Int.J.Curr.Microbiol.App.Sci (2024) *13*(03): 78-101

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 13 Number 3 (2024)**
Journal homepage: http://www.ijcmas.com

Review Article https://doi.org/10.20546/ijcmas.2024.1303.007

A Review on Biodegradation of Toxic Dyes of South Gujarat, India

Aishwarya Bharucha[1], Sumaiya A. Shaikh[2*] and Arti Gaur[1]

[1]*Parul University, Vadodara, Gujarat, India*
[2]*C.B.Patel Computer College & J.N.M.Patel Science College, Bharthana (Vesu), Surat-395017, India*

**Corresponding author*

Keywords

Textile dye, Biodegradation, Effluent, Wastewater treatment, Azo dyes

Article Info

Received:
20 January 2024
Accepted:
26 February 2024
Available Online:
10 March 2024

A B S T R A C T

"Degradation of toxic dyes by isolation and Development of Microbial consortia" provides a comprehensive overview of the environmental impact of textile dye effluents, the historical usage of dyes, the classification of textile dyes, methods for textile dye removal, and the future prospects for enhancing dye biodegradation outcomes. It emphasizes the need for further research to improve dye biodegradation outcomes, including the identification of relevant microorganisms, experimental factor limitations, bioremediation sites, and degradation pathways prior to deploying microorganisms in the field. The document also discusses the characteristics of textile effluents, including the presence of various metals, dyes, and other contaminants, and the differences between simulated and real industrial wastewater. Additionally, it highlights the hazardous nature of industrial wastewater, particularly in terms of organic matter concentration and the presence of metals such as cadmium, lead, zinc, and chromium. The survey conducted to assess the biodegradability of industrial textile wastewater is also mentioned, focusing on specific conductivity, pH, TC, total phosphorus, total nitrogen, and chloride content. Overall, the document underscores the importance of understanding degradation pathways, environmental conditions, and kinetics influencing contaminant removal, and the need to ensure minimal harm to plants and aquatic life during the degradation process.

Introduction

The textile and paper industries are particularly problematic among the numerous industrial sectors because they produce large amounts of wastewater that, if released untreated into the environment, could have negative effects. Different chemicals released by industry end up contaminating the environment over time. Many chemicals, such as dyes, pigments, and aromatic molecular structure compounds, were widely employed in many industrial applications, such as textiles, printing, pharmaceuticals, food, toys, paper, plastic, and cosmetics, as a result of the fast industrialization and urbanization of the world (Mohana *et al.,* 2008). The excessive use of dyes is the primary cause of the environmental issues related to textile activity (Tang *et al.,* 2022). Colors influence consumer preferences as well as several sectors. It also enhances a product's aesthetic quality, which encourages customers to buy and hence promotes economic expansion. The dyes that were used are frequently the source of the many colors and tones that we notice. When compared to synthetic dyes, natural dyes are the more secure and sustainable choice (Saxena & Raja, 2014). Water pollution is one of the most serious environmental pollutants endangering biodiversity, with dye-based sectors such as the textile industry being the primary source of effluents into water bodies (Chanwala *et al.,* 2019). Surface and ground waters near dyeing industries are severely contaminated by the brightly colored wastewater from the textile industries, which include colors ranging from 2% for basic dyes to 50% for reactive dyes (O'Neill, 1999).

Wastewater from the standard cotton textile sector is generally distinguished by high pH, color, and biological and chemical oxygen demand (BOD and COD). Untreated dye wastewaters have a high BOD and color, which lowers the dissolved oxygen content and light penetration in receiving water bodies, respectively. If these wastewaters weren't properly treated, they would devastate the natural aquatic ecosystem (Banat, 1996). Colors can be eliminated by using bacteria; novel bacterial strains that are able to decolorize a wide range of colors have also been discovered and studied. Even though a lot of research has been done on how bacteria decolorize dye, more work needs to be done to isolate novel bacteria that can break down a variety of structurally distinct colors. It's also crucial to research their physiological traits and the underlying processes of dye biodegradation at particular pH and temperature ranges (Wang *et al.,* 2009).

On the other hand, a large range of microorganisms, including yeast, fungi, bacteria, and algae, can degrade azo dyes (McEldowney *et al.,* 1993). Dyes can be collapsed by them and transformed into CO2 and H2O (Lade, 2012). Thus, it is now becoming clear that the mineralization and purification of azo dyes through biodegradation is a useful strategy (Willet, 2019). In the current situation, microbial or enzymatic therapy provides an essential, economical, and environmentally friendly way to restore ecosystems contaminated by azo dyes. It may also assist to cut down on the massive amount of water required in comparison to physicochemical techniques. Current studies are concentrated on treating this source of pollution effectively through the use of various biotechnological techniques (Rai, 2005). Numerous microorganisms, such as bacteria, fungi, yeasts, actinomycetes, and algae, may break down azo dyes. Of these, bacterial cells are a cheap and effective method for eliminating different azo dyes from textile dye effluents. It has been documented that certain bacteria, either in pure cultures or in consortiums, are capable of decolorizing dyes (Dafale, 2008).

Dye removal from wastewater effluent has been accomplished using a variety of physicochemical techniques. The use of physical/chemical methods, however, has several inherent disadvantages, including the fact that they are not economically feasible due to the increased energy and chemical requirements, that they cannot completely remove the azo dyes and/or their organic metabolites, that they produce a large amount of sludge that could lead to secondary pollution issues, and that they involve complex procedures (Forgacs *et al.,* 2004; Zhang *et al.,* 2004).

In contrast to physicochemical treatment approaches, microbial or enzymatic decolorization and degradation is an ecologically friendly and economically competitive substitute for chemical decomposition processes that may assist minimize water use (Rai *et al.,* 2005; Verma and Madamwar, 2003). This paper examines different approaches to treating textile effluent that contains azo dyes and highlights the significance of biological approaches, primarily bacterial in nature. Furthermore, we concentrate on the impact of the physical and chemical surroundings, the enzymatic processes involved in bacterial decolorization, and the toxicity of the breakdown by products.

History of Dyes

Since prehistoric times, color has been used as a means of expression, a form of visual communication, and a symbolic art of society. It has also been linked to the cultural evolution of humans, as the use of color in various prehistoric environments has been linked to individual development on the artistic and cognitive levels (Mohadi *et al.,* 2017). The prehistoric record shows that the usage of various colors increased over time, albeit in varied ways depending on the period and location.

The Middle Stone Age/Middle Paleolithic in Africa and Europe is when pigments were first used (150,000–30,000 BC) (Hovers *et al.,* 2003). Though the latest known paintings were created in the fifteenth century in various caves and caverns on the island of Mona, the usage of these colors in cave art dates back further (Samson *et al.,* 2017). Because of the advent of agriculture, prehistoric man's lifestyle shifted from nomadic to sedentary, resulting in the late Neolithic period (6000–3500 BC) and the Bronze Age (3000–1200 BC) marking the beginning of human civilization (Chekalin *et al.,* 2019). Pigments also emphasized the relief of cuneiform tablets, which were created during the emergence of Mesopotamian civilization (3000–2000 BC). However, the pigment created varied in composition according to its intended use. For instance, the red pigment used for black and red decorations in the Mayan civilization (2000 BC–900 AD) contained cerium, whereas the pigment used to adorn pots with red line designs was enhanced with iron and chrome (Pugh *et al.,* 2012). It was challenging to obtain colors in primitive times other than ochre and black. As an illustration, the color blue, which is regarded highly and costs as much as gold, was formerly exclusively found in lapis lazuli reserves in Afghanistan [68], which caused other civilizations to devise methods for producing the colors. The color blue was connected by the ancient Egyptians with the sky and water. They were the first to create Egyptian blue, an artificial blue dye that was created between 2900 and 2750 BC of the fourth dynasty (2630 BC under Sneferu the pharaoh and 2500 BC under Shepseskaf the pharaoh) (Berke, 2002 and Abel, 2012).

The color purple had an impact on many civilizations as well, and it was so unique that only powerful or wealthy individuals could afford to wear clothing dyed in that hue. The Phoenicians were notable for their skill in processing and commercializing the purple color known as "Tyrian," which they derived from either *Murex trunculus* or *Murex brandaris* snails. It is thought that this color first appeared towards the end of the Bronze Age (1550–1200 BC) (Jensen, 1963). In order to produce diverse colors from minerals, vegetables, or insects, it was a constant endeavor for the various civilizations to obtain pigments or dyes. The use of color during the Medieval Ages (the fifth to the fifteenth century) was vivid, distinct, and well-defined.

In contrast to improvements in the dying technique and the movement of colorants around Europe during that era, there was little invention of new dyes during that time (Barnett *et al.,* 2006). Cornelius Drebbel combined tin with cochineal red, which is derived from insects, in 1630 to increase the stability of natural dyes and create the first dye that was mistakenly labeled as manmade (Cornelius, 1630). Carl Scheele created the Emerald Green, also known as Scheele Green, pigment in 1788. Because it was made of copper aceto-arsenite, it was extremely hazardous and wasn't used again until 1960. Because it was made of copper aceto-arsenite, Carl Scheele created the highly deadly Emerald Green, or Scheele Green, pigment in 1788. It wasn't used again until 1960 (Barnett *et al.,* 2006). In 1854, Henry Perkin created and patented Mauveine, the first synthetic color made from coal tar. Perkin's resolution of the production issue signaled the start of new processes for creating artificial colors (Abel, 2012 and Johnston, 2008). The production of new colors was made possible by the use of components derived from coal tar; by 1869, inexpensive synthetic dyes had taken the place of some natural dyes, like alizarin. Subsequently, the synthesis of dyes has expanded, with over 100,000 synthetic ones reported (Abel, 2012 and Paz *et al.,* 2017). The production of dyes was centered in Europe at the start of the 20th century. China and India are currently the world's two biggest manufacturers and suppliers of textiles (Tkaczyk *et al.,* 2020).

Classification of Dyes

Textile dyes have been classified according to their chemical structural (Azo dyes, Nitro dyes, Indigo dyes, Anthraquinone dyes, Phthalein dyes, Triphenyl methyl dyes, Nitrated dyes, etc.) or their industrial application.

Azo dyes

Scientists who have been verified as credible estimate that around one million tons of azo dyes are produced worldwide each year. It comes in a variety of shapes and sizes, and there are currently over 2,000 azo dyes in use that differ fundamentally from one another (Fatima *et al.,* 2017). A single azo linkage exists in monoazo dyes, although azo bond linkages (–N = N–) can occur more than once. Whereas triazodyes have three connections and diazo dyes have two, respectively.

Azole dyes make up about 70% of all dyes used in industry. The textile, cosmetic, leather, pharmaceutical, paper, paint, and food industries all make extensive use of them. The textile, food, paper, printing, leather, and cosmetic sectors are the main businesses that employ azo dyes, which account for over half of all synthetic dyes.

Although azo dyes have a variety of structures, the presence of azo linkage, or N=N, is the most significant structural characteristic. Since this bond can occur more than once, monoazo dyes contain one azo linkage, diazo dyes have two, and triazo dyes have three (Chang & Lin, 2001).

Reactive dyes

Although they are more effective at achieving a high wet strength than the less costly direct dyes, their employment is not always feasible due to the challenges associated with achieving adequate unison. Because reactive dyes are the only textile colorants intended to form a covalent bond with the substrate during the manufacturing process, they have a slightly lower chlorine-fastness and excellent light-fastness under extreme conditions than vat dyes. Reactive dyes also provide a wide range of shades with good light-fastness and excellent wash-fastness on cotton. These characteristics put this category of dyes at the premium end of the market (Farouk & Gaffer, 2013). The first commercial reactive dyes for cotton were based on the dichloro-s-triazine reactive group. These dyes are the second largest classes of dyes because of their wide spectrum of colors, great wet fastness, and brilliance, reactive dyes have grown increasingly popular (Zhang *et al.,* 2005).

Vat dyes

The vat dyes are designed to be applied to cellulosic fibers, particularly cotton, which exhibits exceptional fastness to various agents such as washing, bleach, light, and so on. This is primarily because the dyes are insoluble in water (Burkinshaw *et al.,* 2013). Vat dyes are rarely, if ever, used on other kinds of fiber, where alternative dye classes are preferred. In fact, when it comes to synthetic fibers, vat dyes are rarely used because of their generally low substantivity and the generally pale depths of hues that result from their limited diffusional behaviour within the fibers. They are mainly soluble in hot water and some are soluble in the presence of little Na_2CO_3.The most significant natural vat dye is called indigo, or indigotin, which is present in different species of the indigo plant Indigofera as its glucoside, indican. When extremely high light- and wet-fastness qualities are needed, vat dyes are employed (BenkhayaM'rabet & El Harfi, 2020).

Sulphur dyes

The first sulphur dye has been prepared in 1873 by Croissant and Bretonnière (Holme, 2006). The most important natural vat dye is known as indigo, or indigotin, and it can be found in several species of the Indigofera plant as the glucoside indican. Vat dyes are used when very high light- and wet-fastness requirements are met (Nguyen & Juang, 2013). Sulphur dyes accounted for 9.1% of all US dye output in 1966 and 15.8% of dyes used on cellulosic fibers (Mohadi *et al.,* 2017). Global production was estimated to be between 110,000 and 120,000 tons annually. Vat dyes include the sulfur dyes (Benkhaya, M'rabet & El Harfi, 2020).

Direct dyes

A variety of factors, including chromophore, fastness qualities, and application features, are used to categorize direct dyes. These are the main chromophoric types: formazan, anthraquinone, quinolone, thiazole, and other minor chemical classes including azo, stilbene, phthalocyanine, and dioxazin (Burkinshaw, 1995). Based on a variety of factors, including chromophore, fastness qualities, and application features. The chromophoric category of direct dyes consists of oxazine, phthalocyanine, stibene, and azo, as well as some thiazole and copper complex azo dyes (Pillai *et al.,* 2011). The moderate wash-fastness of these dyes, despite their wide shade gamut and ease of application, has caused them to be somewhat replaced by reactive dyes, which have substantially higher wet and washing fastness qualities on cellulose substrates.

Characteristics of Textile Dye Effluent

The textile plant's general effluent is often averaged to reflect the textile wastewater characteristics reported in literature. Although Yaseen and Scholz (2019) focused on the fragmented data pertaining to simulated textile wastewater, they did provide a critical analysis of the literature that is currently accessible regarding typical and genuine characteristics of the textile effluents. It is noteworthy to mention that numerous experimental studies on simulated textile wastewater, if not in single dye or model dye mixtures, have been conducted in the literature on dye removal. The treatment of simulated wastewater differs significantly from that of real industrial wastewater, as demonstrated by Bilinska *et al.,* in (Wrebiak *et al.,* 2014).

A variety of metals, dyes, and other contaminants can be found in the wastewater released by the dye industry. Industrial wastes can be classified as either liquid or solid, depending on the type of waste generated during the manufacturing process. These wastes comprise any substance that can be decreased during the product manufacturing process. Because liquid waste (also known as wastewater released by industry) contains many hazardous elements, it poses a threat to both the environment and living things currently in existence. However, the kind of production method and goods used determine the nature and features of industrial effluent (Saxena and Bharagava, 2017).

Metals and their complexes, which are either dissolved or present in various forms in actual water effluents, are recognized as one of the main contaminants in wastewater treatment. The most hazardous metals discovered in wastewater from textile industry manufacturing processes include cadmium, lead, zinc, and chromium, among others (Hussein, 2013).

Wet process effluent from the dye industry is characterized by significant differences in a number of characteristics, including pH, total solids (TS), biological oxygen demand, chemical oxygen demand (COD), water use, and color. Wastewater with a BOD/COD ratio of 0.25 indicates that it is industrial wastewater with a high concentration of organic matter that is not biodegradable.

A survey was conducted to assess the biodegradability of industrial textile wastewater from various dyehouse operations, including specific conductivity, pH, COD, BOD, TC, TOC, total phosphorus, total nitrogen, and chloride content (Bili ´nska, Gmurek and Ledakowicz, 2016). Biodegradability was determined based on BOD5/COD, N/P, BOD5/N/P, and toxicity towards activated sludge microorganisms.

Based on this, it was determined that dye effluent streams needed to be divided based on how biodegradable they were. This is in line with the recommendations of the revised BREF document (December 2019) (European Commission, 2019) and the July 2003 (The European Commission, 2003) European Commission Integrated Pollution Prevention and Control (IPPC) Reference Document on Best Available Techniques for the Textiles Industry (The European Commission, 2003)—decentralized treatment on site of specific, segregated single wastewater streams.

Methods Used in Textile Dyes Removal

These days, protecting aquatic life in water bodies through the development of cost-effective treatment solutions for wastewater discharge from textile businesses is the main priority. Thus, the techniques could be biochemical, physio-chemical, or any combination of the two, which will provide efficient strategies for eliminating impurities from wastewater originating from the textile industries.

Physicochemical Methods

A combination of chemical and physical methods is known as physico-chemical degradation. A physico-chemical treatment is a procedure in which chemical changes may or may not occur at different stages of the process, but physical changes remain constant (Karimifard and Alavi Moghaddam, 2018).

Despite the fact that physico-chemical wastewater treatment techniques are simple to apply, they might not necessarily be economical or environmentally beneficial (De Gisi *et al.,* 2016). Due to the production of numerous byproducts and sludge that cannot be recycled, a high electricity consumption with a low output is necessary (Khandare and Govindwar, 2015; Demirbas, 2009). These techniques involve a multistage treatment approach with a lengthy retention period rather than a single phase. Physical approaches that rely on the coagulation-flocculation of colors work well for removing mostly sulfur and dispersed dyes, but they have very minor effect on acid, direct, reactive, and vat dyes. Furthermore, the implementation of these procedures is limited by the high amount of sludge produced and low color removal efficacy (Vandevivere *et al.,* 1998). Several physical approaches, including ion-exchange, oxidation, radiation, filtration, and adsorption, are frequently employed in wastewater treatment and have yielded beneficial results (Aplin and Waite, 2000). The increased efficacy of adsorption techniques in eliminating a broad spectrum of dyes has attracted significant attention. High affinity, capacity for target chemicals, and the potential for adsorbent regeneration are among the qualities that go into choosing an adsorbent (Subramaniam *et al.,* 2009). Because of its expensive cost, activated carbon (AC) is not frequently employed even though it is a very good adsorbent for many kinds of dyes (Robinson *et al.,* 2001). Some researchers use inexpensive adsorbent materials for the color removal of dye wastewater, such as peat, bentonite clay, fly ash, polymeric resins, ion exchangers, and many biological materials like corn/maize cobs, maize stalks, and wheat straw, in order to make the process more economically viable (Vandevivere *et al.,* 1998). However, difficulties with their regeneration or disposal, significant sludge production, poor efficacy with a wide range of dyes, and high cost have restricted the practical utilization of these adsorbents (Anjanayelu *et al.,* 2005;

Karcher *et al.,* 2001). Researchers shed light on the adsorption method's limitations in handling undissolved dye compounds and the need for a different desorption technique. The irradiation process demands a high concentration of dissolved oxygen, yet it has the ability to treat modest volumes of colored water. On the other hand, when various additives are present in the same wastewater, the ion exchange systems respond inadequately and show more deteriorating results when treating different dyes (Bousher *et al.,* 1997; Abu-Saiyed *et al.,* 2013). Reverse osmosis, nanofiltration, and ultra filtration are a few examples of filtration techniques that have been applied to chemical recovery and water reuse. Membranes are a useful tool in the textile industry for separating hydrolyzed colors and dyeing auxiliaries that simultaneously lower wastewater's color, BOD, and COD levels. They are also excellent for bleaching and mercerizing wastewater. Under this method, the kind and porosity of the filter are chosen based on the chemical makeup of the wastewater and the particular temperature needed for the operation (Dos Santos *et al.,* 2007). Membranes, however, have a number of serious disadvantages, such as high investment costs, the possibility of membrane fouling, and the creation of secondary waste streams that require additional treatment (Dos Santos *et al.,* 2007; Robinson *et al.,* 2001).

A variety of chemical treatment techniques are used to eliminate both organic and inorganic contaminants found in wastewater. Chemical oxidation techniques allow dye molecules to be destroyed or broken down. These techniques involve a variety of oxidizing chemicals, including hydrogen peroxide (H_2O_2) and ozone (O_3), and manganese oxide (MnO_4). These oxidizing agents cause alterations in the chemical composition of a substance or a combination of compounds, making the dye molecules more prone to degradation (Metcalf *et al.,* 2003). Nevertheless the actual implementation of this technology is limited by its short life, ineffectiveness against dispersed dyes and those insoluble in water, low capacity to remove COD, and high cost of ozone (Anjaneyulu *et al.,* 2005).

Biological Methods

Pollutants can be broken down biologically, which is environmentally benign and results in full mineralization of organic compounds with little sludge production. According to several studies this approach is the most successful (Varjani *et al.,* 2015; Bhatia *et al.,* 2017; Varjani *et al.,* 2019; Kumar *et al.,* 2020). Anaerobic or aerobic environments can be used for biological deterioration. To decolorize and break down dyes, a variety of microorganisms including bacteria, fungus, yeast, and algae were employed (Ajaz *et al.,* 2020; Ali *et al.,* 2010). An important field of study in the environmental sciences is bioremediation, or the employment of microbial methods to treat pollutants. These methods allow bacteria to spontaneously adapt to the hazardous wastes, giving rise to new, resistant strains that subsequently change different toxic compounds into less dangerous versions. The activity of the biotransformation enzymes is the basis for the biodegradation of resistant substances in the microbial system (Saratale *et al.,* 2007). Studies have shown the significance of enzymes including azoreductase, laccase, peroxidise, and exo-enzymes in the breakdown of dyes. The biological technique aids in the elimination of color by breaking down synthetic dyes into a relatively less hazardous inorganic substance by the breakdown of bonds (i.e., chromophoric groups) (Babu *et al.,* 2015). Several biotechnological approaches have drawn attention as viable environmentally acceptable ways to reduce the pollution caused by azo dyes. These strategies mostly include the utilization of bacteria and frequently involve physicochemical processes as well. The azo dyes are broken down into amines in two stages: first, the colors undergo azo bond breaking, and then, in an aerobic environment, the aromatic amines are further catabolized into small, non-toxic molecules (Chequer *et al.,* 2011).

In order to fully degrade the azo linkages created inside the dyes, methods are being developed to take advantage of bacteria's capacity to live in both aerobic and anaerobic environments. The two-phase approach, in which anaerobic processes precede aerobic processes in the first phase, has been shown to be successful and beneficial in the development of biological technologies for decolorization in the future (Muda *et al.,* 2013).

Azo dyes are xenobiotics by nature and resistant to biodegradation; hence, the following benefits can be obtained by treating textile effluent with microbes or enzymes to completely decolorize and degrade these colors: The advantages of this process over physicochemical approaches include: (1) being less water-intensive; (2) producing less sludge; (3) being cost-competitive; (4) yielding end products that are non-toxic or have complete mineralization; and (5) being environmentally benign (Banat *et al.,*1996; Rai *et al.,* 2005).

Table.1 Azo dye (Sharma *et al.,* 2021)

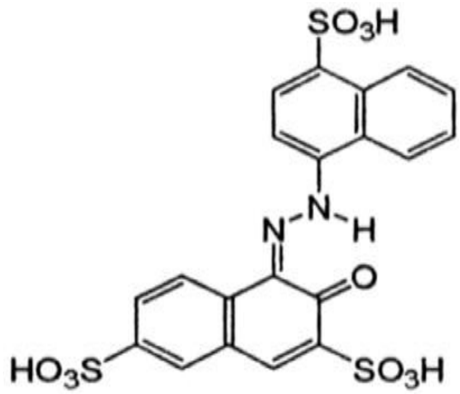
Dye	C.I No.	Class	Chemical Structure
C.I. Acid Red	C.I.16185	Azo	

Table.2 Reactive dye (Khatri *et al.,* 2014a, b)

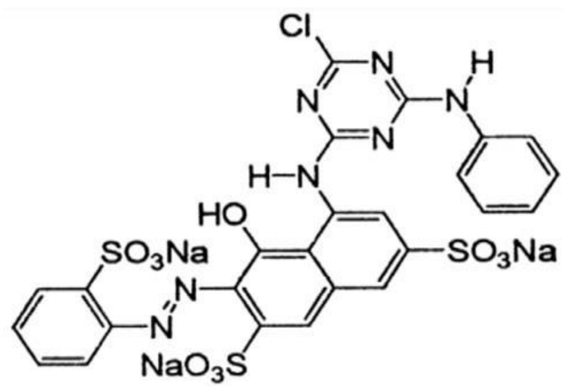
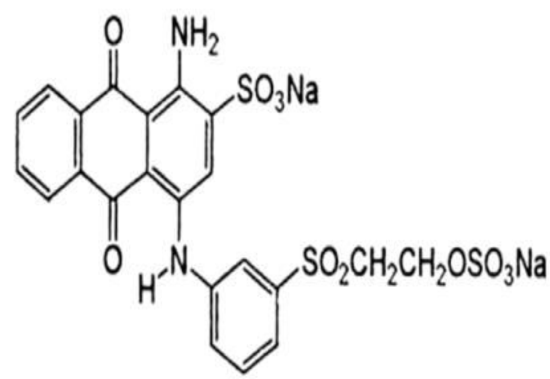
Dye	C.I No.	Class	Chemical Structure
C.I. Reactive Red 3	C.I.18159	Azo	
C.I. Reactive Blue 19	C.I. 61200	Anthraquinones	

Table.3 Vat dye (Hihara *et al.,* 2002; Sirianuntapiboon *et al.,* 2006; Sanchez, 2015).

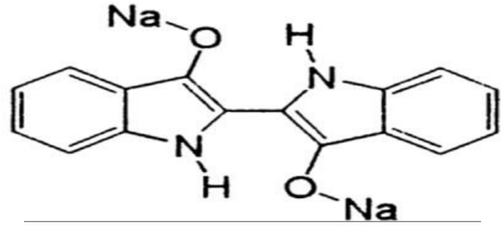
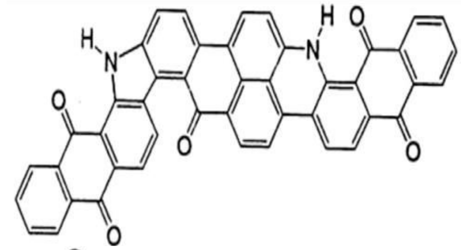
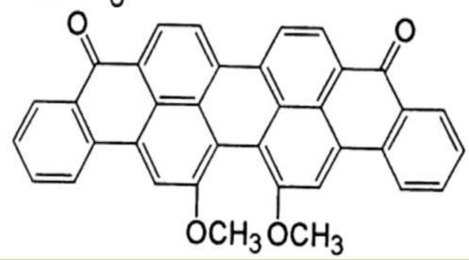
Dye	C.I No.	Class	Chemical Structure
C.I. Vat Blue 1	C.I.73001	Indigo class	
C.I. Vat Black 25	C.I.69525	Anthraquinones	
C.I. Vat Green 1	C.I.59825	Violanthrone	

Table.4 Sulfur dye (Zinatloo-Ajabshir and Salavati-Niasari, 2016).

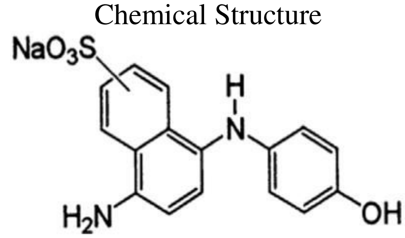
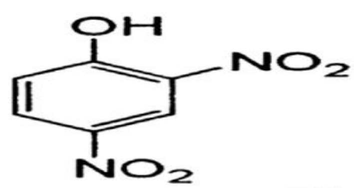
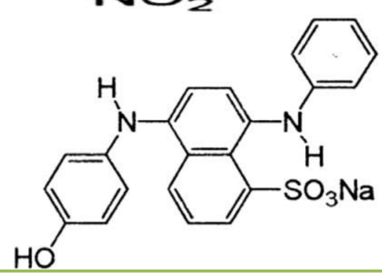
Dye	C.I. No.	Chemical Structure
C.I. Sulfur Blue 15	C.I.53540	
C.I. LeucoSulfur Black1	C.I.53185	
C.I. Sulfur Green 3	C.I.53570	

Table.5 Direct dyes (Lorimer *et al.,* 2021)

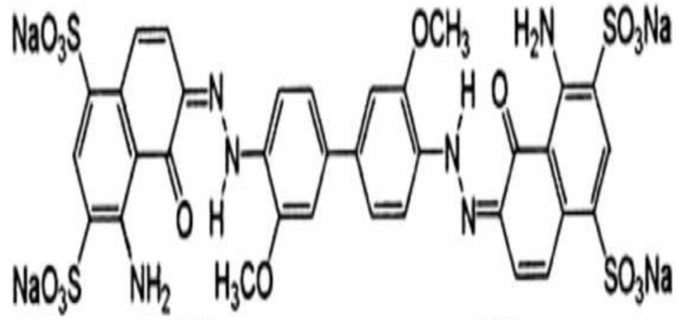
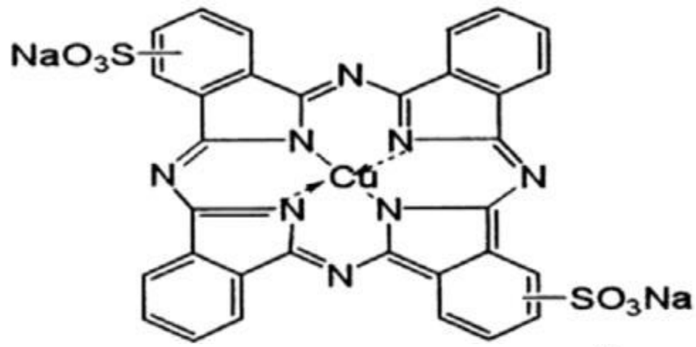
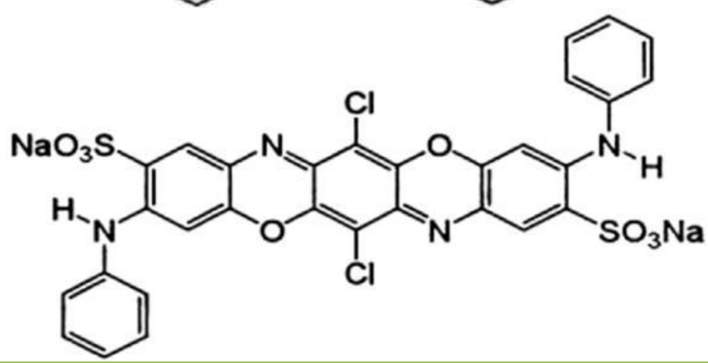
Dye	C.I No.	Class	Chemical Structure
C.I. Direct Blue 1	C.I.24410	Azo	
C.I. Direct Blue 86	C.I.74180	Phthalocyanine	
C.I. Direct Blue 106	C.I.51300	Triphenodioxazine	

Table.6 Current development in processes used in dye removal

Processes	Current Development	References
Adsorption	Synthesizing of new, efficient, nature-based, or waste-originating adsorbents, kinetic, equilibrium and thermodynamic studies on biosorption.	(Zhang *et al.,* 2021; Bonetto *et al.,* 2021; Zhou *et al.,* 2021; Maruthanayagam *et al.,* 2020; Radwan *et al.,* 2020)
Coagulation/Flocculation	Creation of novel, effective, naturally occurring, or waste-producing coagulants and use of magnetic fields to speed up sedimentation	(Kristianto *et al.,* 2020; Mateus *et al.,* 2020; Reck *et al.,* 2020; Padhiyar *et al.,* 2020; Puteri *et al.,* 2020; Garvasis *et al.,* 2020)
Electro-coagulation	Ultrasound aid, nanofilms on cathodes, and solar power	(Ozyonar *et al.,* 2020;

	utilization.	Akhtar *et al.,* 2020; Fan *et al.,* 2020; Phalakornkule *et al.,* 2020; Rodrigues *et al.,* 2020; Criado *et al.,* 2020)
Electrochemical Oxidation	Novel materials and electrode coatings, membrane anodes, air-diffusion cathodes, and the electro-peroxone process	(dos Santos *et al.,* 2020; Yang *et al.,* 2020; Lu *et al.,* 2020; Ghalebizade *et al.,* 2020; Di *et al.,* 2020; Qaseem *et al.,* 2020)
Membrane Filtration	Novel membrane materials stabilized by biomacromolecules and enhanced by the inclusion of grapheme	(Nawaz *et al.,* 2021; Zhang *et al.,* 2021; Meng *et al.,* 2021; Vatanpour *et al.,* 2021; Zeng *et al.,* 2021; Mehrjo *et al.,* 2021)
Ozonation	Addition of the catalyst, improvement through ultrasonography, and hydrodynamic cavitation	(Khataee *et al.,* 2020; Choksi *et al.,* 2020; (Wang *et al.,* 2020; Muniyasamy *et al.,* 2020; Bilinska *et al.,* 2020)
O_3/ UV	Membranes with photocatalytic activity	(Wang *et al.,* 2020)
O_3 /H_2O_2	Proposal for degradation mechanism enhancement using electrolysis and heterogeneous catalyst addition.	(Sun *et al.,* 2019; Sadhegi *et al.,* 2020; Abdi et al. 2020)
UV/H_2O_2	Changes in cytotoxicity, mutagenicity, and phytotoxicity were measured, and a degradation process was proposed. Different UV sources were compared.	(Muneer *et al.,* 2020; Emadi *et al.,* 2020; Ding *et al.,* 2020; Murcia *et al.,* 2020; Aristizábal *et al.,* 2020; Laftani *et al.,* 2019)
Photocatalytic oxidation	Green catalyst production using nanoparticles or difunctional catalysts that are efficient under visible light.	(Fattahimoghaddam *et al.,* 2021; He *et al.,* 2021; Hui *et al.,* 2021; Rambabu *et al.,* 2021; Zhang *et al.,* 2020; Shi *et al.,* 2021)
Fenton	Fenton-like heterogenous catalysts such as zero-valent iron catalysts, green or one-spot catalyst synthesis, fixed bed reactor application, and use of sulphate radical anions that allow dye degradation over a broad pH range.	(Morshed *et al.,* 2020; Qian *et al.,* 2020; Punathil *et al.,* 2020; Kumar *et al.,* 2020; Nwanji *et al.,* 2020)
Photo-Fenton	Fenton-like heterogeneous catalysts that allow dye degradation in the presence of light, catalysts derived from waste, and a degradation mechanism suggestion	(Wu *et al.,* 2021; Mushtaq *et al.,* 2020; Tan *et al.,* 2020; Silva, E.D.N. *et al.,* 2020; Chen, J *et al.,* 2020; Ain, Q.U., *et al.,* 2020)
Electro-Fenton	Analysis of dynamics and expenses, creation of nanocomposite electrodes, air-diffusion cathode, mechanism and degradation paths suggested, innovative orbiting electrode reactor, and recirculating flow-through reactor	(Suhan, M.B.K. *et al.,* 2020; Setayesh, S.R. *et al.,* 2020; Marquez *et al.,* 2020; Zahrani and Ayati, 2020; Ergan and Gengec, 2020; Jiao,Y *et al.,* 2020)
Bacterial Treatment	Isolation of novel strains or consortiums from activated	(Ayed *et al.,* 2020; Guo *et*

	sludge, oxide ditch, palm oil mill effluent, or desert soil; application of alkali-, halo-, and thermophilic strains; consortium with algae; immobilization of bacteria; addition of co-substrates; mechanism and pathway suggestions; genome and transcriptome analysis.	*al.,* 2020; Dhaouefi *et al.,* 2019; Louati *et al.,* 2020; Pandey *et al.,* 2020; Reddy *et al.,* 2020; Shi *et al.,* 2021; Chen *et al.,* 2020; Franca *et al.,* 2020; Thanavel *et al.,* 2019; Montañez-Barragán *et al.,* 2020)
Fungal Treatment	Implementation of microbial consortiums, such as yeast consortiums capable of lignin valorization, dye treatment, and biodiesel generation, as well as fungus immobilization and strain isolation from plant roots or effluent sites.	(Agrawal *et al.,* 2020; Ali *et al.,* 2021; Zhao *et al.,* 2020; Gao *et al.,* 2020; Laraib *et al.,* 2020; Habeeb *et al.,* 2020; Noman *et al.,* 2020; Al-Tohamy *et al.,* 2020; Chatterjee *et al.,* 2020; Šlosarˇcíková *et al.,* 2020; Khan *et al.,* 2020)
Enzyme Treatment	Enzyme synthesis, immobilization, metabolite optimization, and toxicity evaluation optimization.	(Sosa-Martínez *et al.,* 2020; Vineh *et al.,* 2020; Xu *et al.,* 2020; Navas *et al.,* 2020; Yin *et al.,* 2019; Uber *et al.,* 2020)
Algal Treatment	Immobilization, genetic manipulation of algae and cyanobacteria, co-contaminant impact on dye biodegradation, addition of graphene oxide, and lipid synthesis.	(Abou-El-Souod, G.; Hamouda, R.A.; El-Sheekh, M, 2020; Han, S. *Et al.,* 2020; Mahajan, P. and Kaushal, J., 2020; Oyebamiji *et al.,* 2019; Behl, K. *Et al.,* 2020)
Activated and Anaerobic Sludge	Anaerobic core with an aerobic shell granule formation, metagenomic analysis in anaerobic MBR, resuscitation-promoting factor addition, anaerobic and aerobic reactor integration, halotolerant yeast addition, and magnetic field	(Zhu *et al.,* 2020; Berkessa *et al.,* 2020; Cai *et al.,* 2021; Gadow, S.I. and Li, Y.Y, 2020; Tang *et al.,* 2020; Zhuang *et al.,* 2020; Nguyen *et al.,* 2020; . Shoukat, R.; Khan, S.J. and Jamal, Y., 2019; Carvalho *et al.,* 2020)
Biofilms	New biocarrier applications, co-substrate addition, kinetic analysis, process optimization, biomass acclimatization, and anoxic/aerobic sequencing batch moving bed bioreactor optimization	(Hameed, B.B. and Ismail, Z.Z., 2020; Hameed, B.B. and Ismail, Z.Z., 2020; Cui *et al.,* 2020; Ong, C.; Lee, K.; Chang, Y., 2020; Castro *et al.,* 2020)

Factors Affecting Bacterial Degradation

In addition to being practically and financially feasible, microbe-based treatments for the degradation of hazardous environmental pollutants also aid in the management of environmental contaminants (Varjani and

Upasani, 2019). Wastewater from the dye industry contains a variety of azo dyes as well as other dye materials with distinct structural characteristics. According to reports, metals, salts, and other substances impede the decomposition of dyes and are harmful to bacterial growth (Ghosh *et al.,* 2020). Factors like temperature, pH, dissolved oxygen, nutrients, dissolved organic matter, metals and organic pollutants influence water quality.

Environmental Factors Affecting Degration

Temperature

The temperature of the water has an impact on processes that occur there, like mineralization, diffusion, and chemical reactions that raise the pH of the water (Delpla *et al.,* 2009). The ideal temperature for bacterial culture is typically believed to be between 30 and 40 degrees Celsius for the majority of bacteria. This will result in a faster rate of dye breakdown. Reactive green 19 was broken down by a bacterial consortium consisting of *Bacillus pumilus* HKG212 and Zobellellataiwanensis AT 1-3, Das and Mishra (2017) found that the maximum degradation occurred at 32.04oC. Nevertheless, there aren't many thermophilic microorganisms known to degrade azo dye at high temperatures (Das and Mishra, 2017). The decolorization rate of azo dyes was shown to increase until it reaches the ideal temperature, at which point the decolorization activity marginally decreases. Denaturation of an azo reductase enzyme or the loss of cell viability are the two possible causes of this decrease at higher temperatures (Chang, 2017).

pH

pH is essential for bacterial growth and is also required for the treatment of wastewater (Varjani and Upasani, 2019). The rate of color removal is higher at the optimum pH, and tends to decrease rapidly at strongly acid or strongly alkaline pH. The type of dyes and salts employed can determine whether the pH is neutral, acidic, or alkaline. The pH of the effluent containing dye can alter the rate of dye breakdown.

The issue can be resolved by either (a) choosing a microbial species that can flourish at the pH of the effluent or (b) changing the effluent's pH to encourage the growth of bacteria that break down dyes (Al-Amrani *et al.,* 2014).

Changes in pH that fall between 7.0 and 9.5 usually have minimal impact on the dye degradation process.

Chang *et al.,* (2001b), on the other hand, discovered that the dye reduction rate became insensitive to pH in the range of 7.0–9.5, but it rose almost 2.5 times as the pH was elevated from 5.0 to 7.0 (Chang *et al.,* 2041)

Oxygen and Agitation

Dye degradation and decolorization are directly impacted by environmental factors. There is literature out there that claims agitation and oxygen have an impact on microbial metabolism (Varjani and Upasani, 2017). Microorganisms require varied environments, including aerobic, anaerobic, and semi-anaerobic. Shaking contributes to oxygen supply and aeration. Shaking can help with oxygenation. Reductive enzyme activity is thought to be able to increase in anaerobic conditions.

Additionally, it was noted that azo dye decolorization performed under strictly anaerobic circumstances was far better, albeit it also took place in semi-anaerobic environments (Knapp and Newby, 1807). Although it is thought that reductive enzyme activity are higher in anaerobic environments, oxidative enzymes that break down azo dyes also need a tiny quantity of oxygen.

Nutrients

Soluble Salts

Although significant concentrations of salt are used in the dying process, wastewater from the dye business has a high electric conductivity, which can be measured using a conductivity meter. In order to enhance the ionic strength and facilitate the growth of color fixation on textiles, dye baths typically contain salts such as Na2SO4, NaCl, and NaNO3.Salts are discharged into industrial effluent together with dye contaminants. High salt content dyes may slow down the process of biodegradation by limiting biological mobility (Basutkar and Shivannavar, 2019).

Carbon and Nitrogen

Microorganisms require nutrient supplements for quick degradation of pollutants (Varjani and Upasani, 2019). It has been observed that both pure cultures and mixed cultures can quickly and efficiently degrade dyes when using organic supplies such as peptone, yeast extract, or a blend of carbohydrates and complex organic sources. The addition of glucose can improve the efficiency of dye breakdown.

Reducing equivalents from diverse carbon sources have been seen to be transferred to the dye during the decolorization process of azo dyes by reduction of azo bonds. Additionally, it was shown that in anaerobic consortia, acidogenic bacteria transform soluble substrates like carbohydrates into volatile organic acids or alcohols like methanol and acetic acid. These substances then serve as rival substrates for bacteria that are methanogenic, sulfate-reducing, and acetogenic (Georgiou *et al.,* 1975). Phosphorus has 360 been reported as very important factor for growth of microorganism.

Future Prospects

Further research is required to improve dye biodegradation outcomes. This includes determining the (a) relevant microorganisms, (b) experimental factor limitations, (c) bioremediation site, and (d) degradation pathways prior to deploying microorganisms in the field.

As this study makes clear, a great deal of research has been done on the distinct chemical oxidation and biodegradation of dyes as well as integrated techniques that combine the two processes.

Comparable deductions could be made concerning the biodegradation of colors. A thorough investigation was conducted into the biodegradation mechanisms, encompassing the metabolic pathways of intermediates. Additionally, research should be done on the pollutants' competition for chemical oxidants as well as the kinetics of different substrates and co-substrates in biological mixed cultures.
The goal of upcoming research on dye degradation should be to lessen the constraints placed on microbial activity.

An effective biodegradation method should take into account degradation pathways, environmental conditions, degradation rates, and degradation processes that influence contaminant removal. It would be crucial to make sure that neither plants nor aquatic life will be harmed by the deteriorated goods.

To better understand bacterial degradation kinetics, processes and hypotheses for dye wastewater breakdown by bacteria should be studied (Varjani *et al.,* 2020).

Author Contribution

Aishwarya Bharucha: Investigation, formal analysis, writing—original draft. Sumaiya A. Shaikh: Validation, methodology, writing—reviewing. Arti Gaur:—Formal analysis, writing—review and editing.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

References

Abdi, M., Balagabri, M., Karimi, H., Hossini, H., & Rastegar, S. O. (2020). 'Degradation of crystal violet (CV) from aqueous solutions using ozone, peroxone, electroperoxone, and electrolysis processes: A comparison study.' Applied Water Science, 10, 1–10. [CrossRef]

Abel, A. (2012). The history of dyes and pigments: From natural dyes to high performance pigments. In Colour design (pp. 557-587). Woodhead Publishing.

Abou-El-Souod, G., Hamouda, R.A., & El-Sheekh, M. (2020). 'Influence of heavy metal as co-contamination on biodegradation of dyes by free and immobilized Scenedesmus obliquus.' Desalination and Water Treatment, 182, 351–358. [CrossRef]

Abu-Saied, M. A., Abdel-Halim, E. S., Fouda, M. M., and Al-Deyab, S. S. (2013). 'Preparation and characterization of iminated polyacrylonitrile for the removal of methylene blue from aqueous solutions.' International Journal of

Electrochemical Science, 8, pp. 5121-5135.

Agrawal, K., & Verma, P. (2020). 'Myco-valorization approach using entrapped Myrothecium verrucaria ITCC-8447 on synthetic and natural support via column bioreactor for the detoxification and degradation of anthraquinone dyes.' International Biodeterioration & Biodegradation, 153, 105052. [CrossRef]

Ain, Q.U., Rasheed, U., Yaseen, M., Zhang, H., & Tong, Z. (2020). 'Superior dye degradation and adsorption capability of polydopamine modified Fe3O4-pillared bentonite composite.' Journal of Hazardous Materials, 397, 122758. [CrossRef]

Ajaz, M., Shakeel, S., and Rehman, A. (2020). 'Microbial use for azo dye degradation-a strategy for dye bioremediation.' International Microbiology, 23(2), pp. 149-159.

Akhtar, A., Aslam, Z., Asghar, A., Bello, M. M., & Raman, A. A. A. (2020). 'Electrocoagulation of Congo Red dye-containing wastewater: Optimization of operational parameters and process mechanism.' Journal of Environmental Chemical Engineering, 8, 104055. [CrossRef]

Al-Amrani, W.A., Lim, P.E., Seng, C.E., & Wan Ngah, W.S. (2014). Factors affecting bio-decolorization of azo dyes and COD removal in anoxic-aerobic REACT operated sequencing batch reactor. Journal of Taiwan Institute of Chemical Engineers, 45(2), 609-616.

Al-Tohamy, R., Sun, J., Fareed, M.F., Kenawy, E.R., & Ali, S.S. (2020). 'Ecofriendly biodegradation of Reactive Black 5 by newly isolated *Sterigmatomyces halophilus* SSA1575, valued for textile azo dye wastewater processing and detoxification.' Scientific Reports, 10, 1–16. [CrossRef] [PubMed]

Ali, H. (2010). 'Biodegradation of Synthetic Dyes: A Review.' Water Air Soil Pollution, 213, pp. 251-273.

Ali, S.S., Sun, J., Koutra, E., El-Zawawy, N., Elsamahy, T., & El-Shetehy, M. (2021). 'Construction of a novel cold-adapted oleaginous yeast consortium valued for textile azo dye wastewater processing and biorefinery.' Fuel, 285, 119050. [CrossRef]

Anjaneyulu, Y., Sreedhara Chary, N., and Raj, S. S. D. (2005). 'Decolourization of Industrial Effluents-Available Methods and Emerging Technologies—A Review.' Reviews in Environmental Science and Biotechnology, 4, p. 245.

Anjaneyulu, Y., Sreedhara Chary, N., and Raj, S. S. D. (2005). 'Decolourization of Industrial Effluents-Available Methods and Emerging Technologies—A Review.' Reviews in Environmental Science and Biotechnology, 4, p. 245.

Aplin, R. and Waite, T. D. (2000). 'Comparison of three advanced oxidation processes for degradation of textile dyes.' Water Science and Technology, 42, pp. 345-354.

Aristizábal, A., Perilla, G., Lara-Borrero, J.A., & Diez, R. (2020). 'KrCl and XeClexcilamps and LP-Hg lamp for UV and UV/H2O2 decolourization of dyes in water.' Environmental Technology, 41, 238–250. [CrossRef]

Ayed, L., Ladhari, N., Achour, S., & Chaieb, K. (2020). 'Decolorization of Reactive Yellow 174 dye in real textile wastewater by an active consortium: Experimental factorial design for bioremediation process optimization.' Journal of the Textile Institute. [CrossRef]

Babu, S. S., Mohandass, C., Vijayaraj, A. S., and Dhale, M. A. (2015). 'Detoxification and color removal of Congo Red by a novel Dietzia sp. (DTS26)–a microcosm approach.' Ecotoxicology and Environmental Safety, 114, pp. 52-60.

Banat, I. M., Nigam, P., Singh, D., & Marchant, R. (1996). Microbial De-colorization of Textile Dye Containing Effluents: A Review. Biotechnology, 58, 217-227.

Banat, I. M., Nigam, P., Singh, D., and Marchant, R. (1996). 'Microbial Decolorization of Textile Dye-Containing Effluents: A Review.' Bioresource Technology, 58, p. 217.

Barnett, J. R., Miller, S., & Pearce, E. (2006). Colour and art: A brief history of pigments. Optics & Laser Technology, 38(4-6), 445-453.

Basutkar, M.R., & Shivannavar, C.T. (2019). Decolorization Study of Reactive Red-11 by using Dye Degrading Bacterial Strain *Lysinibacillus boronitolerans* CMGS-2. International Journal of Current Microbiology and Applied Sciences, 8(6), 1135-1143.

Behl, K., Joshi, M., Sharma, M., Tandon, S., Chaurasia, A.K., Bhatnagar, A., & Nigam, S. (2019). 'Performance evaluation of isolated electrogenic microalga coupled with graphene oxide for decolorization of textile dye wastewater and subsequent lipid production.' Chemical Engineering Journal, 375, 121950. [CrossRef]

Benkhaya, S., M'rabet, S., & El Harfi, A. (2020). A review on classifications, recent synthesis and applications of textile dyes. Inorganic Chemistry Communications, 115, 107891.

Berkessa, Y.W., Yan, B., Li, T., Jegatheesan, V., & Zhang, Y. (2020). 'Treatment of anthraquinone dye textile wastewater using anaerobic dynamic membrane bioreactor: Performance and microbial dynamics.' Chemosphere, 238, 124539. [CrossRef]

Bhatia, D., Sharma, N. R., Singh, J., and Kanwar, R. S. (2017). 'Biological methods for textile dye removal from wastewater: A review.' Critical Reviews in Environmental Science and Technology, 47(19), pp. 1836-1876.

Bili ´nska, L.; Gmurek, M.; Ledakowicz, S. (2016). Comparison between industrial and simulated textile wastewater treatment by AOPs—Biodegradability, toxicity and cost assessment. Chem. Eng. J., 306, 550–559.

Bili´nska, L., Blus, K., Foszpa´nczyk, M., Gmurek, M., & Ledakowicz, S. (2020). 'Catalytic ozonation of textile wastewater as a polishing step after industrial scale electrocoagulation.' Journal of Environmental Management, 265, 110502. [CrossRef]

Bonetto, L. R., Crespo, J. S., Guégan, R., Esteves, V. I., and Giovanela, M. (2021). 'Removal of methylene blue from aqueous solutions using a solid residue of the apple juice industry: Full factorial design, equilibrium, thermodynamics and kinetics aspects.' Journal of Molecular Structure, 1224, 129296.

Bousher, A., Shen, X., and Edyvean, R. G. (1997). 'Removal of coloured organic matter by adsorption onto low-cost waste materials.' Water Research, 31, pp. 2084-2092.

Burkinshaw, S. M., Jeong, D. S., & Chun, T. I. (2013). The coloration of poly (lactic acid) fibres with indigoid dyes: Part 2: Wash fastness. Dyes and Pigments, 97(2), 374-387.

Cai, J., Pan, A., Li, Y., Xiao, Y., Zhou, Y., Chen, C., Sun, F., & Su, X. (2021). 'A novel strategy for enhancing anaerobic biodegradation of an anthraquinone dye reactive blue 19 with resuscitation-promoting factors.' Chemosphere, 263, 127922. [CrossRef]

Carvalho, J.R.S., Amaral, F.M., Florencio, L., Kato, M.T., Delforno, T.P., & Gavazza, S. (2020). 'Microaerated UASB reactor treating textile wastewater: The core microbiome and removal of azo dye Direct Black 22.' Chemosphere, 242, 125157. [CrossRef]

Castro, F.D., Bassin, J.P., Alves, T.L.M., Sant'Anna, G.L., & Dezotti, M. (2020). 'Reactive Orange 16 dye degradation in anaerobic and aerobic MBBR coupled with ozonation: Addressing pathways and performance.' International Journal of Environmental Science and Technology, 1–20. [CrossRef]

Chang, J. S., Chou, C., Lin, Y., Ho, J., & Hu, T. L. (n.d.). Kinetic Characteristics of Bacterial AzoDye Decolorization by Pseudomonas luteola. Water Research, 35, 2041.

Chang, J. S., Chou, Y. P., & Chen, S. Y. (n.d.). Decolorization of Azo Dyes with Immobilized Pseudomonas luteola. Process Biochemistry, 36, 757.

Chang, J. S., & Lin, C. Y. (2001). Decolorization kinetics of a recombinant *Escherichia coli* strain harboring azo-dye-decolorizing determinants from *Rhodococcus* sp. Biotechnology Letters, 23, 631-636.

Chanwala, J., Kaushik, G., Dar, M. A., Upadhyay, S., & Agrawal, A. (2019). Process optimization and enhanced decolorization of textile effluent by Planococcus sp. isolated from textile sludge. Environmental Technology & Innovation, 13, 122-129.

Chatterjee, S., Dey, S., Sarma, M., Chaudhuri, P., & Das, S. (2020). 'Biodegradation of Congo Red by Manglicolous Filamentous Fungus *Aspergillus flavus* JKSC-7 Isolated from Indian Sundarbans Mangrove Ecosystem.' Applied Biochemistry and Microbiology, 56, 708–717. [CrossRef]

Chekalin, E., Rubanovich, A., Tatarinova, T. V., Kasianov, A., Bender, N., Chekalina, M.,... & Morozova, I. (2019). Changes in biological pathways during 6,000 years of civilization in Europe. Molecular Biology and Evolution, 36(1), 127-140.

Chen, G., An, X., Feng, L., Xia, X., & Zhang, Q. (2020). 'Genome and transcriptome analysis of a newly isolated azo dye-degrading thermophilic strain Anoxybacillus sp.' Ecotoxicology and Environmental Safety, 203, 111047. [CrossRef] [PubMed]

Chen, J., Xing, Z., Han, J., Su, M., Li, Y., & Lu, A. (2020). 'Enhanced degradation of dyes by Cu-Co-Ni nanoparticles loaded on aminomodified octahedral metal–organic framework.' Journal of Alloys and Compounds, 834, 155106. [CrossRef]

Chequer, F. M. D., Dorta, D. J., and de Oliveira, D. P. (2011). 'Azo dyes and their metabolites: does the discharge of the azo dye into water bodies represent human and ecological risks?' In Advances in treating textile effluent. InTech, pp.

27-49.

Chiriu, D., Ricci, P. C., Carbonaro, C. M., Nadali, D., Polcaro, A., & Collins, P. (2017). Raman identification of cuneiform tablet pigments: Emphasis and colour technology in ancient Mesopotamian mid-third millennium. Heliyon, 3(3).

Chokshi, N. P., & Ruparelia, J. P. (2020). 'Catalytic Ozonation of Reactive Black 5 Over Silver–Cobalt Composite Oxide Catalyst.' Journal of the Institution of Engineers Series A, 101, 433–443. [CrossRef]

Cornelius Drebbel combined tin with cochineal red, which is derived from insects, in 1630 to increase the stability of natural dyes and create the first dye that was mistakenly labeled as manmade.

Criado, S. P., Gonçalves, M. J., Ballod Tavares, L. B., & Bertoli, S. L. (2020). 'Optimization of the electrocoagulation process for disperse and reactive dyes using the response surface method with reuse application.' Journal of Cleaner Production, 275, 122690. [CrossRef]

Cui, M.H., Sangeetha, T., Gao, L., & Wang, A.J. (2019). 'Efficient azo dye wastewater treatment in a hybrid anaerobic reactor with a built-in integrated bioelectrochemical system and an aerobic biofilm reactor: Evaluation of the combined forms and reflux ratio.' Bioresource Technology, 292, 122001. [CrossRef] [PubMed]

Dafale, N., Rao, N. N., Meshram, S. U., & Wate, S. R. (2008). Decolorization of azo dyes and simulated dye bath wastewater using acclimatized microbial consortium–biostimulation and halo tolerance. Bioresource technology, 99(7), 2552-2558.

Das, A., & Mishra, S. (2017). Removal of textile dye reactive green-19 using bacterial consortium: Process optimization using response surface methodology and kinetics study. Journal of Environmental Chemical Engineering, 5(1), 612–627.

De Gisi, S., Lofrano, G., Grassi, M., and Notarnicola, M., 2016. 'Characteristics and adsorption capacities of low-cost sorbents for wastewater treatment: A review.' *Sustainable Materials and Technologies*, 9, pp. 10-40.

Delpla, I., Jung, A.V., Baures, E., Clement, M., & Thomas, O. (2009). Impacts of climate change on surface water quality in relation to drinking water production. Environmental International, 35(8), 1225-1233.

Demirbas, A., 2009. 'Agricultural based activated carbons for the removal of dyes from aqueous solutions: A review.' *Journal of Hazardous Materials*, 167, pp. 1-9.

Dhaouefi, Z., Toledo-Cervantes, A., Ghedira, K., Chekir-Ghedira, L., & Muñoz, R. (2019). 'Decolorization and phytotoxicity reduction in an innovative anaerobic/aerobic photobioreactor treating textile wastewater.' Chemosphere, 234, 356–364. [CrossRef]

Di, J., Zhu, M., Jamakanga, R., Gai, X., Li, Y., & Yang, R. (2020). 'Electrochemical activation combined with advanced oxidation on NiCo2O4 nanoarray electrode for the decomposition of Rhodamine B.' Journal of Water Process Engineering, 37, 101386. [CrossRef]

Ding, X., Gutierrez, L., Croue, J.P., Li, M., Wang, L., & Wang, Y. (2020). 'Hydroxyl and sulfate radical-based oxidation of RhB dye in UV/H2O2 and UV/persulfate systems: Kinetics, mechanisms, and comparison.' Chemosphere, 253, 126655. [CrossRef]

dos Santos, A. B., Cervantes, F. J., and van Lier, J. B. (2007). 'Review Paper on Current Technologies for Decolourisation of Textile Wastewaters: Perspectives for Anaerobic Biotechnology.' Bioresource Technology, 98, p. 2369.

Dos Santos, A. J., Brillas, E., Cabot, P. L., &Sirés, I. (2020). 'Simultaneous persulfate activation by electrogenerated H2O2 and anodic oxidation at a boron-doped diamond anode for the treatment of dye solutions.' Science of the Total Environment, 747, 141541. [CrossRef]

Emadi, Z., Sadeghi, M., Mohammadi-Moghadam, F., Sadeghi, R., Forouzandeh, S., & Sadeghi, R. (2020). 'Decolorization of reactive black-5 high concentration by vermicompost microflora and detoxification of by-products by UV-C/H2O2 post-treatment.' Pollution, 6, 503–511.

Ergan, B.T., & Gengec, E. (2020). 'Dye degradation and kinetics of an online Electro-Fenton system with thermally activated carbon fiber cathodes.' Journal of Environmental Chemical Engineering, 8, 104217. [CrossRef]

European Commission. (2019). European IPPC Bureau Review of the Best Available Techniques (BAT) Reference Document for the Textiles Industry; European Commission: Bruseels, Belgium, Volume 1, pp. 2–32.

Fan, T., Deng, W., Feng, X., Pan, F., & Li, Y. (2020). 'An integrated electrocoagulation—Electrocatalysis water treatment process using stainless steel cathodes coated with ultrathin TiO2 nanofilms.' Chemosphere, 254, 126776. [CrossRef] [PubMed]

Farouk, R., & Gaffer, H. E. (2013). Simultaneous dyeing and antibacterial finishing for cotton cellulose using a new reactive dye. Carbohydrate Polymers, 97(1), 138-142.

Fattahimoghaddam, H., Mahvelati-Shamsabadi, T., & Lee, B.K. (2021). 'Efficient Photodegradation of Rhodamine B and Tetracycline over Robust and Green g-C3N4 Nanostructures: Supramolecular Design.' Journal of Hazardous Materials, 403, 123703. [CrossRef]

Forgacs, E., Cserhati, T., & Oros, G. (2004). Removal of Synthetic Dyes from Wastewaters: A Review. Environmental International, 30, 953.

Franca, R.D.G., Vieira, A., Carvalho, G., Oehmen, A., Pinheiro, H.M., Barreto Crespo, M.T., & Lourenço, N.D. (2020). 'Oerskoviapaurometabola can efficiently decolorize azo dye Acid Red 14 and remove its recalcitrant metabolite.' Ecotoxicology and Environmental Safety, 191, 110007. [CrossRef]

Gadow, S.I., & Li, Y.Y. (2020). 'Development of an integrated anaerobic/aerobic bioreactor for biodegradation of recalcitrant azo dye and bioenergy recovery: HRT effects and functional resilience.' Bioresource Technology Reports, 9, 100388. [CrossRef]

Gao, T., Qin, D., Zuo, S., Peng, Y., Xu, J., Yu, B., Song, H., & Dong, J. (2020). 'Decolorization and detoxification of triphenylmethane dyes by the isolated endophytic fungus, Bjerkanderaadusta SWUSI4, under non-nutritive conditions.' Bioresources and Bioprocessing, 7, 1–12. [CrossRef]

Garvasis, J., Prasad, A. R., Shamsheera, K. O., Jaseela, P. K., & Joseph, A. (2020). 'Efficient removal of Congo red from aqueous solutions using phytogenic aluminumsulfate nano coagulant.' Materials Chemistry and Physics, 251, 123040. [CrossRef]

Georgiou, D., Metallinou, C., Aivasidis, A., Voudrias, E., & Gimouhopoulos, K. (n.d.). Decolorization of Azo-Reactive Dyes and Cotton-Textile Wastewater Using Anaerobic Digestion and Acetate-Consuming Bacteria. Biochemical Engineering Journal, 19, 75.

Ghalebizade, M., & Ayati, B. (2020). 'Investigating electrode arrangement and anode role on dye removal efficiency of electro-peroxone as an environmentally friendly technology.' Separation and Purification Technology, 251, 117350. [CrossRef]

Ghosh, S.K., Saha, P.D., & Francesco Di, M. (Eds.). (2020). Recent Trends in Waste Water Treatment and Water Resource Management. Springer Nature Singapore Pvt. Ltd. Springer, Singapore.

Guo, G., Hao, J., Tian, F., Liu, C., Ding, K., Xu, J., Zhou, W., & Guan, Z. (2020). 'Decolorization and detoxification of azo dye by haloalkaliphilic bacterial consortium: Systematic investigations of performance, pathway, and metagenome.' Ecotoxicology and Environmental Safety, 204. [CrossRef]

Habeeb Mohamed, V.B., Arunprasath, R., & Purusothaman, G. (2020). 'Biological treatment of azo dyes on effluent by Neurospora sp isolated and adopted from dye contaminated site.' Journal of The Textile Institute, 111, 1239–1245. [CrossRef]

Hameed, B.B., & Ismail, Z.Z. (2020). 'Biodegradation of reactive yellow dye using mixed cells immobilized in different biocarriers by sequential anaerobic/aerobic biotreatment: Experimental and modelling study.' Environmental Technology, 1–20. [CrossRef] [PubMed]

Hameed, B.B., & Ismail, Z.Z. (2020). 'New application of *Orchis mascula* as a biocarrier for immobilization of mixed cells for biodegradation and detoxification of reactive azo dyes.' Environmental Science and Pollution Research, 27, 38732–38744. [CrossRef] [PubMed]

Han, S., Han, W., Chen, J., Sun, Y., Dai, M., & Zhao, G. (2020). 'Bioremediation of malachite green by cyanobacterium *Synechococcus elongatus* PCC 7942 engineered with a triphenylmethane reductase gene.' Applied Microbiology and Biotechnology, 104, 3193–3204. [CrossRef]

He, Z., Liang, R., Zhou, C., Yan, G., & Wu, L. (2021). 'Carbon quantum dots (CQDs)/noble metal co-decorated MIL-53(Fe) as difunctional photocatalysts for the simultaneous removal of Cr(VI) and dyes.' Separation and Purification Technology, 255, 117725. [CrossRef]

Hihara, T., Okada, Y., Morita, Z. (2002). 'Photo-oxidation and -reduction of vat dyes on water-swollen cellulose and their lightfastness on dry cellulose'. *Dye. Pigment.*, 53. [Online] Available at: http://dx.doi.org/10.1016/S0143-7208(02)00017-7.

Hovers, E., Ilani, S., BarYosef, O., & Vandermeersch, B.

(2003). An early case of color symbolism: ochre use by modern humans in Qafzeh Cave. Current Anthropology, 44(4), 491-522.

Hui, J., Pestana, C.J., Caux, M., Gunaratne, H.Q.N., Edwards, C., Robertson, P.K.J., Lawton, L.A., & Irvine, J.T.S. (2021). 'Graphitic-C3N4 coated floating glass beads for photocatalytic destruction of synthetic and natural organic compounds in water under UV light.' Journal of Photochemistry and Photobiology A: Chemistry, 405, 112935. [CrossRef]

Hussein, F.H. (2013). Chemical properties of treated textile dyeing wastewater. Asian J. Chem., 25, 9393–9400.

Jiao, Y., Ma, L., Tian, Y., & Zhou, M. (2020). 'A flow-through electro-Fenton process using a modified activated carbon fiber cathode for orange II removal.' Chemosphere, 252, 126483. [CrossRef]

Jensen, L. B. (1963). Royal purple of Tyre. Journal of Near Eastern Studies, 22(2), 104-118.

Karcher, S., Kornmuller, A., and Jekel, M. (2001). 'Screening of Commercial Sorbents for the Removal of Reactive Dyes.' Dyes and Pigments, 51, p. 111.

Karimifard, S., Alavi Moghaddam, M. R., 2018. 'Application of response surface methodology in physicochemical removal of dyes from wastewater: A critical review.' *Science of the Total Environment*, 640-641, pp. 772-797.

Khan, S.A., Mehmood, S., Nabeela, Iqbal, A., & Hamayun, M. (2020). 'Industrial polluted soil borne fungi decolorize the recalcitrant azo dyes Synozol red HF–6BN and Synozol black B.' Ecotoxicology and Environmental Safety, 206, 111381. [CrossRef]

Khandare, R. V., and Govindwar, S. P., 2015. 'Phytoremediation of textile dyes and effluents: Current scenario and future prospects.' *Biotechnology Advances*, 33, pp. 1697-1714.

Khataee, A., Fazli, A., Zakeri, F., & Joo, S. W. (2020). 'Synthesis of a high-performance Z-scheme 2D/2D WO3@CoFe-LDH nanocomposite for the synchronic degradation of the mixture azo dyes by the sonocatalytic ozonation process.' Journal of Industrial and Engineering Chemistry, 89, 301–315. [CrossRef]

Khatri, A., White, M., Padhye, R., Momin, N.H. (2014a). 'The use of reflectance measurements in the determination of diffusion of reactive dyes into cellulosic fiber'. *Color Res. Appl.*, 39. [Online] Available at: http://dx.doi.org/10.1002/col.21764.

Knapp, J. S., & Newby, P. S. (n.d.). The Microbiological Decolorization of an Industrial Effluent Containing a Diazo-Linked Chromophore. Water Research, 29, 1807.

Kristianto, H., Tanuarto, M. Y., Prasetyo, S., & Sugih, A. K. (2020). 'Magnetically assisted coagulation using iron oxide nanoparticles-Leucaena leucocephala seeds' extract to treat synthetic Congo red wastewater.' International Journal of Environmental Science and Technology, 17, pp. 3561–3570. [CrossRef]

Kumar, J.E., Mulai, T., Kharmawphlang, W., Sharan, R.N., & Sahoo, M.K. (2020). 'Decolourisation, mineralisation and detoxification of a mixture of azo dyes using Fenton and Fenton-type advanced oxidation processes.' Chemical Papers, 74, 3145–3159. [CrossRef]

Kumar, V., Chandra, R., Thakur, I. S., Saxena, G., and Shah, M. P. (2020). 'Recent Advances in Physicochemical and Biological Treatment Approaches for Distillery Wastewater.' In: Shah M., Banerjee A. (eds) Combined Application of Physico Chemical and Microbiological Processes for Industrial Effluent Treatment Plant. Springer, Singapore, pp. 79-118.

Lade, H. S., Waghmode, T. R., Kadam, A. A., & Govindwar, S. P. (2012). Enhanced biodegradation and detoxification of disperse azo dye Rubine GFL and textile industry effluent by defined fungal-bacterial consortium. International Biodeterioration & Biodegradation, 72, 94-107.

Laftani, Y., Chatib, B., Boussaoud, A., El Makhfouk, M., Hachkar, M., & Khayar, M. (2019). 'Optimization of diazo dye disappearance by the UV/H2O2 process using the Box–Behnken design.' Water Science and Technology, 80, 1731–1739. [CrossRef]

Laraib, Q., Shafique, M., Jabeen, N., Naz, S.A., Nawaz, H.R., Solangi, B., Zubair, A., & Sohail, M. (2020). 'Luffa cylindrica immobilized with *Aspergillus terreus* QMS-1: An efficient and cost-effective strategy for the removal of congo red using a stirred tank reactor.' Polish Journal of Microbiology, 69, 193–203. [CrossRef]

Lorimer, J.P., Mason, T.J., Plattes, M., Phull, S.S., Walton, D.J. (2001). 'Degradation of dye effluent'. In: *Pure and Applied Chemistry*. [Online] Available at: http://dx.doi.org/10.1351/pac200173121957.

Louati, I., Elloumi-Mseddi, J., Cheikhrouhou, W., Hadrich, B., Nasri, M., Aifa, S., Woodward, S.,

&Mechichi, T. (2020). 'Simultaneous cleanup of Reactive Black 5 and cadmium by a desert soil bacterium.' Ecotoxicology and Environmental Safety, 190, 110103. [CrossRef]

Lu, J., Chen, Z., Ayele, B. A., Liu, X., & Chen, Q. (2020). 'Electrocatalytic activities of engineered carbonaceous cathodes for the generation of hydrogen peroxide and the oxidation of recalcitrant reactive dye.' Journal of Electroanalytical Chemistry, 878, 114579. [CrossRef]

Mahajan, P., & Kaushal, J. (2020). 'Phytoremediation of azo dye methyl red by macroalgae Chara vulgaris L.: Kinetic and equilibrium studies.' Environmental Science and Pollution Research, 27, 26406–26418. [CrossRef]

Márquez, A.A., Sirés, I., Brillas, E., & Nava, J.L. (2020). 'Mineralization of Methyl Orange azo dye by processes based on H2O2 electrogeneration at a 3D-like air-diffusion cathode.' Chemosphere, 259, 127466. [CrossRef] [PubMed]

Maruthanayagam, A., Mani, P., Kaliappan, K., and Chinnappan, S. (2020). 'In vitro and In silico Studies on the Removal of Methyl Orange from Aqueous Solution Using Oedogonium subplagiostomum AP1.' Water, Air, Soil Pollution, 231, pp. 1–21.

Mateus, G. A. P., dos Santos, T. R. T., Sanches, I. S., Silva, M. F., de Andrade, M. B., Paludo, M. P., Gomes, R. G., & Bergamasco, R. (2020). 'Evaluation of a magnetic coagulant based on Fe3O4 nanoparticles and *Moringa oleifera* extract on tartrazine removal: Coagulation-adsorption and kinetics studies.' Environmental Technology, 41, pp. 1648–1663. [CrossRef]

McEldowney, S., Hardman, D. J., & Waite, S. (1993). Pollution: ecology and biotreatment. Longman Scientific & Technical.

Mehrjo, F., Pourkhabbaz, A., & Shahbazi, A. (2021). 'PMO synthesized and functionalized by p-phenylenediamine as a new nanofiller in PES-nanofiltration membrane matrix for efficient treatment of organic dye, heavy metal, and salts from wastewater.' Chemosphere, 263, 128088. [CrossRef] [PubMed]

Meng, J., Xie, Y., Gu, Y. H., Yan, X., Chen, Y., Guo, X. J., & Lang, W. Z. (2021). 'PVDF-CaAlg nanofiltration membranes with dual thin-film composite (TFC) structure and high permeation flux for dye removal.' Separation and Purification Technology, 255, 117739. [CrossRef]

Metcalf, E. (2003). 'Wastewater Engineering: Treatment and Reuse,' 4th ed., McGraw-Hill, New York, USA.

Mohadi, R., Hanafiah, Z., Hermansyah, H., & Zulkifli, H. (2017). Adsorption of procion red and congo red dyes using microalgae Spirulina sp. Science and Technology Indonesia, 2(4), 102-104.

Mohana, S., Shrivastava, S., Divehi, J., & Medawar, D. (2008). Response surface methodology for optimization of medium for decolorization of textile dye Direct black 22 by a novel bacterial consortium. *Bioresource Technology*, 99, 562-569.

Montañez-Barragán, B., Sanz-Martin, J.L., Gutiérrez-Macías, P., Morato-Cerro, A., Rodríguez-Vázquez, R., & Barragán-Huerta, B.E. (2020). 'Azo dyes decolorization under high alkalinity and salinity conditions by *Halomonas* sp. in batch and packed bed reactor.' Extremophiles, 20, 239–247. [CrossRef]

Morshed, M.N., Pervez, N., & Behary, N. (2020). 'Statistical modeling and optimization of heterogeneous Fenton-like removal of organic pollutant using fibrous catalysts: A full factorial design.' Scientific Reports, 10, 1–14. [CrossRef]

Muda, K., Aris, A., Salim, M. R., and Ibrahim, Z. (2013). 'Sequential Anaerobic-Aerobic Phase Strategy Using Microbial Granular Sludge for Textile Wastewater Treatment.' In Biomass Now-Sustainable Growth and Use. InTech, pp. 231-264.

Muneer, M., Kanjal, M. I., Saeed, M., Javed, T., Haq, A. U., Ud Den, N. Z., Jamal, M. A., Ali, S., & Iqbal, M. (2020). 'High energy radiation-induced degradation of reactive yellow 145 dye: A mechanistic study.' Radiation Physics and Chemistry, 177, 109115. [CrossRef]

Muniyasamy, A., Sivaporul, G., Gopinath, A., Lakshmanan, R., Altaee, A., Achary, A., & Velayudhaperumal Chellam, P. (2020). 'Process development for the degradation of textile azo dyes (mono-, di-, poly-) by advanced oxidation process—Ozonation: Experimental & partial derivative modelling approach.' Journal of Environmental Management, 265, 110397.

Murcia, M.D., Gómez, M., Gómez, E., Gomez, J.L., Hidalgo, A.M., Murcia, S., & Campos, D. (2020). 'Comparison of two excilamps and two reactor configurations in the UV-H2O2 removal process of amaranth.' Journal of Water Process Engineering, 33, 101051. [CrossRef]

Mushtaq, F., Zahid, M., Mansha, A., Bhatti, I.A., Mustafa, G., Nasir, S., & Yaseen, M. (2020). 'MnFe2O4/coal fly ash nanocomposite: A novel sunlight-active magnetic photocatalyst for dye degradation.' International Journal of Environmental Science and Technology, 17, 4233–4248. [CrossRef]

Navas, L.E., Carballo, R., Levin, L., & Berretta, M.F. (2020). 'Fast decolorization of azo dyes in alkaline solutions by a thermostable metal-tolerant bacterial laccase and proposed degradation pathways.' Extremophiles, 24, 705–719. [CrossRef]

Nawaz, H., Umar, M., Ullah, A., Razzaq, H., Zia, K. M., & Liu, X. (2021). 'Polyvinylidene fluoride nanocomposite super hydrophilic membrane integrated with Polyaniline-Graphene oxide nano fillers for treatment of textile effluents.' Journal of Hazardous Materials, 403, 123587. [CrossRef]

Nguyen, T.H., Watari, T., Hatamoto, M., Sutani, D., Setiadi, T., & Yamaguchi, T. (2020). 'Evaluation of a combined anaerobic baffled reactor–downflow hanging sponge biosystem for treatment of synthetic dyeing wastewater.' Environmental Technology & Innovation, 19, 100913. [CrossRef]

Noman, E., Al-Gheethi, A., Talip, B.A., Mohamed, R., & Kassim, A.H. (2020). 'Decolourization of Dye Wastewater by A Malaysian isolate of *Aspergillus iizukae* 605EAN Strain: A Biokinetic, Mechanism and Microstructure Study.' International Journal of Environmental Analytical Chemistry, 100, 1–24. [CrossRef]

Nwanji, O.L., Omorogie, M.O., Olowoyo, J.O., & Babalola, J.O. (2020). 'Remediation of industrial dye by Fenton-activated biogenic waste.' Surface and Interfaces, 20, 100555. [CrossRef]

O'Neill, C., Hawkes, F. R., Hawkes, D. L., Lourenço, N. D., Pinheiro, H. M., & Delée, W. (1999). Colour in textile effluents–sources, measurement, discharge consents and simulation: a review. Journal of Chemical Technology & Biotechnology: International Research in Process, Environmental & Clean Technology, 74(11), 1009-1018.

Ong, C., Lee, K., & Chang, Y. (2020). 'Biodegradation of mono azo dye-Reactive Orange 16 by acclimatizing biomass systems under an integrated anoxic-aerobic REACT sequencing batch moving bed biofilm reactor.' Journal of Water Process Engineering, 36, 101268. [CrossRef]

Oyebamiji, O.O., Boeing, W.J., Holguin, F.O., Ilori, O., & Amund, O. (2019). 'Green microalgae cultured in textile wastewater for biomass generation and biodetoxification of heavy metals and chromogenic substances.' Bioresource Technology Reports, 7, 100247. [CrossRef]

Özyonar, F., Gökku¸s, Ö., & Sabuni, M. (2020). 'Removal of disperse and reactive dyes from aqueous solutions using ultrasound-assisted electrocoagulation.' Chemosphere, 258, 127325. [CrossRef]

Padhiyar, H., Thanki, A., Kumar Singh, N., Pandey, S., Yadav, M., & Chand Yadav, T. (2020). 'Parametric and kinetic investigations on segregated and mixed textile effluent streams using *Moringa oleifera* seed powders of different sizes.' Journal of Water Process Engineering, 34, 101159. [CrossRef]

Pandey, K., Saha, P., & Rao, K.V.B. (2020). 'A study on the utility of immobilized cells of indigenous bacteria for the biodegradation of reactive azo dyes.' Preparative Biochemistry & Biotechnology, 50, 317–329. [CrossRef] [PubMed]

Paz, A., Carballo, J., Pérez, M. J., & Domínguez, J. M. (2017). Biological treatment of model dyes and textile wastewaters. Chemosphere, 181, 168-177.

Phalakornkule, C., Suandokmai, T., & Petchakan, S. (2020). 'A solar-powered direct current electrocoagulation system with hydrogen recovery for wastewater treatment.' Separation Science and Technology, 55, pp. 2353–2361. [CrossRef]

Pugh, T. W., & Cecil, L. G. (2012). The contact period of central Petén, Guatemala in color. Res: Anthropology and Aesthetics, 61(1), 315-329.

Punathil, S., Ghime, D., Mohapatra, T., Thakur, C., & Ghosh, P. (2020). 'Fixed Bed Reactor for Removal of Methylene Blue Dye Using Heterogeneous Fenton Catalyst.' Journal of Hazardous, Toxic, and Radioactive Waste, 24, 5515.

Puteri, R. D., Hadisoebroto, R., & Kusumadewi, R. A. (2020). 'Effects of mixing speed on turbidity and dyes removal from wastewater with tiger shrimp shells as biocoagulant.' International Journal of Science and Technology Research, 9, pp. 2089–2095.

Qaseem, S., Dlamini, D. S., Zikalala, S. A., Tesha, J. M., Husain, M. D., Wang, C., Jiang, Y., Wei, X., Vilakati, G. D., & Li, J. (2020). 'Electro-catalytic membrane anode for dye removal from wastewater.' Colloids and Surfaces A: Physicochemical and Engineering Aspects, 603, 125270. [CrossRef]

Qian, H., Hou, Q., Yu, G., Nie, Y., Bai, C., Bai, X., & Ju,

M. (2020). 'Enhanced removal of dye from wastewater by Fenton process activated by core-shell NiCo2O4@FePc catalyst.' Journal of Cleaner Production, 273, 123028. [CrossRef]

Radwan, E.K., Abdel-Aty, A.M., El-Wakeel, S.T., Abdel Ghafar, H.H. (2020). 'Bioremediation of potentially toxic metal and reactive dye-contaminated water by pristine and modified *Chlorella vulgaris*.' Environmental Science and Pollution Research, 27, pp. 21777–21789.

Rai, H. S., Bhattacharyya, M. S., Singh, J., Bansal, T. K., Vats, P., & Banerjee, U. C. (2005). Removal of dyes from the effluent of textile and dyestuff manufacturing industry: a review of emerging techniques with reference to biological treatment. Critical reviews in environmental science and technology, 35(3), 219-238.

Rai, H., Bhattacharya, M., Singh, J., Bansal, T. K., Vats, P., and Banerjee, U. C. (2005). 'Removal of Dyes from the Effluent of Textile and Dyestuff Manufacturing Industry: A Review of Emerging Techniques with Reference to Biological Treatment.' Critical Reviews in Environmental Science and Technology, 35, p. 219.

Rambabu, K., Bharath, G., Banat, F., & Show, P.L. (2021). 'Green synthesis of zinc oxide nanoparticles using Phoenix dactylifera waste as bioreductant for effective dye degradation and antibacterial performance in wastewater treatment.' Journal of Hazardous Materials, 402, 123560. [CrossRef] [PubMed]

Reck, I. M., Baptista, A. T. A., Paixão, R. M., Bergamasco, R., Vieira, M. F., & Vieira, A. M. S. (2020). 'Application of magnetic coagulant based on fractionated protein of *Moringa oleifera* Lam. seeds for aqueous solutions treatment containing synthetic dyes.' Environmental Science and Pollution Research, 27, pp. 12192–12201. [CrossRef] [PubMed]

Reddy, S., & Osborne, J.W. (2020). 'Biodegradation and biosorption of Reactive Red 120 dye by immobilized Pseudomonas guariconensis: Kinetic and toxicity study.' Water Environment Research, 92, 1230–1241. [CrossRef]

Robert, E. (2017). The role of the cave in the expression of prehistoric societies. Quaternary International, 432, 59-65.

Robinson, T., McMullan, G., Marchant, R., and Nigam, P. (2001). 'Remediation of Dyes in Textile Effluent: A Critical Review on Current Treatment Technologies with a Proposed Alternative.' Bioresource Technology, 77, p. 247.

Rodrigues, A. R., Seki, C. C., Ramalho, L. S., Argondizo, A., & Silva, A. P. (2020). 'Electrocoagulation in a fixed bed reactor—Color removal in batch and continuous mode.' Separation and Purification Technology, 253, 117481. [CrossRef]

Sadeghi Rad, T., Khataee, A., Pouran, S. R., & Joo, S. W. (2020). 'The key role of free radicals generated from activation of H2O2, S2O8 2− and ozone over chromium/cerium co-doped magnetite nanoparticles.' Separation and Purification Technology, 239, 116538. [CrossRef]

Sanchez, M. (2015). 'Dyeing of denim yarns with non-indigo dyes'. In: *Denim: Manufacture, Finishing and Applications*. [Online] Available at: http://dx.doi.org/10.1016/B978-0-85709-843-6.00005-6.

Saratale, G. D., Bhosale, S. K., Kalme, S. D., and Govindwar, S. P. (2007a). 'Biodegradation of Kerosene in *Aspergillus ochraceus* (NCIM 1146).' Journal of Basic Microbiology, 47, p. 400.

Saratale, R. G., Saratale, G. D., Chang, J. S., & Govindwar, S. P. (n.d.). Ecofriendly Decolorization and Degradation of Reactive Green 19A Using *Micrococcus glutamicus* NCIM2168. Bioresource Technology, 110, 3897.

Saxena G, Bharagava RN. (2017). Organic and inorganic pollutants in industrial wastes: ecotoxicological effects, health hazards and bioremediation approaches. In: Bharagava RN, editor. Environmental pollutants and their bioremediation approaches. Uttar Pradesh, India: CRC Press, p. 23–56. https://doi.org/10.1201/9781315173351-3.

Saxena, S., & Raja, A. S. M. (2014). Natural dyes: sources, chemistry, application and sustainability issues. In Roadmap to sustainable textiles and clothing: eco-friendly raw materials, technologies, and processing methods (pp. 37-80). Singapore: Springer Singapore.

Setayesh, S.R., Nazari, P., & Maghbool, R. (2020). 'Engineered FeVO4/CeO2 nanocomposite as a two-way superior electro-Fenton catalyst for model and real wastewater treatment.' Journal of Environmental Science, 97, 110–119. [CrossRef] [PubMed]

Sharma, J., Sharma, S., & Soni, V. (2021). 'Classification and impact of synthetic textile dyes on Aquatic Flora: A review'. *Regional Studies in Marine Science*, 45, 101802. [Online] Available at: https://doi.org/10.1016/j.rsma.2021.101802.

Shi, J., Wang, J., Liang, L., Xu, Z., Chen, Y., Chen, S., Xu, M., Wang, X., & Wang, S. (2021). 'Carbothermal synthesis of biochar-supported metallic silver for enhanced photocatalytic removal of methylene blue and antimicrobial efficacy.' Journal of Hazardous Materials, 401, 123382. [CrossRef] [PubMed]

Shi, Y., Yang, Z., Xing, L., Zhou, J., Ren, J., Ming, L., Hua, Z., Li, X., & Zhang, D. (2021). 'Ethanol as an efficient cosubstrate for the biodegradation of azo dyes by Providencia rettgeri: Mechanistic analysis based on kinetics, pathways, and genomics.' Bioresource Technology, 31, 124117. [CrossRef]

Shoukat, R., Khan, S.J., & Jamal, Y. (2019). 'Hybrid anaerobic-aerobic biological treatment for real textile wastewater.' Journal of Water Process Engineering, 29, 100804. [CrossRef]

Silva, E.D.N., Brasileiro, I.L.O., Madeira, V.S., De Farias, B.A., Ramalho, M.L.A., Rodríguez-Aguado, E., & Rodríguez-Castellón, E. (2020). 'Reusable CuFe2O4-Fe2O3 catalyst synthesis and application for the heterogeneous photo-Fenton degradation of methylene blue in visible light.' Journal of Environmental Chemical Engineering, 8, 104132. [CrossRef]

Sirianuntapiboon, S., Chairattanawan, K., Jungphungsukpanich, S. (2006). 'Some properties of a sequencing batch reactor system for removal of vat dyes'. *Bioresour. Technol.*, 97. [Online] Available at: http://dx.doi.org/10.1016/j.biortech.2005.02.052.

Šlosarˇcíková, P., Plachá, D., Malachová, K., Rybková, Z., & Novotný, C. (2020). 'Biodegradation of Reactive Orange 16 azo dye by simultaneous action of *Pleurotus ostreatus* and the yeast *Candida zeylanoides*.' Folia Microbiologica, 65, 629–638. [CrossRef]

Sosa-Martínez, J.D., Balagurusamy, N., Montañez, J., Peralta, R.M.R.A., Moreira, R.d.F.P.M., Bracht, A., & Morales-Oyervides, L. (2020). 'Synthetic dyes biodegradation by fungal ligninolytic enzymes: Process optimization, metabolites evaluation and toxicity assessment.' Journal of Hazardous Materials, 400, 123254.

Subramaniam, S., Sivasubramanian, S., Swaminathan, K., and Lin, F. H. (2009). 'Metabolically Inactive *Trichoderma harzianum* Mediated Adsorption of Synthetic Dyes: Equilibrium and Kinetic Studies.' Journal of Taiwan Institute of Chemical Engineers, 40, p. 394.

Suhan, M.B.K., Shuchi, S.B., Anis, A., Haque, Z., & Islam, M.S. (2020). 'Comparative degradation study of Remazol Black B dye using electro-coagulation and electro-Fenton processes: Kinetics and cost analysis.' Environmental Nanotechnology, Monitoring & Management, 14, 100335. [CrossRef]

Sun, K., Yuan, D., Liu, Y., Song, Y., Sun, Z., & Liu, R. (2019). 'Study on the efficiency and mechanism of Direct Red 80 dye by conventional ozonation and peroxone (O3/H2O2) treatment.' Separation Science and Technology, 55, 1–9. [CrossRef]

Tan, W., Ai, J., Fan, Y., Liu, X., Xu, Y., Zhang, H., & Huang, Y.H. (2020). 'Enhanced mineralization of Reactive Black 5 by waste iron oxide via the photo-Fenton process.' Research on Chemical Intermediates, 46, 4423–4431. [CrossRef]

Tang, Q., Li, Y., Liu, W., Li, B., & Jin, Y. (2022). One-step synthesis of biomimetic copper–cysteine nanoparticle with excellent laccase-like activity. Journal of Materials Science, 57(22), 10072-10083.

Tang, W., Zhou, B., Xing, K., & Tan, L. (2020). 'Co-enhanced activated sludge system by static magnetic field and two halotolerant yeasts for azo dye treatment.' Water Environment Research, 1–10.

Thanavel, M., Kadam, S.K., Biradar, S.P., Govindwar, S.P., Jeon, B.-H., & Sadasivam, S.K. (2019). 'Combined biological and advanced oxidation process for decolorization of textile dyes.' SN Applied Sciences, 1, 1–16. [CrossRef]

The European Commission. (2003). Integrated Pollution Prevention and Control. Reference Document on Best Available Techniques for the Textiles Industr; The European Commission: Brussels, Belgium, p. 626.

Tkaczyk, A., Mitrowska, K., & Posyniak, A. (2020). Synthetic organic dyes as contaminants of the aquatic environment and their implications for ecosystems: A review. Science of the Total Environment, 717, 137222.

Uber, T.M., Buzzo, A.J.d.R., Scaratti, G., Amorim, S.M., Helm, C.V., Maciel, G.M., Peralta, R.A., Moreira, R.d.F.P.M., Bracht, A., & Peralta, R.M. (2020). 'Comparative detoxification of Remazol Rrilliant Blue R by free and immobilized laccase of Oudemansiellacanarii.' Biocatalysis and Biotransformation, 1–12. [CrossRef]

Vandevivere, P. C., Bianchi, R., and Verstraete, W. (1998). 'Treatment and Reuse of Wastewater from the Textile Wet-processing Industry: Review of Emerging Technologies.' Journal of Chemical Technology and Biotechnology, 72, p. 289.

Varjani, S. J., Rana, D. P., Jain, A. K., Bateja, S., and Upasani, V. N. (2015). 'Synergistic ex-situ biodegradation of crude oil by halotolerant bacterial consortium of indigenous strains isolated from onshore sites of Gujarat, India.' International Biodeterioration & Biodegradation, 103, pp. 116–124.

Varjani, S., & Upasani, V.N. (2019a). Influence of abiotic factors, natural attenuation, bioaugmentation and nutrient supplementation on bioremediation of petroleum crude contaminated agricultural soil. Journal of Environmental Management, 245, 358-366.

Varjani, S., & Upasani, V.N. (2019b). Comparing bioremediation approaches for agricultural soil affected with petroleum crude - A case study. Indian Journal of Microbiology, 59(3), 356-364.

Varjani, S., Joshi, R., Srivastava, V. K., Ngo, H. H., and Guo, W. (2019). 'Treatment of wastewater from petroleum industry: current practices and perspectives.' Environmental Science and Pollution Research, 1-9. https://doi.org/10.1007/s11356-019-04725-x.

Varjani, S., Rakholiya, P., Ng, H. Y., You, S., & Teixeira, J. A. (2020). Microbial degradation of dyes: An overview. Bioresource Technology, 314, 123728.

Varjani, S.J., & Upasani, V.N. (2017a). A new look on factors affecting microbial degradation of petroleum hydrocarbon pollutants. International Biodeterioration & Biodegradation, 120, 71-83.

Vatanpour, V., Mousavi Khadem, S. S., Dehqan, A., Al-Naqshabandi, M. A., Ganjali, M. R., Sadegh Hassani, S., Rashid, M. R., Saeb, M. R., & Dizge, N. (2021). 'Efficient removal of dyes and proteins by nitrogen-doped porous graphene blended polyethersulfone nanocomposite membranes.' Chemosphere, 263, 127892. [CrossRef]

Verma, P., & Madamwar, D. (2003). Decolorization of Synthetic Dyes by a Newly Isolated Strain of *Serratia maerascens*. World Journal of Microbiology and Biotechnology, 19, 615.

Vineh, M.B., Saboury, A.A., Poostchi, A.A., & Ghasemi, A. (2020). 'Biodegradation of phenol and dyes with horseradish peroxidase covalently immobilized on functionalized RGO-SiO2 nanocomposite.' International Journal of Biological Macromolecules, 164, 4403–4414. [CrossRef] [PubMed]

Wang, H., Su, J. Q., Zheng, X. W., Tian, Y., Xiong, X. J., & Zheng, T. L. (2009). Bacterial decolorization and degradation of the reactive dye Reactive Red 180 by Citrobacter sp. CK3. International Biodeterioration & Biodegradation, 63(4), 395-399.

Wang, J., Chen, H., Yuan, R., Wang, F., Ma, F., & Zhou, B. (2020). 'Intensified degradation of textile wastewater using a novel treatment of hydrodynamic cavitation with the combination of ozone.' Journal of Environmental Chemical Engineering, 8, 103959. [CrossRef]

Wang, Z., Zhang, Y., Li, K., Sun, Z., & Wang, J. (2020). 'Enhanced mineralization of reactive brilliant red X-3B by UV driven photocatalytic membrane contact ozonation.' Journal of Hazardous Materials, 391, 122194. [CrossRef]

Willet, J., Wetser, K., Vreeburg, J., & Rijnaarts, H. H. (2019). Review of methods to assess sustainability of industrial water use. Water Resources and Industry, 21, 100110.

Wrebiak, J.; Bili ´nska, L.; Pa ´zdzior, K.; Ledakowicz, S. (2014). Biodegradability assessment of wastewater streams from textile dye house (Ocenabiodegradowalno´sciwyodr˛ebnionychstru mieni ´scieków z farbiarni). Przegl ˛adWłókienniczy—WłóknoOdziezSk ˙ óra, 46–49.

Wu, Q., Siddique, M.S., & Yu, W. (2021). 'Iron-nickel bimetallic metal-organic frameworks as bifunctional Fenton-like catalysts for enhanced adsorption and degradation of organic contaminants under visible light: Kinetics and mechanistic studies.' Journal of Hazardous Materials, 401, 123261. [CrossRef]

Xu, L., Sun, K., Wang, F., Zhao, L., Hu, J., Ma, H., & Ding, Z. (2020). 'Laccase production by Trametes versicolor in solid-state fermentation using tea residues as substrate and its application in dye decolorization.' Journal of Environmental Management, 270, 110904. [CrossRef]

Yang, H., Bi, Y., Wang, M., Chen, C., Xu, Z., Chen, K., Zhou, Y., Zhang, J., &Niu, Q. J. (2020). 'β-FeOOH self-supporting electrode for efficient electrochemical anodic oxidation process.' Chemosphere, 261, 127674. [CrossRef]

Yaseen, D.A.; Scholz, M. (2019). Textile Dye Wastewater Characteristics and Constituents of Synthetic Effluents: A Critical Review; Springer: Berlin/Heidelberg, Germany, Volume 16, ISBN 0123456789.

Yin, Q., Zhou, G., Peng, C., Zhang, Y., Kües, U., Liu, J., Xiao, Y., & Fang, Z. (2019). 'The first fungal laccase with an alkaline pH optimum obtained by directed evolution and its application in indigo dye decolorization.' AMB Express, 9, 1–13. [CrossRef]

Zahrani, A.A., & Ayati, B. (2020). 'Improving Fe-based heterogeneous Electro-Fenton nano-catalyst using transition metals in a novel orbiting electrodes reactor.' Chemosphere, 256, 127049. [CrossRef]

Zeng, H., Yu, Z., Shao, L., Li, X., Zhu, M., Liu, Y., Feng, X., & Zhu, X. (2021). 'A novel strategy for enhancing the performance of membranes for dyes separation: Embedding PAA@UiO-66-NH2 between graphene oxide sheets.' Chemical Engineering Journal, 403, 126281. [CrossRef]

Zhang, F., Yediler, A., Liang, X., & Kettrup, A. (2004). Effects of Dye Additives on the Ozonation Process and Oxidation By-Products: A Comparative Study Using Hydrolyzed CI Reactive Red 120. Dyes and Pigments, 60, 1.

Zhang, M. Y., Wang, X. P., Lin, R., Liu, Y., Chen, F. S., Cui, L. S., Meng, X. M., & Hou, J. (2021). Improving the hydrostability of ZIF-8 membrane by biomolecule towards enhanced nanofiltration performance for dye removal. Journal of Membrane Science, 618, 118630. [CrossRef]

Zhang, S., Ma, W., Ju, B., Dang, N., Zhang, M., Wu, S., & Yang, J. (2005). Continuous dyeing of cationised cotton with reactive dyes. Coloration Technology, 121(4), 183-186.

Zhang, S., Zhong, L., Wang, J., Tang, A., & Yang, H. (2021). Porous carbon-based MgAlF5•1.5H2O composites derived from carbon-coated clay presenting super high adsorption capacity for Congo Red. Chemical Engineering Journal, 406, 126784.

Zhang, X., Jia, X., Duan, P., Xia, R., Zhang, N., Cheng, B., Wang, Z., & Zhang, Y. (2020). V2O5/P-g-C3N4 Z-scheme enhanced heterogeneous photocatalytic removal of methyl orange from water under visible light irradiation. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 608, 125580. [CrossRef]

Zhao, J., Wu, Q.X., Cheng, X.D., Su, T., Wang, X.H., Zhang, W.N., Lu, Y.M., & Chen, Y. (2020). 'Biodegradation and detoxification of the triphenylmethane dye coomassie brilliant blue by the extracellular enzymes from mycelia of *Lactarius deliciosus*.' Frontiers of Chemical Science and Engineering, 1–16. [CrossRef]

Zhou, S., Fu, Z., Xia, L., Mao, Y., Zhao, W., Wang, A., Zhang, C., Ding, C., and Xu, W. (2021). 'In situ synthesis of ternary hybrid nanocomposites on natural Juncus effusus fiber for adsorption and photodegradation of organic dyes.' Separation and Purification Technology, 255, 117671.

Zhu, Y., Wang, W., Ni, J., & Hu, B. (2020). 'Cultivation of granules containing anaerobic decolorization and aerobic degradation cultures for the complete mineralization of azo dyes in wastewater.' Chemosphere, 246, 125753. [CrossRef]

Zhuang, H., Shi, J., Shan, S., Ping, L., & Zhang, C. (2020). 'Enhanced anaerobic treatment of azo dye wastewater via direct interspecies electron transfer with Fe3O4/sludge carbon.' International Journal of Hydrogen Energy, 45, 28476–28487. [CrossRef]

Zinatloo-Ajabshir, S., Salavati-Niasari, M. (2016). 'Facile route to synthesize zirconium dioxide (ZrO2) nanostructures: Structural, optical and photocatalytic studies'. *J. Mol. Liq.*, 216. [Online] Available at: http://dx.doi.org/10.1016/j.molliq.2016.01.062.

How to cite this article:

Aishwarya Bharucha, Sumaiya A. Shaikh and Arti Gaur. 2024. A Review on Biodegradation of Toxic Dyes of South Gujarat, India. *Int.J.Curr.Microbiol.App.Sci.* 13(3): 78-101. **doi:** https://doi.org/10.20546/ijcmas.2024.1303.007