, nanocatalysts enable chemical reactions that break down complex organic pollutants into simpler, less toxic compounds. For example, Pd nanoparticles can catalyze the reduction of chlorinated organic compounds in textile wastewater, transforming them into less harmful substances [58]. In catalytic oxidation, nanocatalysts facilitate the oxidation or reduction of pollutants. For example, Pd nanoparticles can transfer oxygen molecules to pollutants to promote the oxidation of organic compounds and cause their decomposition. Similarly, Pt nanoparticles can catalyze the reduction of specific pollutants by accepting electrons from them [96]. In the absence of chemicals, anodic oxidation is a straightforward approach to electrochemically produce hydroxyl (•OH) radicals. The oxidation of water directly produces •OH radicals at the anode surface. High O₂ evolution overvoltage anodes and a proposed catalytic mechanism for the reaction also include the production of heterogeneous hydroxyl radicals M(•OH) by water electrolysis and the oxidation of organic materials, as shown in equation 1 and 2 [97].



Where M is the anode material.

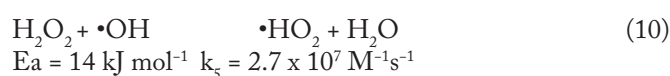
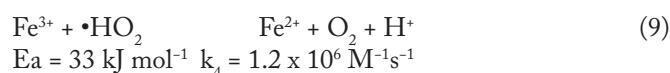
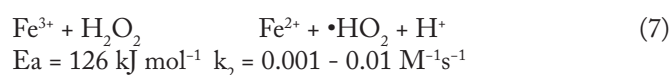
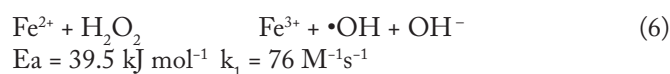
Photocatalysis and advanced oxidation process

Photocatalysis and advanced oxidation processes use the photocatalytic properties of nanomaterials such as TiO₂ nanoparticles in combination with light or other energy sources to decompose organic pollutants [98]. In photocatalysis, TiO₂ nanoparticles absorb photons from a light source and generate electron-hole pairs. These excited electron-hole pairs participate in redox reactions with impurities adsorbed on the external of the nanoparticles or the surrounding water. For ex-

ample, TiO₂ nanoparticles can oxidize organic compounds by donating electrons to them, causing decomposition. The photocatalytic process produces highly reactive •OH radicals that attack and decompose organic pollutants as shown in equation 3 to 5 [99, 100].



Advanced oxidation processes involve the generation of highly reactive species such as hydrogen peroxide (H₂O₂), •OH radicals, and ozone (O₃) to decompose pollutants. For example, the addition of H₂O₂ or O₃ to textile wastewater in the presence or alone of TiO₂ nanoparticles can trigger a series of oxidation reactions leading to the decomposition of organic pollutants [101, 102]. An important type of chemical advanced oxidation processes is the Fenton method, which involves applying a mixture of a soluble iron(II) salt and H₂O₂, often known as the Fenton's reagent, to eliminate and degrade contaminants. The technique was developed as a result of Fenton's groundbreaking research on the oxidation and destruction of tartaric acid using a mixture of H₂O₂ and Fe²⁺. The complex radical and chain mechanism governing the catalytic breakdown of H₂O₂ by iron salts is described [102] in equation 6 to 10.



These examples show how adsorption and ion exchange, catalytic decomposition and oxidation, photocatalysis, and advanced oxidation processes can effectively remove and degrade contaminants in textile wastewater, resulting in sustainable water quality and the environment. It shows how the performance can be improved [103, 104].

Challenges and Future Prospects

Despite advances in conventional and nanotechnology approaches, textile wastewater treatment still faces several challenges to be addressed. Moreover, exploring prospects will help further improve the efficiency, sustainability, and overall effectiveness of textile wastewater treatment processes. Textile wastewater treatment faces delicate challenges, but looking to the future could lead to further improvements in efficiency and effectiveness [105, 106]. A major challenge is

cost efficiency, as advanced processing technologies, including nanotechnology approaches, can be costly to implement and operate for the small textile industry. Wider deployment requires finding cost-effective solutions and optimizing resource utilization. It also deals with stubborn contaminants and more. Complex and persistent compounds in textile wastewater pose significant challenges, and the development of innovative strategies and techniques to efficiently degrade or remove these contaminants is critical [107, 108]. Another challenge lies in scaling up and integrating nanotechnology approaches into existing therapeutic infrastructures. Many of these approaches are still in the research and development stage, and commercialization requires careful consideration of technical and operational challenges. Additionally, the environmental impact of nanomaterials used in textile wastewater treatment needs to be thoroughly evaluated. Assessing the fate, behavior and potential toxicity of nanomaterials is critical to ensure their safe and responsible use [109]. Regulatory compliance is also an important consideration. Meeting regulatory standards for treated wastewater discharge is critical to minimizing pollution and ensuring compliance [110, 111]. Treatment processes and techniques that consistently meet and exceed these standards must be developed. Prospects for textile wastewater treatment include advances in nanomaterials and technology. Continued research and development of advanced nanomaterials with enhanced properties can greatly enhance therapeutic efficacy. New nanomaterials or modifications of existing nanomaterials enable more efficient removal and degradation of contaminants [112, 113]. A hybrid approach that combines multiple treatment techniques is expected to improve overall treatment efficiency. By integrating nanotechnology and conventional methods, a comprehensive solution to combat diverse contaminants in textile wastewater can be achieved [114]. Research into the potential for energy and resource recovery from textile wastewater can contribute to the sustainability of treatment processes. Technologies such as anaerobic digestion, biogas generation, and nutrient recovery can turn waste into valuable resources.

Optimizing treatment processes through advanced monitoring systems, automation, and artificial intelligence increases operational efficiency, reduces energy consumption, and minimizes human error [115, 116]. Strengthening policies and regulations on textile wastewater treatment is critical. Encouraging the adoption of advanced therapeutic technologies through incentives and regulations can promote sustainable practices and ensure compliance. Addressing these challenges and leveraging prospects will contribute to the development of more efficient, cheaper, and more sustainable methods of treating textile wastewater [117]. Cooperation among researchers, industry players, policymakers, and regulators are essential to drive innovation, implement best practices and protect the environment while supporting the growth and competitiveness of the textile industry [117].

Conclusion

In summary, textile wastewater poses significant environmental risks due to its wastewater quality and the

presence of various contaminants. Traditional textile wastewater treatment methods face challenges in effectively removing contaminants and complying with legal standards. However, the use of nanotechnology offers a promising solution to address these challenges. Nanotechnological approaches such as adsorption, ion exchange, catalytic decomposition, oxidation, and photocatalysis show great potential in the treatment of textile wastewater. Nanomaterials exhibit excellent adsorption capacity, catalytic activity, and photocatalytic efficiency due to their unique properties and large surface area. It can effectively remove a wide range of contaminants such as dyes, heavy metals, and organic compounds from textile wastewater. Despite advances in nanotechnology-based textile wastewater treatment, some challenges remain. Cost efficiency, treatment of refractory pollutants, scale-up, environmental impact assessment, and regulatory compliance are some of the key issues that need to be addressed. However, the field has promising prospects. Continued research and development of advanced nanomaterials, hybrid treatment approaches, energy and resource recovery, process optimization, and strong policy frameworks to further improve efficiency, sustainability, and regulatory compliance of textile wastewater treatment processes you can. Efforts to address these challenges and harness prospects will require collaboration among researchers, industry players, policymakers, and regulators. By working together, we can develop and implement innovative and sustainable solutions that ensure the protection of the environment and human health while supporting the growth and competitiveness of the textile industry. In summary, the use of nanotechnology approaches offers great potential for the treatment of textile wastewater, and concerted efforts can reduce the environmental impact of textile production, resulting in a more sustainable and responsible textile industry can do.

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Conflict of Interest

None.

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