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Bioremediation of Textile Dyeing Effluent Using Algae - A Review

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Authors' contributions

This work was carried out in collaboration between both authors. Author MA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author MP managed the analyses of the study. Both authors read and approved the final manuscript.

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Review Article

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ABSTRACT

The textile industry is a substantial consumer of water and it produces enormous volumes of contaminated water: the most important contaminants are dyes and chemicals. Synthetic dyes have an adverse effect on aquatic ecosystem and their toxic substances have to be removed from the effluent before their discharging. Microbial processes for the treatment of textile wastewater have the advantage of being cost effective, environment friendly and producing less sludge. The mechanism of microbial decolourisation occurs from adsorption, enzymatic degradation or a combination of both. The reductase and oxidase enzymes are involved in the microbial degradation process. The goal of microbial treatment is to decolourise and detoxify the dye contaminated wastewater. Recent studies have been focused on the decolourisation or degradation of azo dyes using algae, yeast, fungi and bacteria. Biosorption is simply defined as the removal of substances from solution by biological material. Such substances can be organic, inorganic, gaseous and soluble or insoluble forms. Biosorption is a property of both living and dead organisms. It acts as an indicator for the removal of pollutant from wastewater because of its efficiency, simplicity, analogous operation to conventional ion exchange technology and availability of biomass. A vast number of low cost adsorbents are recommended for wastewater treatment because of their local

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availability, technical feasibility, engineering applicability and cost effectiveness. The low cost adsorbents are well perform in dye removal and widely used in industries not only minimize cost but also improve probability with maximum output. Biological decolourisation of textile dyeing effluent is receiving much concern due to cost effective and less regeneration by microorganisms such as bacteria, fungi, algae, and plants. Algal based remediation technology can provide an excellent resolution for textile wastewater pollution problems. Current status of biological decolourisation and remediation of textile dyeing effluents deals with the most on purpose part on the effects of various parameters like pH, temperature and dye concentrations is briefly discussed in this article.

Keywords: Degradation; biosorption; wastewater; parameters; microalgae.

1. INTRODUCTION

Colour is an observable pollutant which is in effluent has now been measured a pollutant that needs to be treated before discharging it. Industries have shown a significant increase in the use of synthetic complex organic dyes as the colouring material. Almost all the colours that you see today are synthetic dyes. Synthetic dyes today have evolved into a multibillion dollar industry. They are widely used for dyeing and printing in a broad range of industries. There are over 10,000 dyes, and the annual production globally, exceeds over 7×10^5 metric tons [1-3].

The first human-made (synthetic) organic dye; mauveine, was discovered by William Henry Perkin in 1856. Many thousands of synthetic dyes have since been prepared and synthetic dyes quickly replaced the traditional natural dyes. They cost less, they offered a vast range of new colours and they imparted better properties to the dyed materials. India's dye industry produces every type of dyes and pigments. Production of dye stuff and pigments in India is close to 80,000 tones. India is the second largest exporter of dye stuffs and intermediates after China. The textile industry accounts for the largest consumption of dyestuffs, at nearly 80% [4].

Dyes make the world more beautiful through coloured substances, but on the other hand they represent a serious pollution problem for the environment. Almost one million tons of dyes are annually produced in the world [5]. Azo dyes are the most common synthetic colorants released to the environment through textile, pharmaceutical and chemical industries. Over the last decades, the increasing demand for dyes by the textile industry has shown a high pollution potential. It is estimated that around 10 -15% of the dyes are lost in the waste water during the dyeing processes. The effluent from textile industries thus carries a large number of dyes and other additives which are added during the colouring process [6]. The textile industry is the largest consumer of dye stuffs. During the coloration process a large percentage of the synthetic dye does not bind and is lost to the waste stream [7].

Dyes are difficult to remove in conventional water treatment procedures and can be transported easily through sewers and rivers especially because they are designed to have high water solubility. They may also undergo degradation to form products that are highly toxic and carcinogenic. Thus dyes are a potential hazard to living organisms. It is hence important to safeguard the environment from such contaminants. The cleavage of the azo bond to aromatic amine can be stereochemically transformed to an electrophile compound that forms covalent bonds with DNA and deteriorates the DNA double helical structure. This mechanism could initiate the growth of abnormal cancerous cells [8,9]. Many dyes and pigments are hazardous and toxic for human as well as aquatic life at the concentration at which they are being discharged to receiving water. The high concentration of dyes is known to cause ulceration of skin, and mucous membrane, dermatitis, perforation of nasal septum, severe irritation of respiratory tract and on ingestion may cause vomiting, pain, haemorrhage and sharp diarrhoea [10]. A bladder tumour has been identified particularly in dye industry workers than in the general population [11].

Textile industry is one of the fast evolving industries in India, and their rapid growth leads to serious environmental problems especially from bleaching and dyeing units like agriculture issues, rise of heavy metals in ground water, drastic effects on flora and fauna in the surrounding area, etc. Several physicochemical methods (adsorption, chemical precipitation, photolysis, chemical oxidation and reduction, electrochemical treatmen, filtration, coagulation and chemical flocculation,) have been used for textile effluent treatment. However, the performance of physicochemical methods has the inherent drawbacks of being economically unfeasible, being unable to completely remove the recalcitrant azo dyes and their organic metabolites, generating secondary sludge which may cause secondary pollution problems are describe by Forgacs E. et al. [12] still, where as Parikh A. et al. stated that microbial or enzymatic decolorization and degradation is an ecofriendly, low cost alternative to chemical decomposition process that could help reduce water consumption compared to physicochemical treatment methods [13].

Due to a general alarm about the treatment of wastewater, a large number of microorganisms have been used for the treatment of textile wastewater. This review summarises that the algae can be used as an effective biosorptive material for the removal of dyes from textile industry effluent and discusses the mechanism and factors affecting the biosorption process.

1.1 Classification of Dyes

Reactive dyes, including many structurally different dyes, are extensively used in the textile industry because of their wide variety of colour shades, high wet fastness profiles, ease of application, brilliant colors, and minimal energy consumption. The three most common groups are azo, anthraquinone and phthalocyanine [14]. Reactive azo dyes are the most prevalent type of dyes that have been used by the textile industry due to its color intensity and good reactivity toward cellulose [15]. Acid dyes are water soluble generally used for colouring the nylon, wool, silk, leather, paper, food and cosmetics. The chemical classes of these dyes are azo, anthraquinone, triphenylmethane, azine, xanthenes, nitro and nitroso [16].

Azo dye is the largest group of dyes, with a-N=N- as a chromophore in an aromatic system. There are monazo, disazo, trisazo, tetrakisazo and polyazo dyes depending upon the number of azo-groups present. Azo pigments are colourless particles which have been coloured using an azo compound [17]. There are different class of organic compounds characterized by the presence of unsaturated groups such as -C=C- , -N=N- and -C≡N-, which are responsible for the dye colours and functional groups are responsible for their fixation to fibres [18].

Triarylmethane dyes: Triarylmethane dyes are derivatives of the hydrocarbon triarylmethane a hydrocarbon. Acidic triarylmethane dyes containing atleast two SO3H group are used to dye wool and silk fibres. Dyes containing only one SO3H group are used as indicators (e.g. phenolphthalein). Basic triarylmethane dyes are used extensively in the manufacture of stamping inks, writing and printing [19].

Anthraquinone dyes: Anthraquinone dyes have a sulfonic acid group which make them soluble in water. They are used to dye wool and silk due to their affinity towards auxiliary binding agents. A subclass of acid dye called food colouring dyes are used to dye protein fibres and some nylon fibres under high temperature [20].

Direct dyes are used extensively to dye protein fibres can also be used to dye synthetic fibres like nylon and rayon. These dyes are applied under an aqueous bath containing electrolytes and ionic salts. Direct dyes lack the property of getting dried-up fast after they are applied on fabrics [21]. Basic dyes are also considered as cationic dyes. They form a coloured cationic salt when dissolved in water. These cationic salts are found to react with the anionic surface of the substrate. These dyes are found to be powerful colouring agents for acrylic fibres [22].

Disperse dyes are water-insoluble non-ionic dyes and mainly used on polyester, nylon, cellulose and acrylic fibres. It contains azo, anthraquinone, styryl, nitro and benzodifuranone groups. Solvent dyes are used for plastics, gasoline, lubricants, oils and waxes. These dyes are solvent soluble. The chemical classes are predominantly azo and anthraquinone. Sulphur dyes are used for colouring the cotton, rayon, silk, leather, paper and wood. Vat dyes are water insoluble and mainly used for colouring the cellulosic fibres. The primary chemical classes are anthraquinone and indigoids [23].

1.2 Hazardous Effects of Dyes

Effluent from the textile and dyeing industries release highly coloured dyes which is the most obvious indicator of water pollution. The discharge of these highly coloured effluents can damage the aquatic environment [24].

Natural pigments used for colouring textile have been replaced by fast colours which do not fade on exposure to sunlight, heat and water. These features unfortunately go with the perils of harmful effluent quality. About 15% of textile dyes used for dyeing process are released into water. Besides being anaesthetic, these effluents are mutagenic, carcinogenic and toxic [25].

Industrial effluents containing dyes reduce sunlight penetration in receiving water bodies affect the photosynthetic activities of aquatic flora and the growth of microorganisms. The thin layer of discharged dyes formed over the surface of receiving water body also decreases the amount of dissolved oxygen in the water, there by affecting the aquatic flora and fauna. Furthermore, dye containing effluents increase the COD level which indicates high degree of pollution [26].

[27] observed an adverse effect in *Aillum cepa* chromosomal aberrations like fragmentation, bridge formation, lagging chromosome, multipolarity and lack of cytokinesis in *Aillum cepa* treated with textile dyeing effluent. The untreated dyeing effluents that are directly used in irrigation have a serious impact on environment by reducing the soil fertility, seed germination, chlorophyll and protein content of plants. The textile dyes damage the liver, gills, intestine and gonads of aquatic organisms also [28].

Dyes undergo alteration in chemical structure and leads to the formation of new xenobiotic compounds which have a serious impact on environment. They can also cause skin irritation, allergy, cancer, human health disorders such as nausea, vomiting, paralysis and causes severe damages to liver, kidney, reproductive system, brain and central nervous system [29].

2. PRESENT TREATMENT METHODS FOR DYE TREATMENT

The increasing demand of water and the dwindling supply has made the treatment and reuse of industrial effluents an attractive option. Standards for treated wastewater are becoming increasing stringent and therefore the improved efficiency of biological treatment processes is indispensable at industrial effluent treatment plants [30]. The most problematic industries in terms of dye release to the environment in the form of wastewater are the dye manufacturing and the dyeing industries. The uncontrolled release of these dyes to the environment causes severe problems, since they are designed to be chemically and photolytically stable and they are highly persistent in natural environment [31].

Water pollution control is one of the most challenging area and increasing effects are directed to research and development of novel wastewater treatment methods [32]. Several physicochemical methods such as precipitation, sorption, ozonation, ultrafiltration, reverse osmosis and electrochemical treatment have been attempted to decolourize the textile effluents. The conventional biological treatment methods employed in the industry includes the use of aerated lagoons and activated sludge processes. The conventional physic-chemical treatments are not only cost prohibitive, but also produce non eco-friendly sludge and also lead to toxic metabolite formation. Hence the advanced alternative biological wastewater treatment strategies will be required which are not only ecological, but also viable environmental friendly, cost effective with no toxic effects on any life forms, including humans [33].

A great variety of microbial biomass materials have been investigated in biosorption studies for the removal of dyes. These biosorbents mainly include bacteria, microalgae and fungi because the cellulosic composition of the microbial cell wall provides binding sites such as hydroxyl and carboxyl groups [34].

3. BIOSORPTION

Sorption refers to the action of either absorption or adsorption. Absorption means the incorporation of a substance in one state into another of a different state (liquids being absorbed by a solid or gases being absorbed by a liquid). However, adsorption is the physical bonding of ions and molecules onto the surface of another molecule. Sorption have numerous advantages like effectiveness, trouble-free operation, easy revival and reprocessing of adsorbent [35,36]. Biomass from algae, yeast, fungi and bacteria has been used for the removal of dyes by biosorption [37]. The biosorption ability of microorganisms is attributed to the heteropolysaccharide and lipid compounds of the cell wall, which contains different functional groups including amino, carboxyl, hydroxyl and phosphate groups. These charged groups causing strong attractive forces between the azo dye and the cell wall [38,39].

3.1 Factors Affecting Biosorption of Dyes from Effluent

Culture conditions affect the molecular structure and activity of microbes which is essential for effective biodegradation. As different compounds possess various abilities to decolourize favourable for microbial growth and thus make the microbial possess the maximum ability to decolourize dyes in wastewater. Biosorption ability of the algae can be substantially increased by optimizing the operational conditions such as nutrient content of the culture media, pH, temperature, biosorbent dosage, agitation etc. [40].

3.1.1 Effect of pH

pH is the most important parameter affecting not only the biosorption capacity, but also the colour and the solubility of some dyes. The net charge on biosorbent is also pH dependent because the biosorbent surface has polymers with many different functional groups such as carboxyl, hydroxyl, amino and phosphates. At lower pH, the biosorbent surface becomes protonated and acquires net positive charge and thus, increases the binding of anionic dyes to the biosorbent surfaces. Higher pH values also increases the net negative charge on the biosorbent surface leading to electrostatic attraction of cationic dyes [41].

3.1.2 Incubation time

The contact time between the dye molecules and the sorbent is a significant process in dye treatment. The uptake of sorbent species is fast at the initial stage of the contact period and it becomes slower near equilibrium. In between these two stages of uptake, the rate of sorption is found to be nearly constant. This is clear from the fact that a large number of vacant surface sites are available for sorption during the initial stage, and after a lapse of time the remaining vacant surface sites are difficult to be occupied due to repulsive forces between the solute molecules on the solid and bulk phases [42].

3.1.3 Effect of temperature

Temperature has also influence on both biosorption and denaturation of dyes. The optimized temperature is usually maintained for the treatment of textile effluent. Temperature plays a very important role in biodegradation of dyes, firstly by its direct effect on the chemistry of the pollutants and secondly by affecting their physiology. Temperature also affects the solubility of dyes. Although dye biodegradation can occur over a wide range of temperature, the rate of biodegradation generally decreases with decrease in temperature [43]. Increase in temperature decreases the viscosity of the solution containing dye, thereby increasing the diffusion rate of the dye molecules across the external boundary layer and in the internal pores of the adsorbent particles [44].

3.1.4 Initial effluent concentration

The effect of dye concentration strongly influences the rate of dye removal and also impacts the toxicity of dye molecule. Effluent concentration also affects the efficiency of colour removal. Initial concentration of dye provides an important driving force to overcome all mass transfer resistance of the dye between the aqueous and solid phase. Hence, a higher initial concentration of dye may enhance the adsorption process [45].

3.1.5 Agitation

Agitation played a major role in dye decolourisation. It is important for uniform mixing of the medium components for dispersion of cells and nutrients as well as mass transfer phenomena. Agitation creates shear forces, which affect microorganisms in several ways, causing morphological changes, rupture of the cell wall, variation in their growth and product formation and also damages the cell structure. Agitation speed is a very important factor, since it increases the amount of dissolved oxygen in the cultivation medium [46].

3.1.6 Biomass concentration

Biosorbent dosage also affects the sorption capacity of the biosorbents. It is readily understood that the number of available biosorption sites increases with an increase in biosorption dosage which results in efficient biosorption of dye. However, the sorption capacity decreases with increasing biosorbent dosages due to the increase in solute transfer rate onto the adsorbent surface, that is the amount of solute adsorbed onto unit weight of adsorbent gets split with increasing biomass concentration [47].

4. BIOREMEDIATION

Bioremediation has been established to be an efficient, eco-friendly and more cost-effective for the treatment of variety of wastes [48]. The microorganisms show an ability to decolour, degrade, detoxify and metabolize a number of compounds in various biological treatment processes. Due to the universal nature, they can be used as priceless tools for the biological treatment of textile effluent. As a preliminary phase in the growth of biological treatment for textile effluent, there is a need to isolate bacterial and fungal strains with a potential to decolorize and degrade textile dyes and remove other pollution factors [49].

4.1 Low Cost Biosorbents for Dye Removal from Effluent

Bioremediation through microorganisms has been identified as a cost effective and environment friendly alternative for disposal of textile effluent [50]. In recent years a number of studies have focused on microorganisms capable of degrading and absorbing dyes from wastewater. A wide variety of microorganisms are reported to be capable of decolouring dyes. Such organisms are *Chlorella vulgaris*, yeasts , *Escherichia coli* NO3, *Pseudomonas luteola*, *Azospirillum brasilense, Phnerochaete chrysosporium, Aspergillus niger*, *Spirogyra* species and *Klebsiella pneumoniae* RS-13 [51-58].

4.1.1 Advantages of algal biosorbent

Algae are primary producers in ecological systems, widely distributed around the world and closely connected with human life [59]. Algae have been used as a potential biosorbent because of their availability in both fresh and salt water [60]. The algae have many features that make them ideal for the selective removal, which include high biosorption capacity, ability to grow both autotrophically and heterotrophically, large surface area, phototoxic, phytochelatin production and its potential for genetic manipulation [61,62].

The biosorption capacity of algae is attributed to their relatively high surface area and high binding affinity during biosorption [63]. The functional groups such as hydroxyl, carboxylate, amino and phosphate are found on the algal cell surface which are responsible for removal of contaminants from wastewater. The dye removal using algae may be attributed to the accumulation of dye ions on the surface of algal biopolymers and further to the diffusion of the dye molecules from aqueous phase onto the solid phase of the biopolymer [64].

4.1.2 Removal of textile dye using algal biosorbents

Algae possess good pollutants binding capacities due to the presence of polysaccharides, proteins or lipid on the surface of their cell which contains functional groups such as amino, hydroxyl, carboxyl and sulphates. Microalgae in the dead form acts as an effective biosorbent since it is easier to cultivate, good yield, better efficiency and higher surface area. Algae are ubiquitous in nature and serve as one of the biomaterials with high capacity for removing dye from contaminated waters [65].

Lee and Chang [66] investigated the efficiency of marine algae *Chlorella marina, Isochrysis galbana, Tetarselmis* species*, Nanno chloropsis* species and *Dunaliella salina* and fresh water microalgal cells (*Chlorella* species) in dye removal from the textile effluent. Among the algal species tested, the highest colour removal was noticed in *Isochrysis galbana* (55%) followed by freshwater *Chlorella* species (43%).

Azza et al. [67] observed the biosorption of Acid orange 7, Basic red 46 and Basic blue 3 dyes using *Spirogyra* species. The algae showed the maximum biosorption of dyes at various biomass concentrations of 13.2, 12.2 and 6.2 mg/g respectively within 60 min.

Kumar et al. [68] studied the effect of three independent variables namely biomass dosage, dye concentration and initial solution pH for the biosorption study, of acid black 1 using *Nizamuddin zanardini, Stoepermum glaucescens* and *Stoecospermum marginatum.* The acid black 1 dye removal of 99.27%, 98.12% and 97.62% were obtained for *Nizamuddin zanardini, Stoepermum glaucescens* and *Stoecospermum marginatum,* respectively.

Masoud et al. [69] reported the optimized conditions used for the acid black 1 removal with brown macro algae *Stoechospermum glacescens* and *Stoechospermumm arginatum*. The dye removal capacity increased with the decrease in particle size of biosorbents and the agitation speed at 130 rpm controls the dye sorption capacity. Ehsan et al. [70] studied the adsorption of Congo red by pine cone and they noticed that the adsorption was maximum at pH 3.5. Dawood and Sen [71] studied the removal of malachite green using *Nostoc* species. The colour removal efficiency was 80% within 45min when treated with the *Nostoc.*

Garge and Menghani [72] used *Gracilaria verrucosa* as a potential biosorbent for the removal of phenoxyalkanoic acid herbicide 2,4-D. The biosorption capacity was found as 22.3 mg/g^{-1}. In order to enhance the biosorption efficiency of *Gracilaria verrucosa,* the biosorbent was subjected to chemical modifications. The acid treated biomass, indicated 47% for 2,4-D biosorption when compared with formaldehyde, alkali and alcohol treatment. For 2, 4-D biosorption, functional groups like carboxyl, hydroxyl and amine were identified as the significant surface active groups.

Ayca et al. [73] studied the biosorption of Reactive Red 198 using *Cyanobacterium* and *Nostoc limckia HA 46* which was collected from hydrogen bioreactor. The maximum biosorption capacity of the biomass was 94% at pH 2 and 35℃ with an initial concentration of 100 mg/l. Rammel et al. [74] reported that *Chactophora elegans* have an ability to absorb crystal violet from an aqueous solution and the algal biomass showed quite interesting adsorption capacity under optimized operating conditions (158.7 mg of dye per gram of biomass at 25℃).

Rajeshkannan et al. [75] studied the biosorption of malachite green using *Turbinaria conoides.* The maximum biosorption of malachite green was found at 30℃ at pH 8.0. Cetin et al. [76] studied the biosorption of methylene blue by dried *Ulothrix* species biomass. The biosorption equilibrium time was found as 30min. The biosorption increased with increase in pH, mixing rate and decreased with increase of temperature and adsorption dose.

Macroalgae *Chara* species have been investigated by Khataee et al. [77] for the biodegradation of malachite green in the dye solution and decolourisation was influenced by optimized parameters such as temperature, pH, initial dye concentration, reaction time and the adsorbent dose. They also examined the reusability and efficiency of the live algae in repetitive operational conditions. Lim et al. [78] experimented that *Chlorella vulgaris* was used for the bioremediation of textile wastewater. The results showed that the algae could remove nitrates, phosphates and COD at 45%, 33.3% and 62.3% respectively in the textile waste water.

Chlorella based biomass was used as biosorbent for the removal of malachite green. The fast biosorption of cationic solute using the dead microalgae significantly depended on the initial malachite green concentration and algal loading. The biosorption system explained through the electrostatic interactions existed between the negatively charged biosorbent surface and the positively charged malachite green in the medium [79].

Both living and non-living algae have been used in colour removal from dyes and wastewater. Non-living biomass of *Spirogyra* has been shown to be a useful biosorbent for removal of reactive dye from textile wastewater [80]. Living biomass of macroalgae such as *Caulerpa lentillifera* and *Caulerpa scalpelliformis* were able to remove basic dyes by biosorption. *Chlorella vulgaris* can remove 63-69% of the colour from the mono-azo dye tectilon yellow 2G by converting it to aniline [81].

[82] employed the fermentation waste biomass of *Corynebacterium glutamicum*as a biosorbent for the removal of reactive black 5 from aqueous solution. The biosorption capacity of *Corynebacterium glutamicum* for reactive black 5 was maximum at pH 1 with an initial dye concentration of 500 mg/l. [83] reported that the potential ability of *Spirogyra rhizopus* for the removal of acid red 274 dye. Almost complete removal of acid red 274 dye with concentration lower than 25 mg L^{-1} was done through *Spirogyra rhizopus*as the result of biocoagulation and bisorption.

[84] studied the biosorption of ramazol black B, ramazol red RR and ramazol golden yellow RNL using dried *Chlorella vulgaris.* The algal biomass exhibited the highest dye uptake capacity at the initial pH value of 2.0 for all dyes, but ramazol black B was adsorbed most efficiently by the biosorbent among the three dyes. [85] investigated the treatment of tectilon yellow 2G by *Chlorella vulgaris.* COD removal efficiencies were determined as 69, 66 and 63% for the initial tectilon yellow 2G concentrations of (50, 200 and 400 mg/l), whereas acclimation of *Chlorella vulgaris* caused them to increase to 88, 87 and 88% respectively.

[86] proposed a mechanism of biosorption during the treatment of reactive yellow 22 using spirogyra species whereas [87] observed the ability of four different algal species to degrade the azo dyes. The species of *Chlorella vulgaris, Chlorella pyrenoidosa, Spirogyra* and *Oscillatoria tenuis* can degrade a number of azo dyes to some extent, postulating that the reduction

appears to be related to the molecular structure of the dyes and the species of algae used.

5. SUMMARY AND CONCLUSION

Textile industry is one of the major industries in the world that provide employment with no required special skills and play a major role in the economy of many countries. There are three different types of fibres used in the manufacture of various textile products including cellulose fibres, protein fibres and synthetic fibres. Each type of fibre is dyed with different types of dyes. Cellulose fibres are dyed using reactive dyes, direct dyes, napthol dyes and indigo dyes. Protein fibres are dyed using acid dyes and lanaset dyes. Synthetic fibres are dyed using disperse dyes, basic dyes and direct dyes. The textile industry utilizes various chemicals and large amount of water during the production process. About 200 L of water are used to produce 1 kg of textile.

The water is mainly used for application of chemicals onto the fibres and rinsing of the final products. The wastewater produced during this process contains large amount of dyes and chemicals containing trace metals such as Cr, As, Cu and Zn which are capable of harming the environment and human health. The textile wastewater can cause haemorrhage, ulceration of skin, nausea, skin irritation and dermatitis. The chemicals present in the water block the sunlight and increase the biological oxygen demand thereby inhibiting photosynthesis and reoxygenation process.

Removal of pollutants from wastewater through biosorption has gained significant attention in the recent years since the process offers a number of advantages. The biosorbents from different dead microorganisms and agricultural byproducts act as the potential tool for the sequestration of wastewater pollutants. It is evident that most of the biosorbents employed for wastewater treatment have exhibited efficient sorption capacity. Therefore, such biosorbents play may a vital role especially in the developing and underdeveloped countries. This review article presented a wide range of algal mass in the removal of dyes from aqueous solution. Algal material is one of the most promising adsorbent due to their availability, low costs, large specific surface area and their chemical and mechanical stability. From the large number of published literature reviewed here, it is observed that the various physico-chemical experimental conditions such as solution pH, initial dye concentration, adsorbent dosage, and temperature are the important factors for dye removal. Therefore, these factors are to be taken into account while evaluating the adsorption capacity of different algal adsorbents.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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