

Banned Chemicals Used in Textile Industries: Environmental Impacts, Occupational Health Hazards and Remedial Measures

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ABSTRACT

The textile industry is a major global sector that relies heavily on chemical inputs during processes such as dyeing, printing and finishing, leading to significant environmental and health concerns. Chemicals including azo dyes, heavy metals, pesticides, and auxiliary agents are widely used, with a considerable portion discharged into wastewater due to incomplete fixation on fibers. Azo dyes are of particular concern as they can degrade into toxic aromatic amines, while heavy metals persist and bioaccumulate in ecosystems. Additionally, pesticide use in cotton cultivation and auxiliary chemicals further contribute to soil and water contamination. These pollutants can degrade water quality, disrupt aquatic ecosystems, and pose risks to human health. To address these challenges, various treatment methods such as biological processes, adsorption, membrane filtration, and advanced oxidation have been developed. Sustainable approaches, including eco-friendly dyes, bioremediation, and cleaner production practices, are increasingly being adopted to reduce the environmental footprint of textile manufacturing.

Keywords: Bioremediation, Nanotechnology, Advanced oxidation processes, Green chemistry, Environmental sustainability

INTRODUCTION

The textile industry is one of the largest global manufacturing sectors, playing a pivotal role in economic development, employment generation, and international trade. Textile production involves multiple stages, including fiber preparation, spinning, weaving, dyeing, printing, and finishing, each contributing to the final product quality. Among these, wet processing stages are particularly resource-intensive, requiring substantial inputs of water and chemicals. A wide variety of chemical substances are used to enhance the color, durability, and functional performance of textile materials; however, many of these compounds raise environmental and health concerns due to their potential toxicity (Kant, 2012). A significant proportion of these chemicals does not bind effectively to textile fibers and is released into wastewater, resulting in effluents containing complex mixtures of organic and inorganic pollutants that can adversely affect aquatic

ecosystems (Holkar *et al.*, 2016). A schematic overview of the key stages of textile processing and the corresponding chemical inputs is presented in Fig. 1, highlighting the complexity and chemical intensity of the production chain.

One of the most critical environmental issues associated with textile processing is the discharge of synthetic dyes into water bodies. These dyes are designed for high stability and resistance to degradation, which, while beneficial for fabric quality, limits their breakdown in natural environments. Azo dyes, the most widely used class, are of particular concern due to their ability to degrade into aromatic amines, some of which are toxic, mutagenic, or carcinogenic (Bafana *et al.*, 2011). Consequently, regulatory bodies such as the European Chemicals Agency and certification systems like the OEKO-TEX Association have established restrictions to limit the use of hazardous dyes in textile products.

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Fig. 1 : Major stages of textile processing and associated chemical inputs

In addition to dyes, textile manufacturing involves other hazardous substances, including heavy metals, pesticides used in fiber cultivation, and various auxiliary chemicals. Heavy metals originating from dyes, pigments, and catalysts are particularly problematic due to their persistence and tendency to accumulate in environmental systems (Tchounwou *et al.*, 2012). Similarly, pesticide use in cotton cultivation contributes to soil and water contamination, while auxiliary chemicals further increase the pollutant load in textile effluents. These concerns have driven the development of advanced wastewater treatment technologies such as biological processes, adsorption, membrane filtration, and advanced oxidation, alongside growing interest in sustainable alternatives including eco-friendly dyes and cleaner production practices. This chapter therefore provides an overview of key hazardous substances in the textile sector and examines their environmental impacts along with current strategies for mitigation.

Banned Azo Dyes in Textile Industry

Synthetic dyes are widely used in textile manufacturing due to their ability to produce a broad range of colors, maintain high color fastness, and remain cost-effective for large-scale production. Among these, azo dyes represent the most dominant class, characterized by the presence of an azo linkage ($-N=N-$) connecting aromatic structures, which enables the formation of vivid and stable colors (Bafana *et al.*, 2011). Their versatility, ease of synthesis, and capacity to generate diverse shades such as red, yellow, and black have contributed to their extensive use across both natural and synthetic fibers, accounting for nearly 60–70% of global dye consumption

(Pinheiro *et al.*, 2004). The mechanism of reductive cleavage of azo dyes leading to the formation of aromatic amines is illustrated in Fig. 2.

Despite these advantages, certain azo dyes pose environmental and health risks due to their ability to undergo reductive cleavage under anaerobic conditions, forming aromatic amines with toxic, mutagenic, or carcinogenic properties (Chung, 2016). Compounds such as benzidine and related amines have been linked to serious health concerns, prompting regulatory restrictions in many regions. Authorities such as the European Chemicals Agency and certification bodies like the OEKO-TEX Association have established limits on azo dyes capable of releasing hazardous amines, leading to the phase-out of dyes such as Direct Black 38 and Direct Blue 6. To provide a clearer overview of hazardous chemicals used in textile processing, their sources, associated risks, and regulatory status are summarized in Table 1

The presence of these hazardous chemicals highlights the need for strict regulation and adoption of safer alternatives in textile processing. In response, recent research has focused on developing safer and more sustainable alternatives, including natural dyes and biological treatment methods capable of degrading azo compounds. Advancing understanding of their environmental behavior, toxicity, and regulatory control is essential for promoting sustainable textile production and minimizing the ecological impact of dyeing processes.

Heavy Metals in Textile Industries

Heavy metals represent a significant group of hazardous pollutants associated with textile

manufacturing, introduced through dyes, pigments, catalysts, mordants, and finishing agents. These metals, including chromium, copper, lead, cadmium, and mercury, are commonly detected in textile effluents and originate primarily from dyeing and printing processes. While they

enhance dye fixation and fabric performance, their discharge into the environment without proper treatment poses serious contamination risks (Tchounwou *et al.*, 2012) (Fig. 3).

A major concern related to heavy metals is their

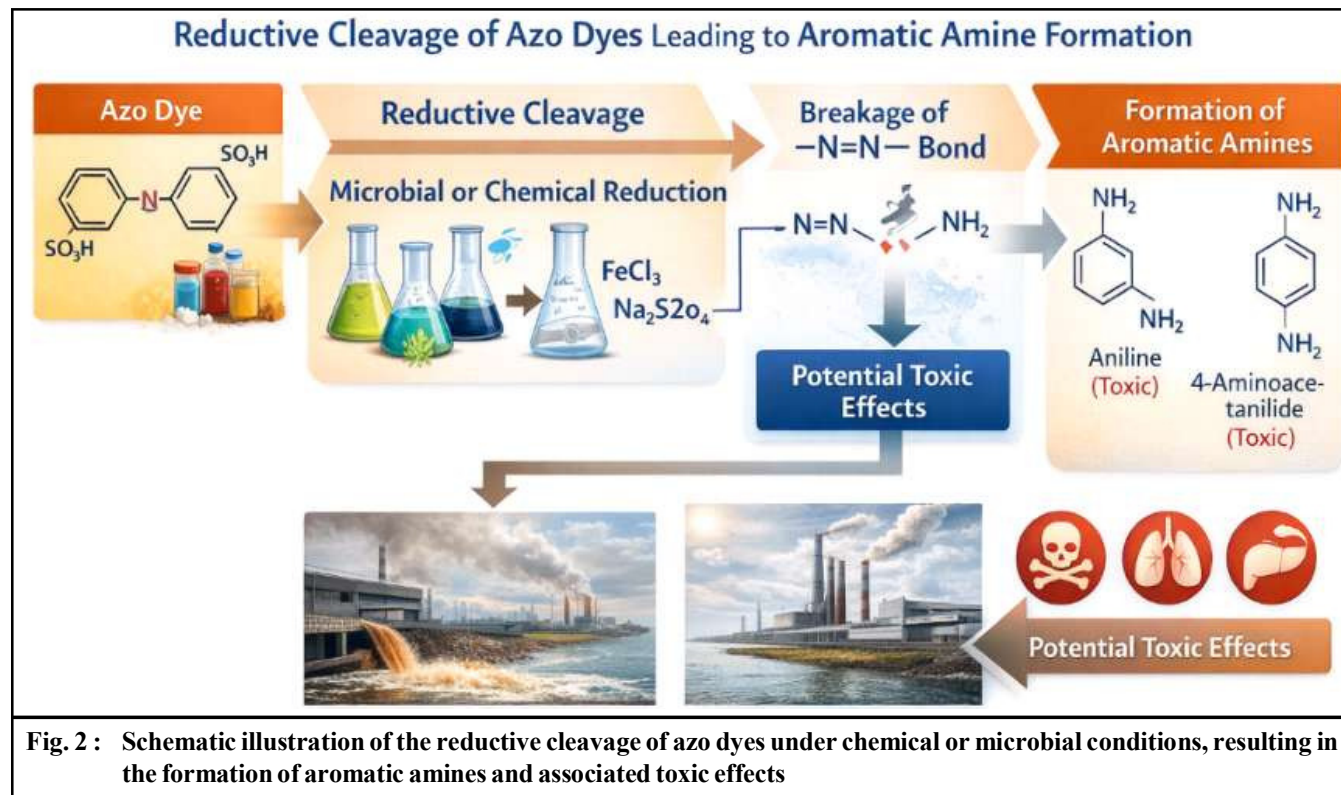


Table 1 : Banned / Restricted Chemicals in Textile Industry

Chemical Name	Source in Textile Process	Major Hazards	Regulation Status
Benzidine-based Azo Dyes	Dyeing (coloring fabrics)	Carcinogenic, mutagenic (forms aromatic amines)	Banned under EU REACH, restricted by OEKO-TEX
Direct Black 38	Dyeing	Releases toxic aromatic amines	Banned in EU and many countries
Direct Blue 6	Dyeing	Carcinogenic breakdown products	Restricted globally
Chromium (Cr VI)	Dyeing, tanning, mordants	Skin irritation, cancer risk, respiratory issues	Strict limits under REACH and OEKO-TEX
Lead (Pb)	Pigments, dyes	Neurotoxic, affects brain and kidneys	Restricted in textile products worldwide
Cadmium (Cd)	Pigments, stabilizers	Toxic, bioaccumulative, kidney damage	Banned/restricted in EU and global standards
Mercury (Hg)	Catalysts, dyes (rare use now)	Highly toxic, affects nervous system	Strictly banned in most applications
Nonylphenol Ethoxylates (NPEs)	Detergents, wetting agents	Endocrine disruptor, aquatic toxicity	Banned/restricted in EU (REACH)
Formaldehyde	Finishing (wrinkle resistance)	Skin irritation, carcinogenic	Limited under OEKO-TEX standards
Organophosphate Pesticides	Cotton cultivation	Neurotoxicity, environmental persistence	Restricted/banned in many countries

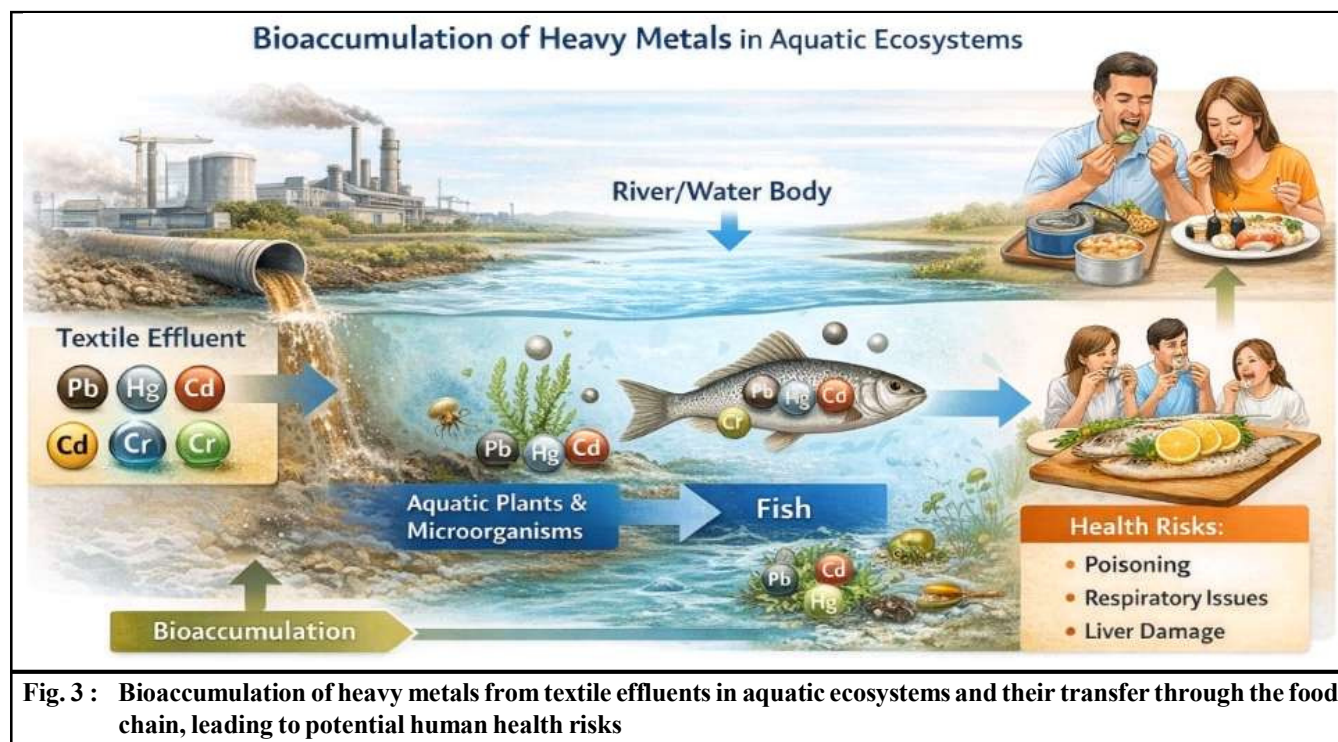


Fig. 3 : Bioaccumulation of heavy metals from textile effluents in aquatic ecosystems and their transfer through the food chain, leading to potential human health risks

persistence in natural ecosystems, as they are not biodegradable and can accumulate in water, soil, and sediments. These metals are readily taken up by aquatic organisms and can enter the food chain through bioaccumulation, posing risks to both ecological systems and human health (Yaseen and Scholz, 2019). Their presence in water bodies can disrupt biological processes, reduce biodiversity, and limit the suitability of water for agricultural and domestic use. Additionally, the use of contaminated wastewater for irrigation can lead to soil accumulation, affecting crop productivity and increasing the risk of human exposure through food systems.

To mitigate these impacts, strict environmental regulations have been established to control heavy metal discharge from industrial activities. Effective wastewater treatment methods, including adsorption, precipitation, membrane filtration, and emerging biological approaches, are essential for reducing metal concentrations in textile effluents. Continued advancements in treatment technologies and sustainable practices are therefore critical for minimizing the environmental footprint of textile industries.

Pesticides Used in Fiber Cultivation

The cultivation of natural fibers, particularly cotton, is fundamental to the textile industry but is closely linked

to intensive pesticide use. Cotton farming is considered one of the most pesticide-dependent agricultural practices, with large quantities applied to control pests such as bollworms, aphids, and whiteflies. While these chemicals help maintain crop yields and ensure a steady supply of raw materials, their excessive use raises significant environmental concerns (Carvalho, 2017).

Pesticides used in cotton production, including organochlorines, organophosphates, carbamates, and pyrethroids, can persist in the environment and spread beyond agricultural fields through runoff, leaching, and atmospheric drift. This leads to contamination of soil and water systems, posing risks to aquatic organisms and non-target species (Aktar *et al.*, 2009). Over time, pesticide residues may accumulate in soils, affecting microbial activity, reducing soil fertility, and disrupting ecological balance by harming beneficial organisms.

To address these challenges, sustainable pest management strategies such as integrated pest management (IPM) and the use of pest-resistant crop varieties have been increasingly adopted. These approaches aim to reduce reliance on chemical pesticides while maintaining agricultural productivity. The transition toward such practices is essential for minimizing environmental impacts and promoting more sustainable textile production systems.

Auxiliary Chemicals Used in Dyeing and Finishing Processes

Auxiliary chemicals are integral to textile processing, particularly in dyeing and finishing operations, where they enhance process efficiency and improve fabric quality. Although they do not impart color directly, these substances facilitate dye uptake, ensure uniform distribution, and help achieve desired properties such as softness, durability, and water repellency. Common dyeing auxiliaries include wetting, dispersing, leveling, and fixing agents, each contributing to consistent and effective dye application.

In finishing processes, auxiliaries such as softeners, resins, flame retardants, and antimicrobial agents are used to enhance the functional and aesthetic characteristics of textiles. However, despite their benefits, some auxiliary chemicals pose environmental risks due to their persistence and toxicity. Compounds such as nonylphenol ethoxylates (NPEs) and formaldehyde-based resins can negatively affect aquatic ecosystems and may act as endocrine disruptors if released into wastewater without proper treatment.

As a result, textile effluents containing auxiliary chemicals contribute significantly to industrial pollution. To mitigate these impacts, effective wastewater treatment and responsible chemical management are essential. Increasingly, research is focused on sustainable alternatives, including biodegradable surfactants and enzyme-based processes, which offer environmentally friendly solutions while maintaining textile performance.

Health Hazards of Textile Workers

Textile workers are routinely exposed to a wide range of chemical substances during production processes such as dyeing, printing, and finishing. These operations involve dyes, heavy metals, solvents, and auxiliary chemicals, with exposure occurring through inhalation, skin contact, or accidental ingestion. Prolonged exposure to these substances can lead to various health risks, particularly in the absence of adequate safety measures.

Skin irritation and allergic reactions are among the most common health issues, often resulting from direct contact with dyes and processing chemicals, including certain azo and reactive dyes. In addition, inhalation of chemical vapors, dye particles, and fiber dust can cause respiratory problems such as irritation, chronic coughing, and asthma-like symptoms, especially in poorly ventilated work environments. Exposure to heavy metals such as

chromium, cadmium, and lead further contributes to occupational health risks, with long-term effects including neurological and kidney disorders (Tchounwou *et al.*, 2012). Workers may also be exposed to pesticide residues present in natural fibers like cotton, adding to cumulative health concerns.

These risks are often exacerbated by inadequate workplace conditions, including limited access to protective equipment, insufficient ventilation, and lack of safety training. Therefore, minimizing occupational hazards requires the implementation of effective safety measures, such as the use of personal protective equipment, improved ventilation systems, regular monitoring of exposure levels, and comprehensive worker training. Strengthening regulatory frameworks is also essential to ensure safer working environments in the textile industry.

Occupational Safety Measures in Textile Industries

Ensuring the health and safety of textile workers requires the implementation of comprehensive occupational safety measures alongside hazard identification. The use of appropriate personal protective equipment (PPE), such as gloves, masks, goggles, and protective clothing, is essential to minimize direct exposure to harmful chemicals during dyeing, printing, and finishing processes. In addition, proper ventilation and air filtration systems should be installed to reduce the concentration of airborne pollutants, including chemical vapors, dust, and fibers, thereby preventing respiratory issues. Regular monitoring of workplace exposure levels and adherence to permissible exposure limits are also critical in maintaining a safe working environment. Furthermore, effective worker training programs should be conducted to educate employees about chemical hazards, safe handling practices, emergency response procedures, and the importance of hygiene. Together, these preventive strategies play a vital role in reducing occupational risks and promoting a safer and healthier textile industry.

Environmental Impacts of Hazardous Chemicals in Textile Industries

The discharge of hazardous chemicals from textile industries represents a significant global environmental concern. Textile processes generate large volumes of wastewater containing complex mixtures of dyes, heavy metals, pesticides, and auxiliary chemicals, which, if released without adequate treatment, can degrade water

quality, contaminate soils, and disrupt ecological systems. Dye pollutants are particularly visible, as even low concentrations can discolor water bodies, reduce light penetration, and impair photosynthetic activity, thereby affecting aquatic life (Yaseen and Scholz, 2019).

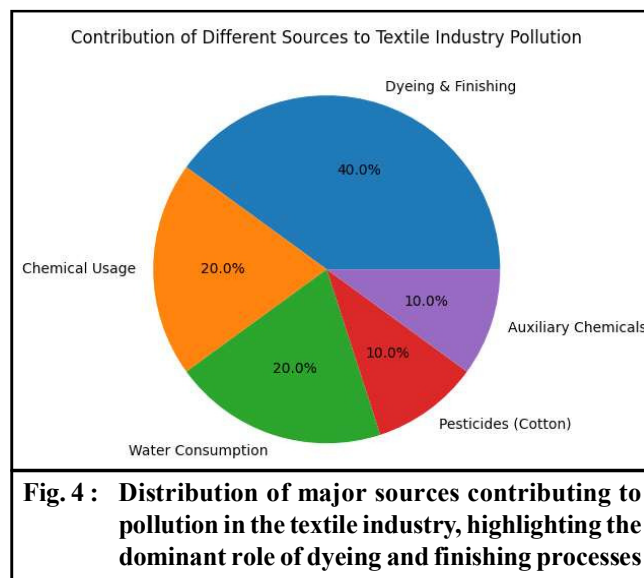
Heavy metals present in textile effluents pose long-term risks due to their persistence and ability to bioaccumulate within food chains, impacting both ecosystems and human health (Tchounwou *et al.*, 2012). In addition, pesticides used in cotton cultivation and auxiliary chemicals from processing stages contribute further to environmental contamination through runoff, leaching, and wastewater discharge. These substances can alter water chemistry, harm aquatic organisms, and interfere with ecological balance, with some compounds exhibiting endocrine-disrupting effects.

Beyond water pollution, textile-related discharges can also lead to soil contamination, affecting microbial activity and agricultural productivity. The cumulative impact of these pollutants results in ecosystem degradation and biodiversity loss. Addressing these issues requires the implementation of effective wastewater treatment technologies, reduced reliance on hazardous chemicals, and the adoption of sustainable and cleaner production practices within the textile industry.

The textile industry contributes to environmental pollution through multiple sources, including dyeing and finishing processes, chemical usage, water consumption, pesticide application, and auxiliary chemicals. Among these, wet processing stages are particularly significant due to their intensive use of water and chemical inputs. Understanding the relative contribution of each source is essential for identifying priority areas for pollution control and sustainable intervention. The distribution of these pollution sources in the textile industry is illustrated in Fig. 4.

The pie chart illustrates the relative contribution of various sources of pollution in the textile industry. Dyeing and finishing processes account for the largest share (40%), primarily due to the extensive use of dyes and chemicals. Chemical usage and water consumption each contribute approximately 20%, reflecting the resource-intensive nature of textile processing. Pesticides used in cotton cultivation and auxiliary chemicals contribute smaller yet significant proportions (10% each), indicating their role in overall environmental contamination.

Remedial Measures and Pollution Control



Technologies in Textile Industries

Growing environmental concerns associated with textile manufacturing have driven the development of strategies aimed at reducing chemical pollution and improving wastewater management. Textile effluents contain complex mixtures of dyes, heavy metals, pesticides, and auxiliary chemicals, making their treatment particularly challenging. As a result, both conventional and advanced remediation approaches have been developed to enhance pollutant removal efficiency. The major stages involved in textile wastewater treatment, including primary, secondary, and tertiary processes, are illustrated in Fig. 5.

Effluent treatment plants (ETPs) are widely used in textile industries, employing a combination of physical, chemical, and biological processes. Primary treatments such as screening, sedimentation, and coagulation remove suspended solids, while secondary biological processes utilize microorganisms to degrade organic pollutants, offering cost-effective and environmentally friendly solutions (Holkar *et al.*, 2016). In addition, advanced technologies such as adsorption, membrane filtration, and advanced oxidation processes (AOPs) have shown high efficiency in removing persistent pollutants, including dyes and heavy metals.

Recent research has also emphasized sustainable approaches such as bioremediation, where microorganisms degrade complex contaminants, and the use of eco-friendly dyes and biodegradable auxiliaries to reduce pollution at the source. Furthermore, cleaner



production techniques, water recycling, and zero liquid discharge (ZLD) systems are increasingly being adopted. Overall, integrating advanced treatment technologies with sustainable practices and regulatory measures is essential for minimizing the environmental impact of textile industries.

Limitations of Current Treatment Methods

Although various wastewater treatment technologies have been developed to mitigate pollution from textile industries, each method presents certain limitations that restrict its overall effectiveness and large-scale applicability. Physical and chemical treatment processes, such as coagulation and precipitation, often generate significant amounts of sludge, which require proper disposal and may pose secondary environmental challenges. Advanced treatment methods like membrane filtration, while highly efficient in removing dyes and heavy metals, are associated with high operational and maintenance costs, as well as issues such as membrane fouling. Similarly, advanced oxidation processes (AOPs) demonstrate strong potential in degrading persistent organic pollutants; however, they are energy-intensive and may involve expensive reagents, limiting their economic feasibility for widespread industrial use.

Biological treatment methods, although environmentally friendly, are often less effective in degrading complex and non-biodegradable compounds such as synthetic dyes. Therefore, despite significant progress, the limitations of existing treatment technologies highlight the need for more cost-effective, sustainable, and integrated approaches for textile wastewater management.

Future Prospects and Emerging Research in Sustainable Textile Processing

Top of Form Growing environmental concerns related to textile manufacturing have prompted increased efforts to develop more sustainable production methods and effective wastewater management strategies. Recent advancements reflect a shift toward reducing the environmental impact of hazardous chemicals through innovative and responsible practices. Among these, the development of eco-friendly and biodegradable dyes derived from natural sources such as plants, microorganisms, and agricultural residues has gained significant attention as a safer alternative to conventional synthetic dyes.

Biological treatment methods have also emerged as promising solutions for wastewater remediation, with microorganisms such as bacteria, fungi, and algae

demonstrating the ability to degrade complex dye molecules into less harmful compounds. In addition, advancements in nanotechnology have enhanced treatment efficiency, as nanomaterials offer high surface area and reactivity for improved adsorption and catalytic degradation of pollutants. Similarly, advanced oxidation processes, including photocatalysis and Fenton-based reactions, have shown effectiveness in breaking down persistent organic contaminants that are resistant to conventional methods.

Alongside treatment technologies, sustainable textile production increasingly emphasizes cleaner manufacturing practices, such as reduced water consumption, adoption of efficient dyeing systems, and implementation of recycling techniques. Regulatory frameworks and international standards further support these efforts by promoting safer chemical management. Overall, integrating innovative technologies, green chemistry principles, and improved industrial practices is essential for advancing sustainability and reducing the environmental footprint of the textile industry.

Conclusion

The textile industry plays a vital role in global economic development; however, its extensive reliance on hazardous chemicals during processing stages such as dyeing, printing, and finishing poses significant environmental and health challenges. Pollutants including azo dyes, heavy metals, pesticides, and auxiliary chemicals contribute to water and soil contamination, ecological imbalance, and occupational health risks. Although various treatment technologies such as biological processes, adsorption, membrane filtration, and advanced oxidation have been developed, their limitations highlight the need for more efficient and sustainable solutions.

Moving forward, a collaborative approach involving policymakers, industry stakeholders, and researchers is essential to address these challenges effectively. Strict regulatory enforcement, adoption of cleaner production techniques, and increased investment in green technologies must be prioritized to reduce the environmental footprint of textile manufacturing.

Furthermore, continued research and innovation in areas such as bioremediation, eco-friendly dyes, and nanotechnology can provide long-term sustainable alternatives.

Ultimately, achieving a balance between industrial growth and environmental sustainability requires a collective commitment to responsible practices, technological advancement, and policy support, ensuring a safer and more sustainable future for the textile sector.

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