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Synthetic Dyes for Textile Colouration: Process, Factors and Environmental Impact

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ABSTRACT
Dyes are substances that enhance the appearance of finished goods by providing uniform colour. Dyeing is the application process of dyes that are fixed in textile fibers. The dyeing process uses various steps, including pre-treatment, desizing, scouring, bleaching, carbonizing, degumming, and mercerization. Water is considered the primary medium for applying dyes and other chemicals for this treatment in the dyeing process. The dyeing process contains many toxic chemicals, metals and non-soluble substances, such as wastewater, which is thrown into the environment. It is noted that, during dyeing , around 50-300 liters of water is required for 1 kg of fiber. On the other hand, 1-2 million liters of water are needed every day for 50,000 meters of daily production. This massive amount of toxic wastewater is highly harmful to the environment, human health, aquatic system, soil, air, water, plants, and animals. This review paper states various dyeing processes with different dyes, including acid dye, direct dye, sulfur dye, reactive dye, vat dye, metal complex dye, azo dye, disperse dye, and basic dye. In contrast, it also describes the influencing factors of dyeing processes and methods. Moreover, this review demonstrates the impacts of textile dyes on the environment (water, soil, air emissions, human health) and illustrates possible remedial actions regarding wastewater.

KEYWORDS
textile dyes, dyeing process, electrochemical destruction, effluent treatment, foam technology, wastewater

INTRODUCTION

The textile industry is a significant source that generates more than $1 trillion in revenue, provides 7% of total global exports and employs more than 35 million people [1]. During dyeing and finishing activities in the textile industry, up to 200,000 tons of colours are lost to pollutants each year due to inefficient dyeing procedures [2]. Additionally, most dyes escape normal wastewater treatment processes. They persist in the environment due to their strong resistance to light, temperature, water, detergents, chemicals, soap, and other properties, such as bleach and sweat [3]. Many intensely coloured effluents from the dyeing industry are discharged into the environment, which is heavily contaminated and high in salts. This chemical load is displayed during the various stages of the textile preparation process. Water is used extensively in the manufacturing processes of the textile industry, primarily in the dyeing and finishing activities of the plants. Textile wastewater is the most polluting of all industrial sectors in volume and effluent composition [4]. Textile dyeing is a sample of a procedure that uses a lot of water, energy for heating, and dye chemicals, all of which greatly impact the environment. Environmental impact analysis is vital for long production in any field. Environmental degradation occurs in the textile industry at numerous stages of production. Some dyes are extremely hazardous and restrict the penetration of light and photosynthetic activity, resulting in oxygen deficiency and limiting upstream beneficial properties, such as recreation, drinking water, and irrigation. Two common dyeing processes are the adsorption (the transport of dyes from an aqueous solution to the interface of the fiber) and diffusion (the transport of colours from an aqueous phase to the surface of the fiber) [5]. In addition to direct absorption, dyeing can also involve the precipitation of colours inside the fiber (vat dyes) or a chemical reaction with the fiber (reactive dyes) [6,7]. Textile dyeing is a chemically intensive procedure that uses a variety of non-biodegradable and environmentally harmful substances. Furthermore, during the last step of processing, enormous quantities of wasted chemicals, as well as the process water, are left. The harmful non-recyclable compounds used in various operations are difficult to remove from wastewater because they require tertiary and additional treatments to address their various qualities; nevertheless, failing to treat these wastewaters results in environmental degradation when released [8]. The discharge of untreated effluent into the environment that pollutes neighboring soil and water is a severe environmental problem in the textile industry. An effluent treatment facility is necessary to reduce the dangers associated with the discharge of untreated water. The quality of the effluent discharge must meet national effluent discharge quality criteria. As water flows through the ETP, contaminants and water quality increase, allowing for ultimate safe discharge to the environment. Workers in the textile industry face various dangers and risks, ranging from noise and hazardous substances to physical handling and working with dangerous machinery. At every stage of the dyeing process, from raw material to final product, finishing, colouring, and packing, workers are exposed to dangers. Some of these are particularly hazardous to women's health. Dyes, solvents, optical brighteners, crease resistance agents, flame retardants, heavy metals, insecticides, and antimicrobic agents are only a few of the chemical substances utilized in the textile industry. These numerous types of dyeing methods and their environmental implications are reviewed in this study [9,10]. The treatments used in the development of natural fibers and the emissions during the creation of synthetic fibers are at the root of the environmental problems of the textile and garment industry [11,12]. To treat fibers, many processes require thousands of individual chemicals, tons of water, and a large amount of energy [13].

The environmental issues that textiles have caused have been reviewed in this study, as well solutions and recommendations in order to minimize environmental pollution have been used [14].

Many researchers have studied the textile colouration process with synthetic dyes along with their influencing parameters. They studied the different techniques to remove toxic dyes from wastewater [15–22]. But there is still a lack of review on the information published in the literature. This review was made to provide general information for academic researchers, textile industry personnel and environmentalists on the use of different synthetic dyes, the dyeing process, the parameters influencing the dyeing, the environmental impact of the dyes and the remedial actions taken regarding textile wastewater treatment.

Dyeing process

Dyeing is a fluid textile treatment procedure that integrates colour into fibers in several forms, including loose thread, yarn, fabric and nonwoven, using a dyeing machine. Because undyed clothes generally do not grab notice, humans have long been charmed by colour. Experts introduced the dyeing method to develop different styles and aesthetic appeal in clothing. One of the most significant aspects of successful textile commerce is the dyeing procedure. In addition to shape and attractive colour, the consumer generally seeks some essential qualities of the product, such as good resistance to light, sweat and washing, during prolonged use [23]. To achieve these features, the molecules that colour the fabric must have a high affinity, uniform colour, fading resistance, and be economically feasible in any aspect that influences modern dyeing technology, including molecular structure, low cost, fixation qualities appropriate for the material surface to be coloured, financial considerations, and many others. Preparatory treatments before dyeing are important in order to eliminate natural and additional contaminants from the fiber. The sequence in which the preliminary processes are completed for each product could differ depending on the dye's properties and the substrate's shape [24–26].

PREPARATORY PROCESSES

The main objective of the preparatory procedure is to prepare the textile substrate for future processing. It could be an additive process, in which the fiber is added, or a subtractive process, in which the undesirable impurities are removed. Removal of contamination from the fabric such as protruding threads, sizing agents, neem seed husks, fatty acids, oils, waxes, dirt, dust, lubricants and so on, and improving moisture absorption and whiteness of the fabric with very little fiber damage, wear retained size, pH, alkalinity, whiteness, moisture absorption and relative humidity are all goals of the dyeing preparation process [27,28]. In the following sections, the most commonly used preparatory processes are briefly described.

Desizing

Desizing is the process of eliminating the extra sizing material using acid or oxidase decomposition. Any sizing ingredients, such as starch, polyethylene glycol, or glycerin, could prevent dyes and chemicals from penetrating the fibers. Desizing solubilizes the sizing material using the substance listed: amylase enzyme, sodium persulfate, inorganic chemicals, hydrochloric acid, and many others. Enzyme-based desizing is the most effective among them because of its long-term durability. The presence of starch, for example, can prevent the dye from entering the fiber, requiring the removal of starch before dyeing or printing. Hydrolysis (by enzymatic preparations or dilute mineral acids) or oxidation (by sodium bromide, sodium chlorite, etc.) process can remove or convert the starch into simple water-soluble compounds [29–31].

Scouring

Scouring is a solubility process that removes the clinging and any other fatty matter contained in the textile material. Natural fibers have impurities, such as pectin, fat, hemicelluloses, oil, minerals, natural colouring matter, and wax [32]. These pollutants are generally acidic and can be easily eliminated in a hot and alkaline atmosphere. Lipase-based and combined scouring and bleaching have recently gained popularity because of their cost-effectiveness and long-term sustainability. Removing these natural colourants and add-ons to create the material that is ready for dyeing is called scouring [33,34].

Bleaching

Bleaching uses reducing or oxidizing substances to remove the natural colouring pigments found in natural fibers. Experts prefer hydrogen peroxide-based bleaching because it is more durable and long-lasting. To save water and energy, a combined scouring and bleaching technique is used for dark colour hues [35,36].

Carbonizing

Carbonization eliminates contaminants, such as burrs, seeds, and dust, from vegetable fibers. Acid backing was used to bind to the greasy wool fleece, and the backing was then neutralized. Sulphuric acid transforms cellulose biomass to dehydro cellulose, which is then converted back to cellulose biomass. The heated mass can be removed by grinding and pressing. This method is typically used for light colour tones [37].

Degumming

The silk cocoon's sticky ingredients (20–25% sericin) are removed by degumming with a hot alkaline solution. The luster, colour, hand, and texture of silk fabrics is improved by degumming [38–40].

Mercerization

Cellulosic textiles are mercerized with 250 g/L NaOH for 180 s at 5 °C to enhance reactivity and brightness. During mercerization, the cellulose molecule is mainly transformed into soda cellulose, which promotes dyeing and adhesive rates in light to dark colours [41]. For this procedure to be sustainable, the concentration of sodium hydroxide must be reduced to get the mercerized effect [42–44].

CLASSIFICATION OF SYNTHETIC DYES

Dye is defined as a chemical that has both chromophore and auxochrome groups. Because of its saturation, the chromophores group is responsible for dye colouration. The dye fiber reactivity is controlled by the auxochrome group [45]. Dye is an organic compound that is used to colour textile fibers. The solubilizing group allows the dye molecule to dissolve in water. The azo group (–N=N–) is a chromophore, the auxochromes –OH, –NH2, and –OCH3 are auxochrome groups, and the SO_3Na is a solubilizing group. The following subsections cover the many types of dyes and their long-term sustainability [15,46]. The chemical structure of acid dyes, direct dyes, reactive dyes, vat dyes, sulphur dyes, azo dyes, metal complex dyes, disperse dyes and basic dyes are shown in Figures 1-11.

Acid dyes

Acid dyes are sodium salts made of sulphonic or carboxylic acid sodium salts (R–SO3Na/R– COONa) that can colour the wool and silk fibers at an acidic pH [47]. Because of their carcinogenicity, most azo-based acid dyes have been banned. These dye groups have now been superseded by metal complex dyes. Cellulosic fibers are affected by acid dyes. Here are the majority of synthetic food colours [48]. Figure 1 indicates the chemical structures of different acid dyes.

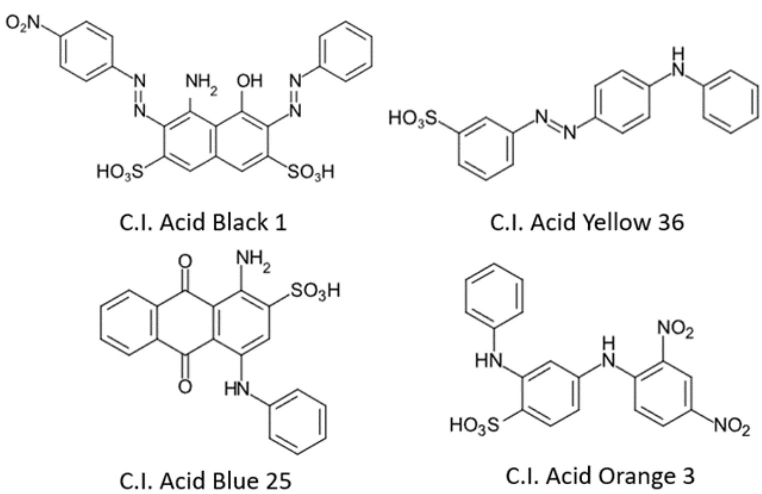


Figure 1. Chemical structure of different acid dyes [49]

Direct dyes

Direct dyes have an excellent affinity for natural fibers in the absence of any compounds. Materials dyed with direct dyes offer moderate washing and light fastness properties due to insufficient hydrogen bonding with the functional groups [50]. Fiber cationic fixing, on the other hand, can improve fastness qualities. The use of azo and benzidine-based direct dyes in the centralized sector has decreased due to their carcinogenicity; nevertheless, cottage enterprises continue to use them, because of their modest price. Direct hues have various washing, light, perspiration, and other wet fastness capabilities, as well as staining properties, on wool, silk, polyester, and acrylic multi-fibers. Most of the direct dyes have poor wet fastness in medium to entire colours unless they have had post-treatment, but some are stronger than others. Wet fastness is significantly improved by resin finish after dyeing, particularly in regenerated cellulosic fiber [51,52]. Figure 2 indicates chemical structures of different direct dyes.

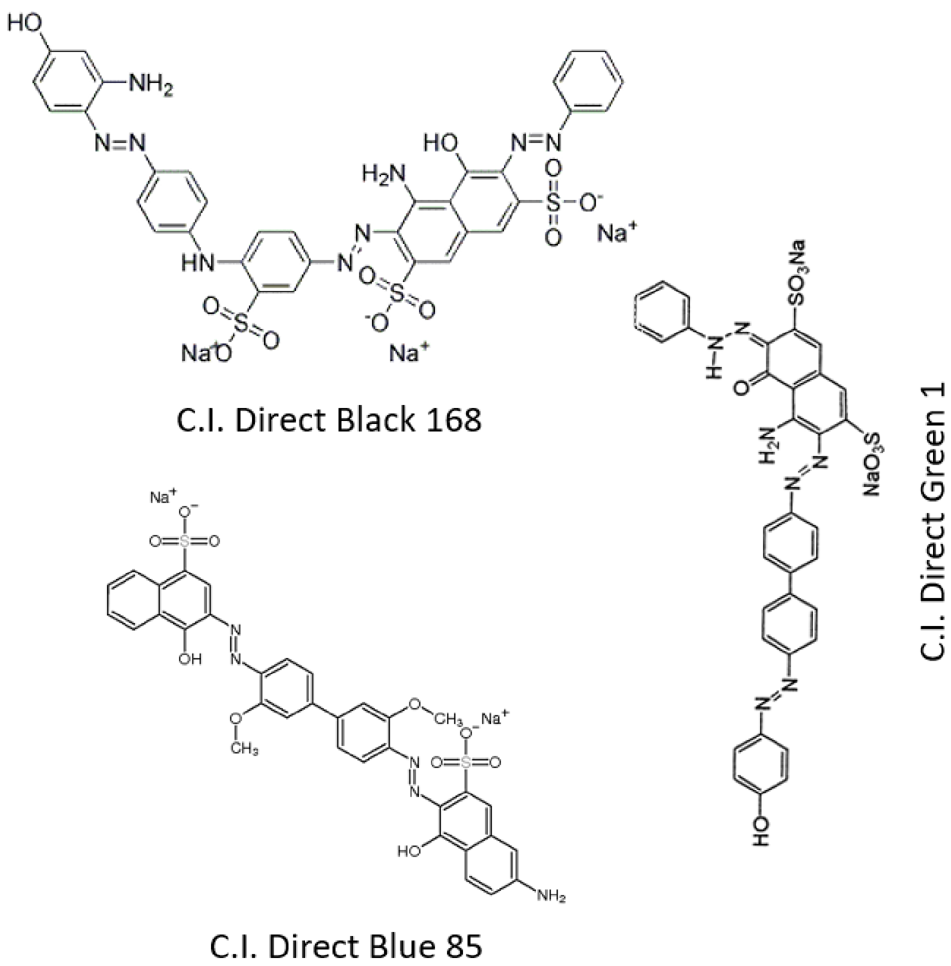


Figure 2. Chemical structure of different direct dyes [53]

Reactive dyes

A reactive dye comprises of a chromophore, one or two reactive auxophores, and a solubilizing group. The paint, which is most commonly employed on cellulosic fibers, forms covalent connections with the fiber's functional groups through a replacement or extension process. For exhaustion, an electrolyte, as well as an alkali, is required for stabilization [54]. Similarly, reactive groups of triazine and sulphatic ethyl sulphone have recently been included in a single dye molecule to generate bifunctional reactive dyes. To promote dye fixation and fastness, choose a moderate dyeing temperature. The essential long-term features are reactive dyes with low salt/alkali fixation, dyeing equipment with low materials to liquour ratio, and excellent bleaching fastness [55,56]. Figure 3 indicates the chemical structures of different reactive dyes.

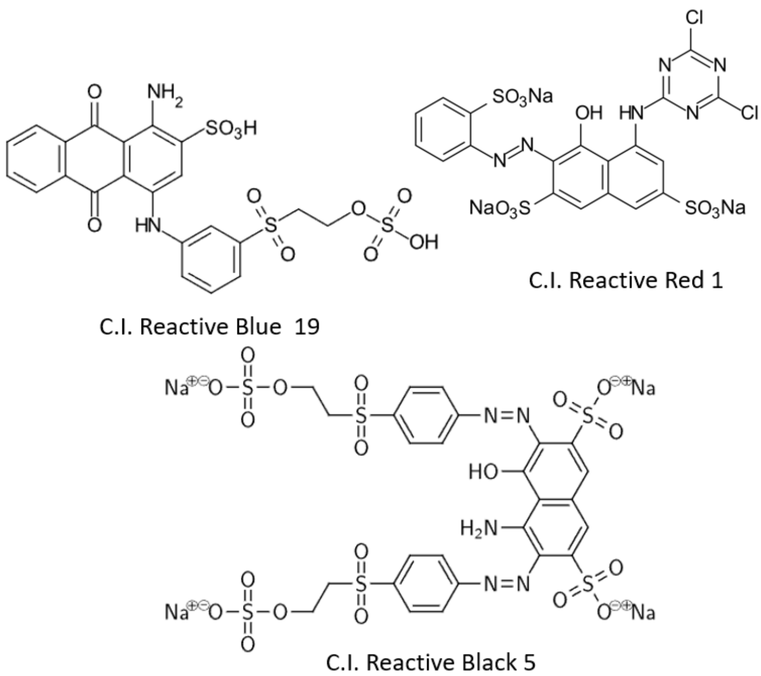


Figure 3. Chemical structure of different reactive dyes [57]

Vat dyes

Vat dyes are insoluble dyes based on anthraquinone or indigo that have been used for centuries. They are used to colour cellulosic materials in a vat [58]. Solubilization and stability of sodium, the salt of leuco-vat dye, which uses more chemicals and energy than other parameters, is a critical element. Interventions in R&D are generally focused on reducing the consumption of the reducing agent to continue the vat dyeing process [59,60]. Figure 4 indicates the chemical structures of different vat dyes.

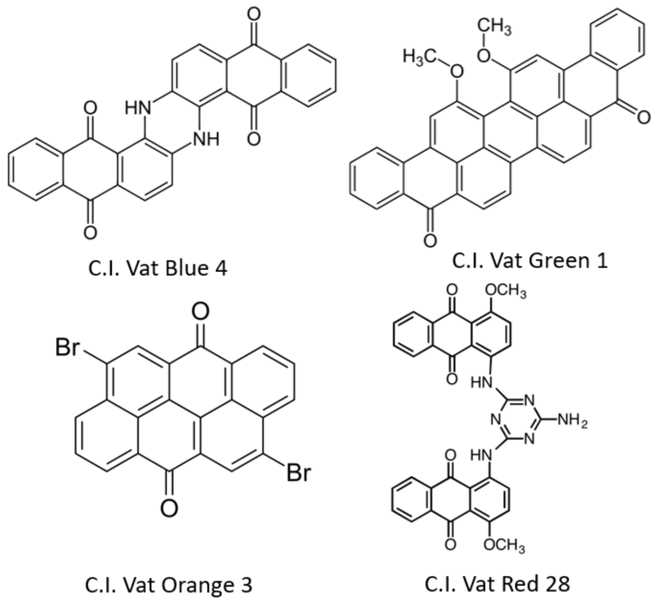


Figure 4. Chemical structure of vat dyes [61]

Sulphur dyes

Sulfur dyes (amino/nitro aromatic compounds with –S=S– linkages) are most commonly used in cellulosic textiles for black and brown hues (Fig. 2). For wild black and brownish colours, sulphur dyes are usually employed in men's fashion clothes [62]. Due to the harmful nature of dye-bath effluent, sulphur dyes have recently been phased out. Dyeing techniques that use glucose to replace sulphide-reducing chemicals and electrochemical techniques to reduce dye are both promising sustainable technologies [63][60]. Figure 5 indicates the chemical structures of different sulphur dyes.

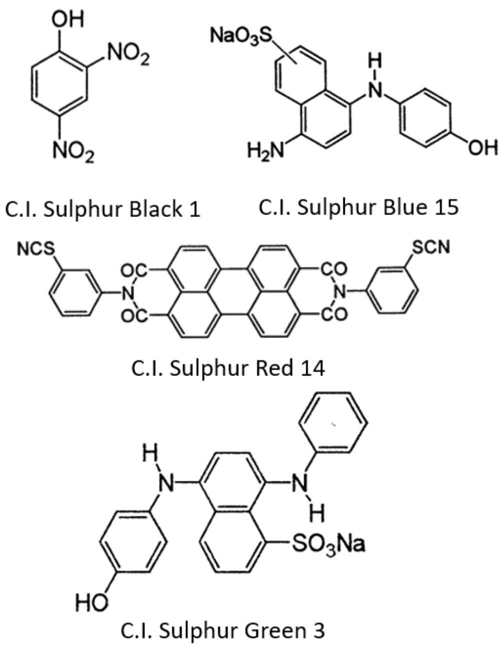
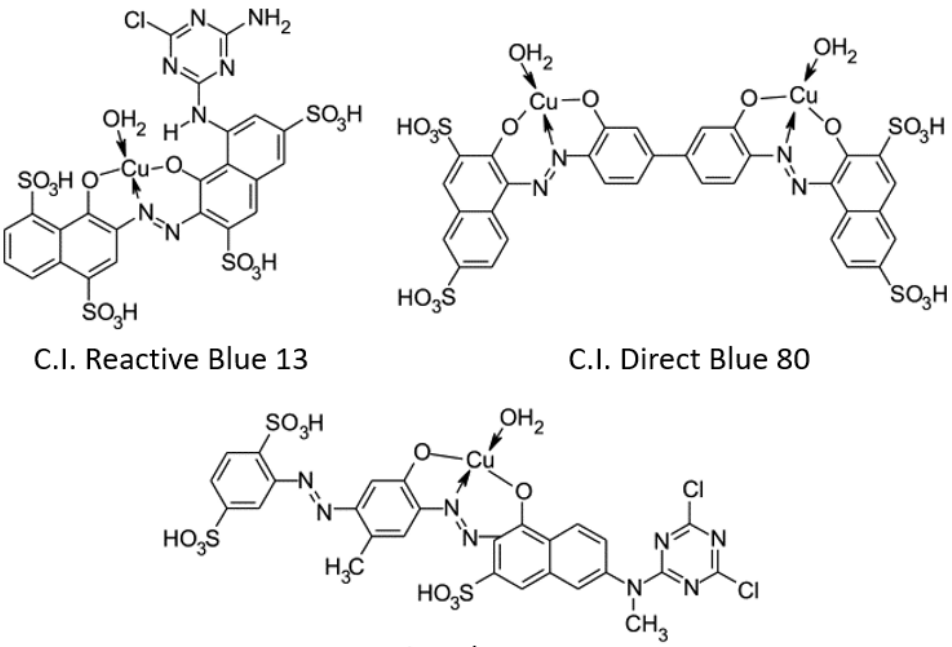


Figure 5. Chemical structure of sulphur dyes [64]

Metal complex dyes

Pre-metalized acid dyes are another name for metal complex dyes. Specific proportions of copper, chromium, cobalt, or nickel are used to make these colours. To make 1:1 metal-complex dyes, one metal ion combines with one dye molecule, whereas to make 1:2 metal-complex dyes, one metal ion reacts with two dye molecules [65]. The 1:1 complex possesses unsaturation since all of the valences of a metal are obtained with only one dye molecule. It is possible that 1:2 unsymmetrical complexes containing two distinct dye molecules will form due to a metal, usually, chromium, being incorporated into the dye molecule during manufacture [66]. Figure 6 indicates the chemical structure of 1:1 copper metal complex azo dyes.

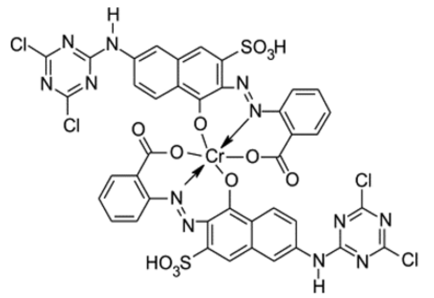


C.I. Reactive Blue 13 C.I. Direct Blue 80

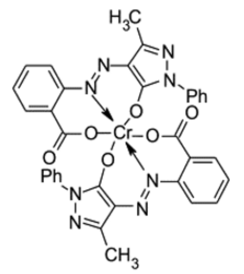
C.I. Reactive Blue 82

Figure 6. Chemical structure of 1:1 copper metal complex azo dyes [67]

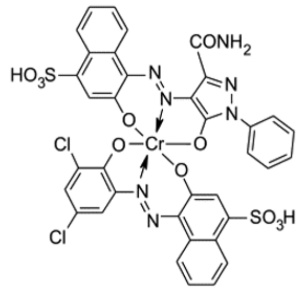
Figure 7 illustrates the chemical structure of 2:1 copper metal complex azo dyes and Figure 8 shows the chemical structure of the mixture of Cr3+ and Co3+ metal complex azo dyes.



C.I. Reactive Brown 10

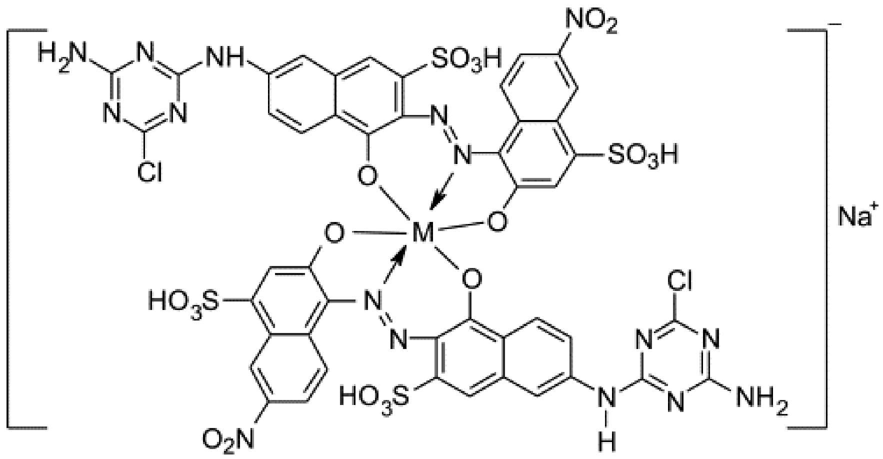


C.I. Solvent Yellow 21



C.I. Acid Violet 121

Figure 7. Chemical structure of 2:1 copper metal complex azo dyes [67]



M = Cr/Co

Figure 8. Chemical structure of mixture of Cr3+ and Co3+ metal complex azo dyes [67]

Azo dyes

Azo dyes contain one or more azo bonds (-N=N-) as well as one or more aromatic groups [68,69]. The nitrogen atoms of the azo group are linked to sp2 hybridized carbon atoms. At least one of these carbon atoms belongs to an aromatic carbocycle (usually a benzene or naphthalene derivative) or a heterocycle (e.g. pyrazolone, thiazole), whereas the second carbon atom adjoining the azo group may also be a part of an enolizable aliphatic derivative (e.g. acetoacetic acid). This diversity of inexpensively produced azo dyes permits a broad spectrum of shades and fastness properties suitable for use on a variety of substrates [70,71]. Figure 9 shows the chemical structure of different azo dyes.

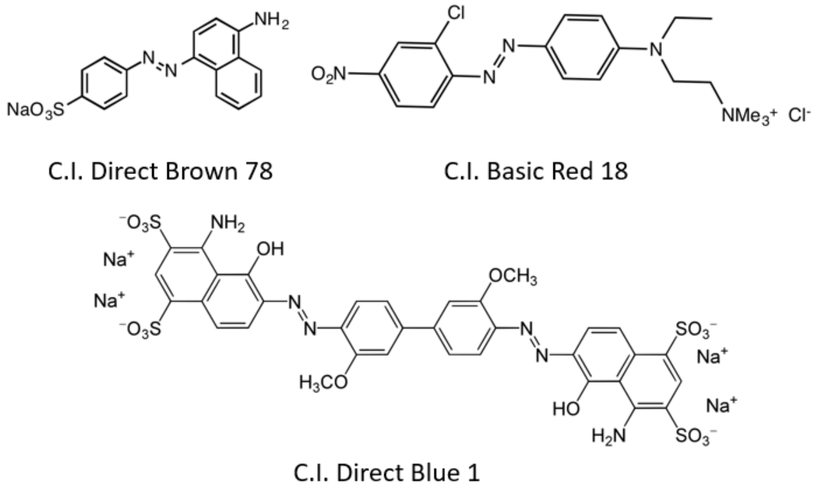


Figure 9. Chemical structure of different azo dyes [72]

Disperse dyes

Most disperse dyes are based on azo compounds; nevertheless, anthraquinone derivatives are frequently used to produce violet and blue colours [73]. These colours are usually insoluble in water or only slightly soluble, non-ionic, and placed on hydrophobic fibers from an aqueous dispersion [15]. They are typically used on polyester, but have also been used on nylon, cellulose acetate, and acrylic fibers. However, some of the wet-fastness of dyes on these substrates is not very good [74]. According to dispersion, azo dyes are the most common dispersion dye, accounting for much more than half of all disperse dyes [75]. These colours are categorized as durable dyes because of their resistant nature and non-biodegradable activity [60,76]. Figure 10 indicates the chemical structure of different disperse dyes.

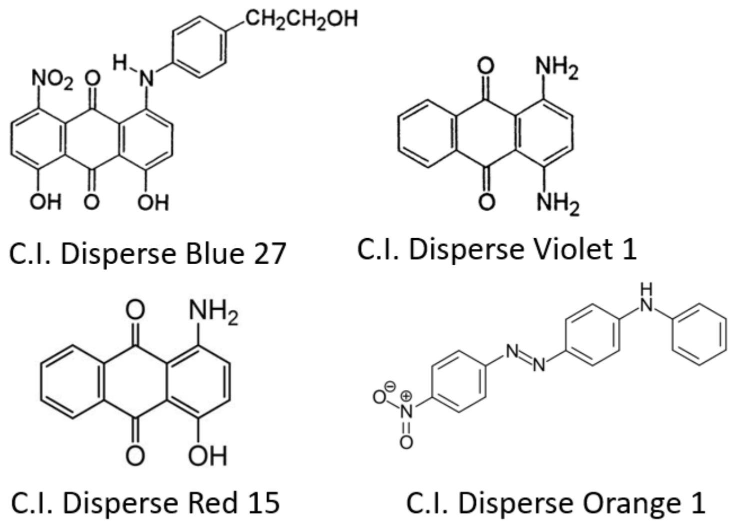


Figure 10. Chemical structure of different disperse dyes [77]

Basic dyes

Basic dyes (tri-arylmethane, xanthenes, and acridine dyes) possess a positive charge on an ammonium group or a delocalized charge on the dye cation [78]. Because of their weak migratory capabilities at the boil, these dye classes are applied with retarders. When using retarders, careful monitoring is required to ensure that anionic sites within the substrate are not blocked, limiting dye uptake and making dark hues challenging to achieve [79,80]. Figure 11 indicates the chemical structure of different basic dyes.

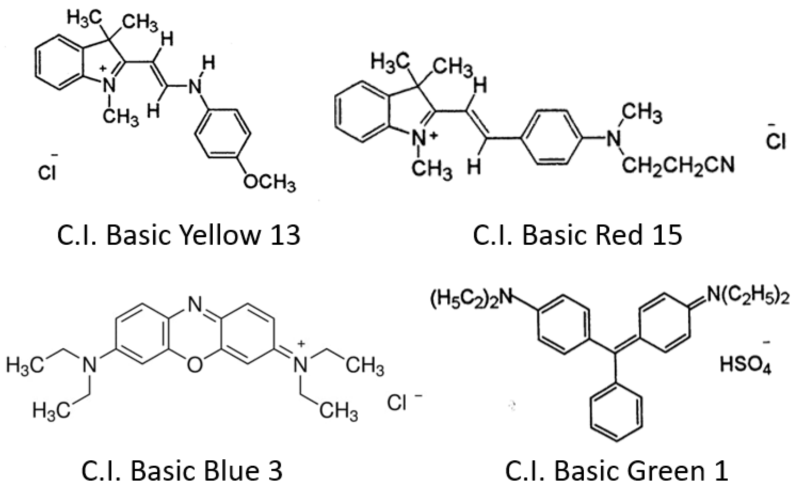


Figure 11. Chemical structure of different basic dyes [81]

INFLUENCING FACTORS FOR THE DYEING PROCESS

The dye molecule for textile fiber fixation is a complicated chemical compound consisting of one chromophore and one or more auxophores [82]. Based on the dye molecule's ionic nature and molecular weight, it can reside in an aqueous solution as an individual or as an aggregation. Dyeing involves the following steps [83,84].

- The dye molecules move from the dye solution to the fiber surface, where they subsequently adsorb.
- Dye adsorption occurs on the substrate surface.
- The dye molecule migrates from the fiber surface to its inner matrix due to the concentration gradient of the dye molecule.
- Fixation of the dye onto and/or within the substrate via covalent bonds, hydrogen bonds, ion-exchange or van der Waals forces, or through insolubilisation of the pre-dissolved dye inside the fibre.

Among the four stages, the diffusion process measures the rate. The diffusion characteristic of the dye molecules varies by fiber, which helps dyers choose the suitable dye for their needs, such as the cost of dyeing, the durability, and the end use. The size, shape, and ionic nature of the shade, as well as the diffusion coefficient, dyeing adsorption profile, substrate type, substrate preparation, and water quality, all have an impact on dye molecule transportation inside the textile material [85].

Pre-treatment

The dyeing will be smooth and solid if the dye molecules' adsorption on the fiber's surface is good for the synthetic dyes. As a result, pre-treatment is required to increase the fiber's wettability and functionality, leading to consistent dyeing [86].

Dye concentration

Dyeing can be achieved in a variety of colours, from pastel to dark hues, to meet the needs of different customers. To get a neutral shade, mild hues require significantly more time, dyeing auxiliaries, and after-treatments. In contrast, dark shades require additional time, dyeing auxiliaries, and after-treatments to boost their fastness qualities [87].

Dyeing condition

The rate is measured by the diffusion of dye molecules from the fiber matrix surface to the interior step. The duration of the dyeing, the temperature, and the ratio of material to liquor all play a role in increasing the dyeing rate. The dyeing time is determined by the affinity of the dye for the textile substrate and the dyeing procedure [88]. Dye compounds with a high molecular weight and poor affinity require longer durations. Low molecular weight polymers are more likely to diffuse and make bonds with fiber than high molecular weight polymers, dye molecules with a strong affinity. Dyeing can be done at a low temperature if the dye molecule is highly compatible with the natural fabric, such as with cold brand reactive dyes, which are coloured at 30 °C. Furthermore, a medium to high temperature (60–95 °C) is required to achieve improved dye aggregation and unique fastness properties. The material-to-liquor ratio (MLR) measures how much liquor is needed to process a given amount of substrate. Based on the dyeing machine and process, MLR can be chosen [89]. An innovative jet dyeing equipment with a low MLR dyeing technique was recently built to save money.

Dyeing auxiliaries

Auxiliaries in the dye bath, such as leveling agents, surfactants, acid, or alkali, are required to keep the dye molecule active and in a particular form. Natural fibers exhibit a negative zeta potential when submerged in water [90]. Electrolytes such as NaCl/Na2SO4 are used to neutralize the zeta potential. Acids and alkalis keep the pH equilibrium in the dyeing bath in order to increase dye fixation.

Compatibility of dyes

For the combination of colours, dye compatibility is required. Both dyes must possess uniform dispersion activity, fixation rate, activation energy, and fastness features for a solid combination shade. Otherwise, the dominant dye would disperse more quickly into the fiber, leaving the second dye in the bath [87].

Mechanical agitation

Mechanical agitation improves the migration of the dye molecule from the dye bath to the surface of the fiber substrate, allowing the dyeing time to be reduced. The consolidation of dye molecules and uneven colouration may occur if the dye bath is not disturbed. A significant degree of smoothness is attained when both the substrate and the dyeing fluid are moved [91].

Dyeing methods

The dyeing method significantly influences the dyeing cost and the dye chosen for a solid substrate with specific shade and fastness requirements [92].

Air dyeing

Air dyeing technology is a process that includes air instead of water to dye textiles, allowing businesses to produce garments with colourful patterns and styles without polluting the water supply or harming the environment. It is today's environmentally friendly alternative to traditional dyeing and decorating methods [93–95].

Digital printing

Digital printing describes the direct printing of a digital image on a variety of mediums [96]. A dye-sublimation printer is an automatic printing technique that uses a heat-based printing process to transfer dye onto materials such as plastic cards, paper, or fabric. Digital textile printing is a technology that allows printing of the designs directly onto the fabric from the computer, eliminating the need for any further steps [97].

Exhaust dyeing

The exhaust dyeing method provides colour to the textile material in a dyeing bath in heat energy, chemical additives, water or solvent, and mechanical action of the dye bath or material [98]. Popular exhaust dyeing equipment includes smooth flow, jigger, and jet dyeing machines. It is a batch dyeing technique that works well with limited batches. Batches range in size from 10 kg to 1000 kg. To limit the amount of pollution, it is important to maintain the temperature of the dyeing liquid [87]. Figure

12 indicates the exhaust dyeing curve.

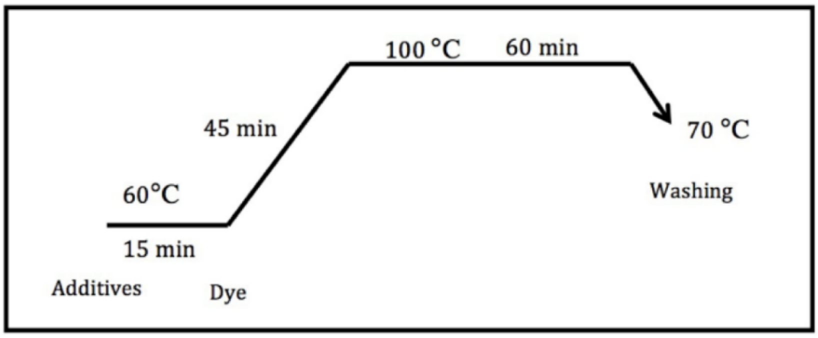


Figure 12. Exhaust dyeing curve [99]

Pad-steam dyeing

For certain reactive and vat dyes, the exhaust dyeing procedure takes time. For the water, as well as vitality to save energy, the pad dry steam procedure is used, in which open-width woven cloth is padded through a 50–300 gpL dyeing solution with a 100% expression, then steamed with saturated steam at 105 °C for 5–10 minutes. Dye molecules on the fibers overcome the enlarged fiber structure and are fixed during steaming. It is a continuous procedure that uses a small amount of liquor, such as MLR of 1:1 or 1:2. However, the fastness qualities are inferior to those of the exhaust dye, and the effluent discharge is more prominent [100]. Figure 13 indicates the cleaner and conventional pad-steam dyeing process.

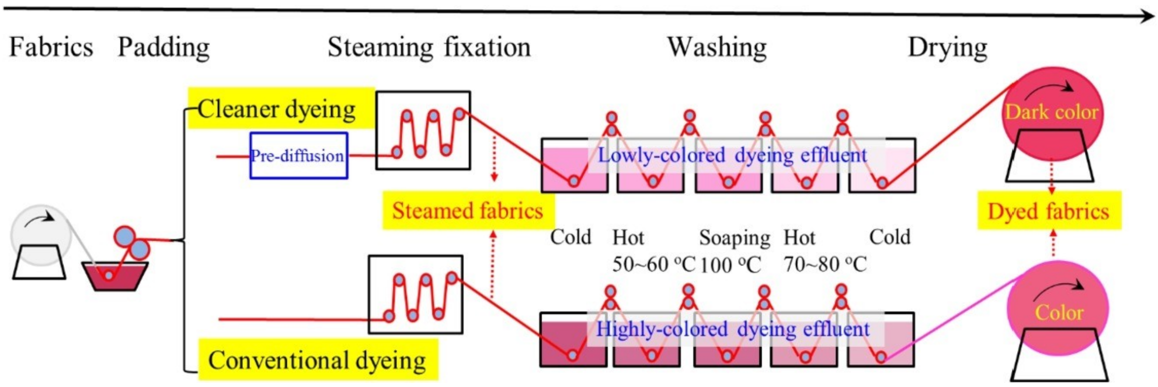


Figure 13. Cleaner and conventional pad- steam dyeing process. Reproduced with permission [101]

Microwave-assisted dyeing

Microwaves have wavelengths ranging from 103 to 1 mm and frequencies ranging from 300 MHz to 300 GHz. It is widely used to rapidly and uniformly heat bulky cheese wool and, as a result, in dyeing since it reduces dyeing time, water, and chemicals. Microwave-assisted dyeing of cellulosic fabrics using reactive dyes reduces dyeing time, salt, and alkali consumption by around 90%, 75%, and 20%, respectively, without affecting fastness properties [102]. Microwaved woollen cloth is dyed at 2450 MHz, 250–1000 W, for 30–180 s. It was found that microwave-modified wool fiber improved colour molecule diffusion without compromising mechanical properties [103]. Figure 14 illustrates the schematic diagram of microwave-assisted dyeing process for obtaining eco-friendly and fluorescent acrylic knitted fabrics.

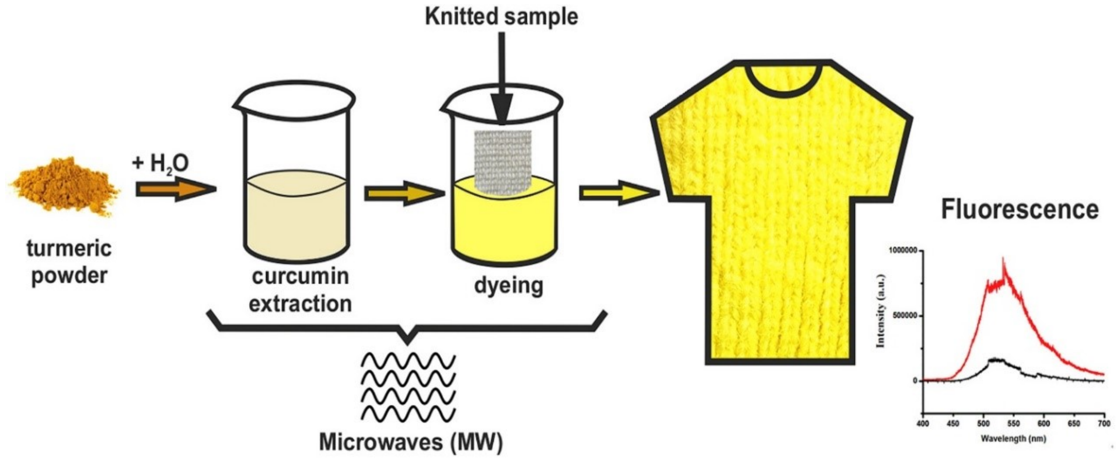


Figure 14. Schematic diagram of microwave-assisted dyeing process for obtaining eco-friendly and fluorescent acrylic knitted fabrics. Reproduced with permission [104]

Environmental impact of the textile dyeing industry

The textile industry is one of the most important sectors for economic development. In the textile industry, many synthetic dyes are used for dyeing. Synthetic dyes, like many other industrial pollutants, are extremely harmful and can lead to cancer. Environmental degradation and various animal-human diseases also affect them [105,106]. The textile industry contributes considerably to the gross domestic product (GDP) of growing economies, such as India, Pakistan, Bangladesh, and Cambodia. The utilization of several textile items varies depending on the country's population and lifestyle. There will be more clothing demands as there are more consumers, leading to the establishment of several textile dyeing companies to meet these demands. The development of effluent treatment plants is a government program that has led to the establishment of dyeing companies. The extraordinary expansion of the dyeing industry can help a country prosper by creating more jobs. Combining dyes with intermediate synthetic chemicals or their degradation products to produce other mutagenic and carcinogenic substances is another option [107]. One of the most prominent environmental issues associated with the textile industry is the discharge of untreated wastewater. Some chemicals, such as dyes and pigments, are toxic or can lower the dissolved oxygen concentration in the water, endangering aquatic life and wreaking havoc on downstream water quality. Dyeing losses account for only 10- 30% of total BOD, COD; dyes account for approximately 2-5%, while dye bath chemicals account for up to 25-35% [108]. Acetic acid has a high BOD and can account for 50-90% of the dye house BOD. It is utilized in polyester dispersed dyes, acrylic cationic dyes, and acid dyes on wool, silk, and nylon [109][46]. Because of their excellent thermal and light stability, the shades can last for a long time in the environment and resist biodegradation. Untreated textile dyeing effluents impact every aspect of the ecosystem, including soil, water, air, and human health, and are discussed below in the following section.

Impact on water

The textile dyeing effluent is a significant source of polluting bodies of water. The most prominent source of drinking water has been identified to be groundwater. It should be noted that groundwater is still unpolluted [98,110]. There are numerous textile dyeing industries in operation. More than 80% of sectors do not have a significant technological treatment plant for wastewater disposal. Only 2% of the composite units (knitting, dyeing, and finishing) have sufficient treatment facilities. Solid waste, liquid waste, and gaseous wastes are the industrial waste. They differ from municipal and commercial waste in terms of their characteristics. The presence of dyes in surface and subsurface water causes various waterborne diseases, including nausea, bleeding, mucous membrane ulceration, dermatitis, perforation of the nasal septum, and severe respiratory tract irritation. Contamination of this water supply poses a significant risk to the overall epidemiological and economic structure of the dam. Industrial effluents contribute a modest portion of the chemical load to the environment, but their integrity degrades their quality. As a result, many settlements inside the embankment are now under threat of environmental degradation. Surface water is used for housework, bathing, irrigation, fish culture, and other critical duties near the esplanades. Additionally, no systemic data on the area's water quality was identified [111]. As a result, a detailed investigation is required to determine the extent of pollution and to save the ecosystems and biodiversity. The authorities require such information to take appropriate action to prevent decay in the area. As a result, an attempt should be taken to assess the extent of pollution levels of various physicochemical, anionic, and heavy metals in the current study to characterize the effluents of the textile dyeing industries. In a volume of 100–230 m^3, the effluent would have BOD of 430–1200 ppm and total solids concentration of roughly 6500 ppm. Cottage businesses did not follow the rules of the pollution control board, whereas organized textile industries treated textile effluents before dumping them into bodies of water [112,113]. Textile effluents are typically hot, alkaline, odorous, as well as colourful. Textile processes have a variety of environmental and ecological consequences. Processing procedures, as well as societal and legal limits, differ significantly from one country to the next. It is time to rethink the current dyeing system and simplify a sustainable dyeing method to protect ecological integrity [114]. The usage of inputs (raw materials, water, energy, and so on) that are converted into products, waste, and by-products defines every industrial process. Wastes generated at all stages of human activity vary in composition and volume, depending on consumer habits and production processes. The possible impact on human health and the environment is the primary source of concern; hazardous waste, which is mainly generated by industry, is incredibly worrying since, if not properly managed, poses a severe threat to the environment and, as a result, to human health, eco-friendly textile dyeing and finishing [115,116]. The textile industry generates a lot of liquid waste. Organic and inorganic chemicals are present in these textile effluents. Not all colours applied to fabrics are fixed on them during the dyeing process, and a certain percentage of these colours always remain unfixed and are rinsed out. In textile effluents, a significant amount of these unfixed colours is detected [117]. An average T-shirt uses 16-20 liters of water during the dyeing process, implying that the worldwide textile sector discharges 40,000 – 50,000 tons of dye into the water system yearly. The absorption and reflection of sunlight entering the water are a primary environmental concern with shades. Because algae are at the bottom of the food chain, light absorption decreases their photosynthetic activity, which has a massive impact on the food chain. Lack of algae is one of the main reasons aquatic life suffers in areas where colours are released, but another factor is the toxicity of dyes [118,119]. Water consumption during wet processing and water usage in the textile sector are shown in Tables 1 and 2, respectively.

Table 1. Water consumption during wet processing [120]

Process	Percent water consumed
Bleaching	38%
Dyeing	16%
Printing	8%
Boiler	14%
Other uses	24%

Table 2. Water usage in the textile sector [121]

Fiber type/ make -up	Material	Mean water consumption, L/kg
By fiber type	Cotton	50–120
	Wool	75–250
	Other natural fibers	10–100
By make-up	Fabric	100–200
	Hosiery	80–120
	Printing	0–400

Impact on soil

The soil is a living organism made up of mineral and organic components. The ground is the foundation of agriculture. The environment is polluted by textile waste. When this effluent can spread freely in the fields, it clogs the pores of the soil, reducing soil production [122,123]. The consistency of the ground is tightened and the permeability of the roots is inhibited. The effluent of the textile dyeing industry is becoming dangerous to the planet. After sufficient treatment and dilution to 25%, textile effluents can be safely used for irrigation. The seed germination of Cicer arietinum is harmed by the presence of a very diluted industrial waste (5%). There are different types of chemicals used in textile dyes, so many wastes are found near the plants. All the waste gets mixed into rivers, ponds and agricultural fields and, consequently, agricultural products are harmed. Textile mill effluent is released on land or into the waterways in large quantities. This effluent has a high biological oxygen demand (BOD), a high chemical oxygen demand (COD), salt and other dissolved solids, micronutrients, and heavy metals [124]. Soils can act as a sink for heavy metals independently of the pollution source. However, there are three primary types of ecological concerns connected with this mechanism. Many textile mill wastewaters are released onto land or into waterbodies. The loss of soil productivity, the pollution of groundwater due to metal leaching and the accumulation of pollutants in the food chain, with consequences on vegetation and animals, including people, all of these occur because of the textile dyes [125]. Natural industrial wastewater can be used as an organic fertilizer and a nutrient source for soil. There are several advantages to using wastewater for irrigation, to minimize immediate and long-term environmental risks. The effect of an industrial effluent varies from crop to crop. Plant growth is limited by soil contamination, which causes oxidative stress and reduces protein content, photosynthesis, and CO_2 absorbing rates [126]. Pre-treatment, colouring, and finishing of textiles are all done with fresh, soft water in the textile wet processing industry. Water is utilized as a chemical transporter to the fiber and to rinse or remove undesirable chemicals from the cloth. About 17–20% of industrial contamination of water is caused by the textile sector. Synthetic dyes have a significant influence on soil because they utilize a lot of water in the dyeing process. Dyes, plastic, polyester, fibers, yarns, and other hazardous elements are found in liquid and solid textile waste [127–129].

Impact on air emissions

Pollutants in the air and water impact the planet, causing a variety of weather occurrences and wasting a large amount of food. Chemicals, particulates, or biological contaminants that penetrate the atmosphere and cause harm or disruption to humans or other organisms are referred to as air pollution [130]. It is well recognized that data on air emissions from textile operations is difficult to obtain. However, many textile processes produce air emissions. After waste disposal, gas emission is the second major contaminant in the textile industry. Air emissions include dust and lint, oil fumes, acid vapor, solvent mists, smell, and boiler exhausts. When oil, plasticizers, and other components in textile fabrics are exposed to high temperatures, they break down and cause fog. The most common source is the stenter frame. Formaldehyde, often known as methane, and acetic acid are also significant sources of emissions [131]. During the carbonization of wool, corrosive acid vapors are produced, as well as acid volatilization. Vapors of hazardous substances, such as kerosene or mineral turpentine oil, formaldehyde, mono- and dichlorobenzene, ethyl acetate, hexane, styrene, and others are produced after dyeing and printing. The odour is connected to oil mists or solvent fumes. Odour is generated by carriers used in polyester dyeing, colour reduction in cotton sulphur dyeing with hydrosulphite, and bleaching with sodium hypochlorite, for example. Dust and lint are produced before the processing of natural and synthetic fibers, as well as during the spinning, napping, and carpet shearing operations. Inhaling them causes a variety of respiratory illnesses [132–134]. Table 3 indicates the air emissions released from different textile processes.

Table 3. Air emissions released from different textile processes [135]

Process	Sources	Pollutants
Energy production	Emissions from boiler	Particulates, NOx, SO_2
Coating, drying, curing	Emissions from high-temperature ovens	Volatile organic components
Cotton handling activities	Emissions from preparation, carding, combing, fabric manufacturing	Particulates
Sizing	Emissions from using sizing compound	Nitrogen oxides, sulphur oxide, carbon monoxide
Bleaching	Emissions from using chlorine compound	Chlorine, chlorine dioxide
Dyeing	Disperse dyeing using carriers, Sulphur dyeing, aniline dyeing	Carriers, H_2S, Aniline vapors
Printing	Emissions	Hydrocarbons, ammonia
Finishing	Resin finishing, heat setting of synthetic fabrics	Formaldehyde, carriers, polymers-lubricating oils
Chemical storage	Emissions from storage tanks for commodities and chemicals	VOCs
Wastewater treatment	Emissions from treatment tanks and vessels	VOCs, toxic emissions

Impact on human health

The majority of dyestuffs used in material colouring and finishing are harmful to human health when exposed to radiation that employees are exposed to in industrial applications. However, all colours and synthetic compounds should be treated with caution. Because of the breathing in of colour particles, the most well-known danger that responsive colours pose are respiratory difficulties. They can alter an individual's resistive framework on occasion. In extreme circumstances, this might indicate that when an individual breathes in the hue again, their body will react dramatically. Respiratory sharpness is a condition that causes tingling, watery eyes, sniffling, and asthma symptoms such as hacking and wheezing [136]. Perhaps the most common medical complications related to the colouring and finishing processes arise from exposure to synthetic compounds that act as irritants. Skin irritation, irritated or blocked nose, sniffling, and sore eyes are possible side effects. They include formaldehyde-based gums, smelling salts, acidic corrosive, certain optical whiteners, soft drink cinder, burning soft drink, and blanch [137]. Certain responsive and scatter colours are also regarded to be skin-sensitive, according to the impact of synthetic dyes on people's health and environment panel. Material businesses generate a large amount of fluid waste. These material effluents contain natural and inorganic mixes. Not all colours associated with textures are established in the colouring forms, and a portion of these colours is frequently washed out because they are not fixed to the surfaces. Some heavy metals, such as Cr, As, Cu, and Zn, are found in these effluents and can cause some medical issues, such as leakage, skin ulceration, nausea, acute skin aggravation, and dermatitis [138]. Many azo colours are also very harmful to the environment and cause genetic mutations, which means that they can have severe to irreversible effects on living forms depending on the period of introduction and the azo colour concentration [139,140]. Skin irritation, contact dermatitis, especially in small children, exophthalmos, permanent visual impairment, rhabdomyolysis, regurgitating gastritis, hypertension, vertigo, and edema of the face, neck, pharynx, tongue, and larynx, as well as respiratory distress, can all be caused by 1,4-diamino benzene. Sweet-smelling amines can be ingested through the skin and other exposed places, such as the mouth, after being activated by water or sweat. Because more colour may be invested in a shorter amount of time, swallowing assimilation is faster and thus potentially more harmful. When metabolized by liver proteins, water-soluble azo colours become dangerous [141–143]. On a global scale, existing textile dyeing techniques are responsible for water pollution. Factories complain that the expenses of additional infrastructure to process their waterwaste are too high, and that because the fashion industry pays so little for their output to enhance profit margins on their quick fashion, the factories are often unable to invest. Coupled with this, a lack of awareness of the issue's seriousness and a fundamental lack of caring or compassion on the part of the important businesses contributes to the dilemma. Toxic dyes and chemicals used in the wet processing of textile goods come into contact with the skin and cause cancer and allergies [98,144].

THE POSSIBLE REMEDIAL ACTIONS

Dyeing processes cause many problems in the environment. All possible remedial steps are listed and described in brief.

Optimization of dyeing processes

Optimization of the dyeing process in order to minimize the environmental effect of the textile industry is essential. Understanding the composition of the waste generated is essential for creating these treatment techniques due to the considerable complexity of the trash formed because of the large number of compounds used in various stages of dyeing materials [145]. Because current methods for obtaining the needed water quality are insufficient, many textile companies will be forced to reuse a considerable amount of all incoming freshwater in the future. Due to the scarcity of water and the increasing demand in the textile sector, it is a preferable alternative to try to improve the water quality of wastewater effluent from a secondary wastewater treatment plant to a higher grade for reuse. So far, this component has received very little consideration. As a result, creating novel processes for the more effective treatment of these effluents could be much less expensive than tertiary treatment to remove these compounds at low concentrations and in the face of additional interference. This will require cost-benefit analysis, as well as the development and commercialization of novel wastewater treatment techniques capable of effectively eliminating these pigments. More effective dyes attached to fibers with greater efficiency are being developed. Minimizing the amount of colour used in the dyeing process, lowering the cost, and improving effluent quality would be an alternative to reduce the obstacles related to the treatment of textile effluents and reducing the amount of dye used in the dyeing process [146–151].

Wastewater treatment

The textile industry has been under tremendous pressure to limit the use of toxic compounds, particularly the mutagenic, carcinogenic, and allergenic impacts of textile chemicals and dyes. The colour restrictions of the effluents are governed by different rules in different nations [152]. Textile dye wastewater treatment involves not only colour removal (decolourization), but also molecular decomposition and mineralization [153]. When the molecules are removed from the solution or the chromophore link is broken, decolourization occurs, but the molecule in the first case, and the large pieces in the second case, remain intact. The electromagnetic spectrum of the linked molecules transforms from the visible to the ultraviolet or infrared spectrum. Synthetic dyes can be removed from waterways and wastewater using a variety of approaches, in order to reduce their environmental impact [154]. Chemical methods include coagulation or flocculation combined with flotation and filtration, precipitation flocculation with Fe(IT)/Ca(OH)2, electrolocation, electrokinetic coagulation, traditional oxidation methods (e.g. with ozone), irradiation, or electrochemical processes; and physical methods include membrane-filtration strategies (nanofiltration, reverse osmosis, electrodialysis) and sorption techniques [155]. Because of the chemical stability of the pollutants, traditional wastewater treatment systems are inefficient in dealing with wastewater from synthetic textile colours [156–158]. Biological approaches have several drawbacks, including high cost, low efficiency, limited adaptability, the need for specialized equipment, interference from other wastewater elements, and the need for specialized apparatus. Despite using chemical procedures to remove colours, the concentrated sludge that results in this sludge can be challenging to break down [159,160]. There is also the chance that the high volumes of chemicals used will produce secondary contamination. Other recently developed strategies, such as enhanced oxidation procedures based on the creation of potent oxidizing agents, such as hydroxyl radicals, have been successfully used for the degradation of pollutants [99]. Although these technologies effectively treat polluted streams, they are costly and commercially undesirable. In order to reduce dye concentrations in wastewater to acceptable levels at a fair cost, it is critical to develop efficient, cost-effective and environmentally friendly technology [161]. Biological methods are often ecologically friendly since they can result in the complete mineralization of organic contaminants at a low cost [162]. BOD, COD, and suspended particles are also removed. The principal constraint may be related to the toxicity of dyes and their breakdown products to the organisms involved in the process in some situations [163–165].

Oxidative processes

The chemical methods used most frequently for textile wastewater treatment are oxidative procedures. The leading oxidizing agent is usually H_2O_2. Specific forms, such as UV light, are required to activate H_2O_2 and it can be used in chemical decolourization processes [166]. By shattering the aromatic ring of the dye molecules, chemical oxidation removes the dyes from the effluents [167,168].

Sodium hypochloride (NaOCl)

This technique targets the chlorine in the amino group of dye molecules. It starts and speeds up the disintegration of azo bonds. This method is not suitable for dyes that are scattered. Because of its adverse effects on receiving waters and because it liberates carcinogenic aromatic amine compounds, the use of chlorine to remove colour has been less widespread in recent years [169].

Photochemical degradation

When dye molecules are exposed to UV light in the presence of H_2O_2, they decompose into CO_2 and water [170]. The advantage of the photochemical treatment is that no sludge is formed, and putrid odors are reduced.

Photocatalytic degradation techniques

Traditional treatment procedures like ozonization, chlorination, and filtering have their own constraints regarding energy sources and waste generation. Photocatalytic degradation techniques of organic dyes should be attractive for the treatment of textile effluents because of their high oxidation capacities, low price, high efficiency, broad applicability, and environmentally friendly nature. Semiconductor photocatalysis is a new practical approach to the treatment of the dye house effluent, capable of decolourizing and dissolving dye molecules into inorganic components such as CO_2 and water [171]. This reduces the risk of producing harmful by-products and sludge, which frequently cause further concerns regarding treatment and disposal [172].

Electrochemical destruction

This is a relatively new treatment that first appeared in the mid 1990s. Because it uses few chemicals, there is no sludge during the process. The degraded metabolites are usually non-toxic, making it safe to discharge treated effluents into recipient water bodies. It is cost-effective and efficiently removes damaged colours [173].

Use of supercritical carbon dioxide in dyeing

Supercritical fluids are materials that exist above critical temperatures and pressures. CO_2 is commonly employed as a solvent due to its non-toxic, non-corrosive, and non-hazardous properties and the fact that it is economically manufactured and quickly transported [174]. Compared to other gasses, CO_2 comparatively easily reaches critical temperature and pressure. The use of supercritical CO_2 as a dyeing medium is a potential new method. The capacity of supercritical CO_2 to dissolve hydrophobic compounds, such as dye dispersants, is a crucial characteristic that allows dyeing. In the dyeing process, the supercritical fluid serves two purposes: (i) heats the substrate and (ii) transfers the colours. The process can be controlled with the adjustment of temperature and pressure. The dyestuff that diffuses into the supercritical fluid's boundary layers is absorbed and diffuses into the fibers [175]. The supercritical CO_2 dyeing technique requires almost no water and does not require drying because CO is emitted in a gaseous condition at the end of the operation. After precipitation of the extracted particles in a separator, up to 90% of CO_2 can be simply recycled. The CO_2 dyeing of polyester and polypropylene fiber has already been produced on a large scale; however, due to the polar character of the dyestuffs, the application of this process to wool, polyacrylate, and cotton remains troublesome. Polyester dyeing in supercritical CO_2 should be done at a pressure of at least 180 bar and a temperature of at least 70 °C. One downside of this approach is the high initial equipment expenditure. This is a significant disadvantage because polyester materials are typically inexpensive [176-178].

Foam technology for textile finishing

Textile wet processing takes a lot of energy and accounts for a considerable portion of the energy consumed in the textile sector in many countries. Most of this energy is used to heat and evaporate the water from the fibers. Wet textile production consumes a substantial amount of water as well. Foam finishing is an alternative process for applying chemicals to textiles in which the liquor is diluted with air rather than water. Because most of the water used in foam finishing is replaced by air, the energy consumption in drying processes is minimized, as well as water consumption and wastewater disposal. Foam technology also addresses a fundamental issue with previous low add-on topical and expression systems: the challenge of evenly spreading a tiny liquor over a large piece of cloth [179]. Foam is a colloidal system of gas bubbles spread throughout a liquid medium. Foam can be made mechanically by blowing air or agitating excessively, chemically by adding foaming chemicals, or both. The blow ratio specifies the relative proportions of air and liquid phases in the foam. The stability, density, and diameter of the foam must all be checked regularly. Horizontal padders, kiss roller coating, knife-over-roller coating, knife on air, and slot applicators are all typical systems used in foam applications. Traditional padding, vacuum application, or a combination of the two can all be used to remove foam after it has been applied to the fabrics. Fabric preparation, dyeing and printing, durable press finishing, softening, soil-release finishing, mercerizing, and various finishes (water- and oil-repellent, fire retardant, anti-static, and so on) can all benefit from foam finishing. Foam can be applied on one or both sides of the materials [180–182].

Microwave energy in wet textile processing

Microwaves are electromagnetic wave frequencies ranging from 1000 to 10,000 megahertz (MHz). Microwave radiation is used in a variety of industrial processes in various industries as an alternative to traditional heating techniques because it provides fast, uniform, and effective heating by permeating matter particles and allowing for continuous heating. Shorter application times, faster heating and drying times, the flexibility to easily modify the processing time to heat different amounts of material, and energy conservation are all advantages of microwave energy [183]**.** Microwave energy has been tested in the textile sector for heating, drying, condensation, dyeing, pressing, finishing, and altering the surface of fabrics. Cellulose fabrics were treated with durable press finishing compounds and cured in a microwave oven in the 1970s, the first attempt to employ microwaves in the textile finishing process [184]. Microwave dyeing, which considers the process's dielectric and thermal properties, is an example of how microwaves are used in textile production. The dielectric property refers to the intrinsic electrical qualities that influence the microwave field on the dipoles and affect dyeing by dipolar rotation of the dye. There are two polar components in an aqueous dye solution. The vibration energy in water and the dye molecules are influenced by high-frequency microwave radiation oscillating at 2450 MHz. Ionic conduction, a type of resistance heating, is the heating mechanism. The rapid passage of the ions through the dye solution causes dye molecules to collide with fiber molecules. Because excessive exposure to microwave radiation is hazardous, safety procedures must be created before deploying microwave energy on a wide scale [185–188].

Awareness to go green

A new look is needed at how the fabric is created and finished. Beautiful, sensual material must be created by using non-toxic, ethical, and sustainable methods. Mainstream manufacturers should have access to environmentally friendly technologies. People need to be aware of the far-reaching consequences of their textile choices. The awareness of buying eco-friendly clothing, curtains, and even carpets has increased. A company cannot claim to sell a "green" shirt if the dyeing procedure used to colour the clothing wastes and pollutes water. As a result, various apparel producers face a significant challenge due to this new wave of eco-friendly products. Some companies have acted and stopped using dyes on specific clothing, but not everyone would be satisfied with merely off-white and beige colours. Colour and diversity are essential for consumers when it comes to clothing [189,190].

Pollution prevention

The phases that explain the activities that reduce the quantity of pollution produced by a process, whether consumer consumption, driving, or industrial output, are referred to as pollution prevention. Although there is a universal agreement that reducing the number of sources is the preferred method, this is not always practicable. Professionals have coined the concept of "recycling" to denote pollution prevention or repurposing. More specific, sub-disciplines of pollution avoidance, such as green chemistry and green design, are included [191]. The textile industry should communicate with raw material suppliers who use less harmful products. Chemicals with a lower environmental impact should be purchased by the industry. The amount of chemicals that is utilized is determined by the bath ratio. When the dyeing industry uses a lower bath ratio, fewer chemicals are needed in the dye bath. As a result, the environment is less contaminated. To avoid pollution caused by excessive dye intake, the temperature of the dye bath should be controlled. If the dye bath is heated with direct steam, it needs to be done slowly to avoid overflowing and subsequent loss of the dye bath solution, which pollutes the environment [192–195].

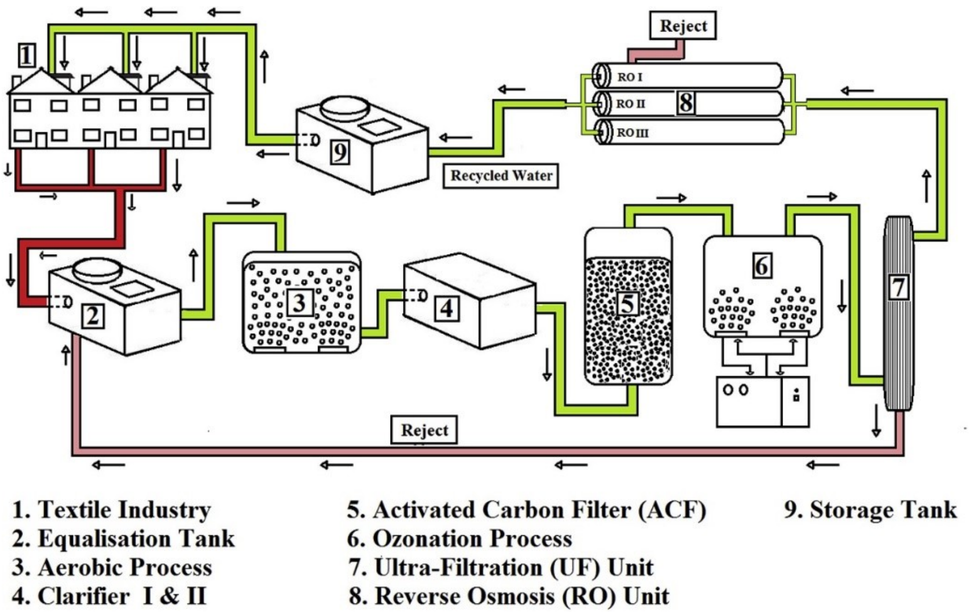


Figure 15. Process layout of the textile ETP. Reproduced with permission [196]

Effluent treatment plant

The technologies that pollute the environment as little as possible are preferred. The most widely accepted environmental safety approach is effluent treatment plants (ETP) [197]. However, no single treatment process is acceptable or generally applicable for every wastewater treatment. Figure 15 indicates the process layout of the textile ETP. Biological treatment solutions, for example, have been widely used in the past, but are ineffective in removing the colour of more resistant dyes. As a result, the waste stream is treated using various methods, including physical, chemical, and biological treatment, depending on the pollutant load. The textile industry generates a large amount of wastewater that contains a variety of compositions and chemicals that are used in dyeing, printing, and other processes. The discharge of untreated effluent by textile companies is highly damaging to the environment, polluting adjacent water and land [198]. An ETP helps to solve these problems by safeguarding the domain from the harmful effects of wastewater in the textile and garment industries. Figure 16 indicates wastewater generation in the textile industry, its toxicity and various treatment approaches. ETP significantly reduces environmental impact while providing benefits to the sector [8,165,199–203]. ETP has several advantages:

- It ensures environmental standards and regulations.
- It recycles/converts wastewater into clean, safe water that can be reused.
- It is the most effective technique for eliminating waste.
- It helps the environment by eliminating harmful pollutants and toxins.
- An ETP that is properly maintained will save money in the long run.

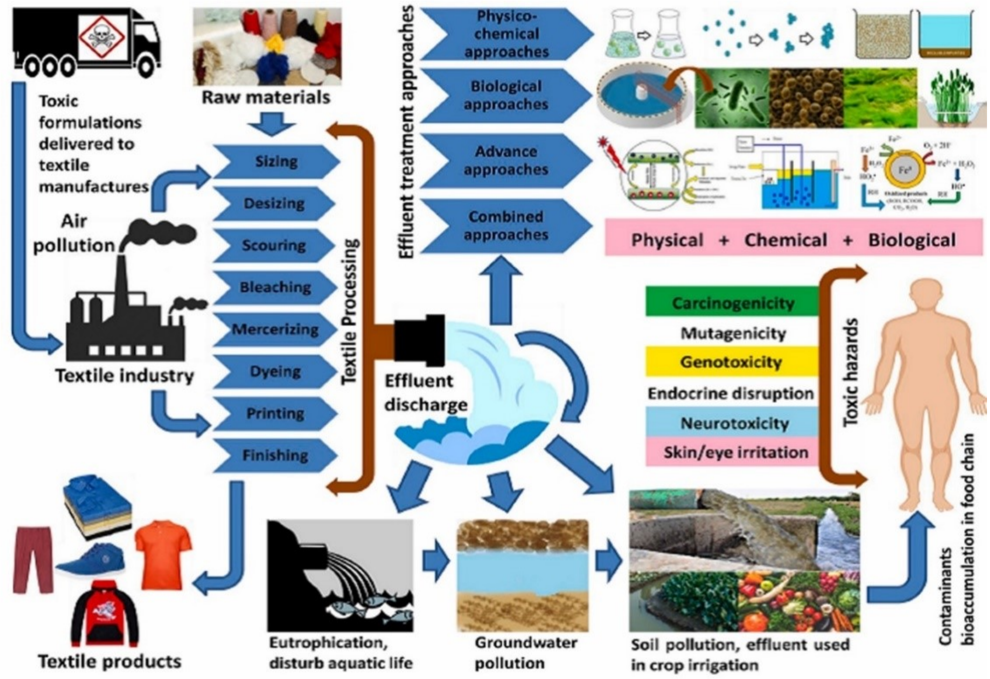


Figure 16. Wastewater generation in textile industry, its toxicity and various treatment approaches. Reproduced with permission [204]

CONCLUSION

Textile dyeing uses a variety of synthetic colours, including various chemicals, in their processes, which influences the environmental ecosystem. The textiles industries throw harmful chemicals, heavy metals, and other toxic substances into the environment. This review demonstrates a variety of elements that influence dyeing procedures. Various remedial actions are also discussed in this review paper, including wastewater treatment, oxidation process, sodium hypo chloride, photochemical degradation, photocatalytic degradation techniques, electrochemical destruction, supercritical carbon dioxide in dyeing, foam technology for textile finishing, microwave energy in the wet processing, awareness to go green, and pollution prevention treatment to minimize the environmental pollution. ETP is the most effective technique for minimizing environmental problems. Therefore, all people involved in the textile dyeing industry should be made aware of these ecological issues and handle them with respect to the safety of humans, animals, plants, and aquatic life.

Authors' contributions

Study conception and design: Islam MT and Repon MR; data collection: Islam MT and Repon MR; analysis and/or interpretation: Islam MT, Islam T and Repon MR; draft manuscript preparation: Islam MT and Repon MR; Supervision: Islam MT and Repon MR; Critical review: Repon MR. All authors reviewed and approved the final version of the manuscript.

Conflict of Interest

The authors have declared no conflicts of interest.

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