Review Article **Biotechnology**

International Journal of Pharma and Bio Sciences

ISSN 0975-6299

TREATMENT OF TEXTILE DYE EFFLUENT BY ALGAE: AN ECO-FRIENDLY AND SUSTAINABLE APPROACH TO THE ENVIRONMENTAL POLLUTION

SUBHASHA NIGAM[1], SURBHI SINHA[1], MAYUR MANGLIK[1] AND RACHANA SINGH[1]

[1]*Amity Institute of Biotechnology, Amity University Uttar Pradesh, Sector-125, Noida.*

ABSTRACT

An increasing number of toxic dyes in aquatic ecosystem have become a matter of concern worldwide over the last few decades; hence, they need to be remedied. These pollutants enter the aquatic ecosystem as a result of various industrial activities. A number of physical, chemical and biological methods have been developed for the treatment of waste waters and among these, the use of algae is considered as a more eco-friendly and economical approaches. Algae are organisms which execute multiple roles in the environment like bioremediation of wastewater, drawing of excess nutrients and in turn, produce biomass, which has a large number of uses in the food, biofuel and pharmaceutical industries. This article deals with the removal of hazardous dyes by living, dead / immobilized forms of algae. These algae are capable of uptake of different types of dyes such as azo, reactive, basic etc under various optimum conditions like pH, temperature, concentration of dyes and biomass, etc.

KEYWORDS: **Textile Dyes, Bioremediation, Microbial biomediation, Phycoremediation, Biosorption, Bioaccumlation.**

RACHANA SINGH
Amity Institute of Biotechnology, Amity University Uttar Pradesh, Sector-125, Noida.

INTRODUCTION

Aquatic ecosystems are under increasing stress due to the fast growing population, technological development, urbanisation and economic growth.Human activities are causing aquatic species to disappear at a shocking rate. It has been evaluated that between 1975 and 2015, species extinction will occur at a rate of 1 to 11 percent per decade[1]. Human actions influence the quality and quantity of fresh water, which can disturb the economic prosperity, social stability, and number of ecological services that aquatic systems provide. Fresh water is already considered a limiting resource in many parts of the world[2]. In coming years, it will become even scarcer due to increased population, urbanization, and climate change. This deficiency will be induced not just by increased demand for water, but also by pollution in freshwater ecosystems. Pollution leads to the decrease in the supply of fresh water and elevates the cost of purifying it. Some pollutants, such as heavy metals or chlorinated organic compounds, pollute the aquatic ecosystem and affect the food chain. This nutrient pollution, together with the human demand for water, influences biodiversity, ecosystem functioning, and the natural services of aquatic systems upon which society depends. These pollutants not only disturb human health, but also interfere with industrial or agricultural water use. If the level of a pollutant in the water supply overreach the satisfactory level for a given water use (e.g., domestic or industrial water supply), the water is considered to be unsafe for use. Since most of the industries are situated near the water bodies, they are continuously polluted by a number of organic and inorganic materials. One group of pollutant that is increasingly causing pollution in fresh water bodies are dyes. India produces 64,000 tonnes of dyes, 2 per cent of which are directly discharged into the environment[3, 4]. With the Indian dyestuff industry growing by over 50 per cent during the last decade, India is now the second largest producer of dyes and intermediaries in Asia[1]. Dyes are chemical compounds that can attach themselves to fabrics or surfaces to give colour. Most dyes are complex organic molecules and are resistant to many things such as the weather and detergents. Synthetic dyes are greatly used in many fields like in several branches of the textile industry[5,6] in leather tanning industry[7,8] in paper production[9], in food technology[10], in agricultural research[11, 12], in light-harvesting arrays[13], in photoelectrochemical cells[14], and in hair colourings[15]. The textile industry consumes large amount of water which is used for dyeing processes, i.e. about 100 L of water is used to process about 1 kg of textile materials which produces large amounts of effluent. All dyes do not bind to the fabric and as a result, 280,000 tons of dyes are released every year worldwide which leads to acute contamination of receiving water bodies[16]. Dyeing industry effluents are one of the most difficult wastewaters to treat as they have high chemical oxygen demand, high biological oxygen demand, suspended solids, turbidity, toxic constituents and also colour, which is the first contaminant to be seen by human eye. Wide range of chemicals presents in effluents from textile and dye stuff industries are listed in Table 1.

Table 1

Various organic and inorganic pollutants and its range in the textile industry raw effluent[17]

S. No.	Parameter	Raw Effluent
1.	Chemical oxygen demand (mg/L)	1,512
2.	Biological oxygen demand (mg/L)	90.64
3.	Surfactants (mg/L)	1.1
4.	Colour (A559)	1.202
5.	Ph	10.5
6.	Conductivity (Mv)	109
7.	Hardness (mg/L)	86.5
8.	Cyanide (mg/L)	0.2
9.	Sodium	70%
10.	Phenolic Compounds (mg/L)	0.077
11.	Total Iron (mg/L)	0.77
12.	N-nitrate (mg/L)	2.0
13.	Sulfate (mg/L)	345.3
14.	Phosphate (mg/L)	12
15.	Fluoride (mg/L)	0.64
16.	Aluminium (mg/L)	< 0.01
17.	Arsenic (mg/L)	< 0.2
18.	Barium (mg/L)	<0.01
19.	Boron (mg/L)	< 2.0
20.	Cadmium (mg/L)	<0.006
21.	Chromium (mg/L)	<0.005
22.	Cobalt (mg/L)	<0.007
23.	Copper (mg/L)	0.2
24.	Lead (mg/L)	< 0.02

Due to large-scale production and extensive application, synthetic dyes can cause considerable environmental pollution and serious health-risk factors. In most developed countries, government legislation is becoming stricter for the removal of dyes from industrial effluents. Environmental protection agencies in Europe are taking steps to prevent the transfer of pollution problems from one part of environment to another.

TOXICITY OF DYES

Dyes usually have a synthetic origin and complex aromatic molecular structure, which make them more stable and difficult to biodegrade. Due to its lethal effects dyes have generated much concern regarding its use.It has been presented that azo and nitro compounds are reduced in sediments[18]and in the intestinal environment[19]resulting in the formation of toxic amines. Anthraquinone based dyes have a greater degree of resistant to degradation due to their fused aromatic structure, which continue to remain coloured for a longer period of time. Some metal based complex dyes leads to the release of metals into the water bodies while basic dyes have high colour intensity, making them difficult to break. Some disperse dyes have also shown the tendency to bio-accumulate[20, 21]. Coloured water may affect the photosynthetic activity in aquatic life due to decreased light penetration and may also be toxic to some aquatic life due to the presence of aromatics, metals, etc. in them[22, 23, 24, 25,26].Apart from being toxic, dye effluents have also been reported to cause carcinogenesis, mutagenesis, chromosomal fractures and respiratory toxicity. McGeorge*et al*. (1985)[27] reported the mutagenic activity of textile wastewater effluents, using the salmonella/microsome assay and contributed the highest percentage (67%) of mutagenic effluents. Costan*et al*. (1993)[28] found that a textile effluent ranked second in toxicity, among eight industrial sectors represented, by using a series of bioassays assessing the acute, sub lethal and chronic toxicity at various tropic levels.

TREATMENT OF DYE CONTAINING WASTEWATER

1. PHYSICO CHEMICAL METHODS

Because of the toxicity and recalcitrant nature, dyes have been classified as hazardous to the environment[29]. The treatment of dye-contaminated wastewater in an environmentally safe manner is necessarily needed prior to its disposal. Various physic-chemical methods are used to remove the dyes from textile wastewater[30, 31, 32, 33, 34, 35]. Adsorption, membrane filtration and coagulation–flocculation are some of the physical methods which are commonly used to treat textile effluent, while ozonation, electrolysis, Fenton oxidation, photocatalytic-H_2O_2 oxidation, photochemical oxidation are the important chemical methods[36, 37]. Table 2 shows the merits and demerits of various physical and chemical methods involved in the dye decolourization of industrial effluents. These methods control the pollution caused by dyes, but their use is limited by their high cost or generation of large amount of sludge.Also, these methods are not environment friendly. Although, active carbon equally has great capacity to remove dyes from the textile effluent but its use is also limited because of high cost[38]. So, there is need of such textile wastewater treatment which is economically feasible, environmental friendly and universal in its application.

Table 2

Various physical and chemical treatment methods of textile industry effluent and their merits and demerits[4].

Physical and Chemical treatment methods	Merits	Demerits
Coagulants/Flocculants	Simple, economical	High amount of sludge formation, high amount of chemical required for pH adjustment
Membrane separation	All types of dyes are decolourized	High pressure, expensive, sludge generation incapable for large scale treatment
Ion Exchange	Effective with no loss of regeneration	Economic constraints, not effective for disperse dyes
Oxidation	Rapid and efficient process	High energy cost, chemical required, by product formation
Fenton's reagent	Efficient decolourization for both soluble and insoluble dyes	Solid waste production, expensive
Ozonation	No toxic metabolite produced, colour removal, applied in gaseous state	Short half life, stability affected by chemicals, expensive
Photo chemical	No sludge production, foul odours are not produced	Secondary pollutants
Irradiation	Efficient in laboratory level and low volume required	Sufficient quantities of DO required

These physical-chemical treatment processes were not able to handle decolourization of the entire textile wastewaters efficiently, so a more customized process, involving the use of microorganisms for the remediation of untreated textile effluent could be applied.

2. MICROBIAL DECOMPOSITION OF DYES

The utilization of micro-organisms for the removal of dyes is an interesting and simple method. The use of microorganisms for the removal of synthetic dyes offers a large number of advantages. The process is reasonably inexpensive, the running costs are low and the end products of complete mineralization are not hazardous. Large number of microbial species has been used for the decolourization of various dyes (Table 3 and Table 4).

Table 3
List of fungi and yeast decolourizing textile dyes

Organism	Dye	Uptake capacity	References
A. Flavis	Reactive Red 198	84.96%	39
A. lentulus	Acid Blue 120	97.54 mg g-1	40
F. Lividus	Orange G	30.8 %	41
F. Lividus	Amido Black 10 B	98.9%	41
T. Rubrum	RemazolTiefschwarz	83%	42
C. albicans	Direct Violet 51	73.2% in live and 87.26% in dead conditions	43
S. Cerevisiae	Remazol Black B	84.6 mg g -1	44
A. niger	Basic Fuschin	81.85 %	45
Baker's yeast strain	Remazol blue	100 %	46
W. Saturnus	Vilmafix Yellow 4R –HE	90.29 %	47

Table 4
List of bacteria decolourizing textile dyes

Organism	Dye	Uptake capacity	References
Bacillus Subtilis	Red RR	91 %	48
Consortia of *Providencia rettegri* strain HSL1 and *Pseudomonas sp.* SUK1	Reactive Black 5	98-99%	49
Bacillus sp. YZU1	Reactive Black 5	87.62 %	50
Rhodopseudomonaspalustris	Reactive Red 195	100%	51
Bacillus subtilis	Fast Red	99%	52
*Bacillus amyloliquefacien*s	Acid Blue 225	111.5 mg g-1	53
Cornybacteriumglutamicum	Reactive yellow 2	178.5 mg g-1	54
Cornybacteriumglutamicum	Methylene Blue	339.2 mg g-1	55

Broad research on dye removal utilizing microbes has displayed that these biological processes alone or together with physical-chemical methods can offer low cost and alternative technique[56,3].Microbial strategy is cost effective as well as environment friendly method[4, 57, 58].However, some difficulty in using microbes as remediation entity has been reported. The presence of co- substrates in the dye solution is required to accelerate the microbial growth and eventually the decolourization process[59]. Additionally, the textile effluents are provided with large amount of salts, variable pH and high temperature, which can seriously affect the rate of decolourization of dyes by microbes[60, 61,59]. Hence, microbial treatment may sometimes not function adequately and different technologies must be developed for the removal of dyes from wastewater. So, a feasible and viable strategy to remove dyes from environment was developed using algae[62].The autotrophic nature of algae circumvents the issues faced in bioremediation by microbes.

3.*PHYCOREMEDIATION*

Phycoremediation is the use of algae (macroalgae or microalgae) for the removal or biodegradation of pollutants from wastewater [63].Algae represent an important part of the microbial diversity of wastewaters, which also plays role in the self-purification of these wastewaters[64]. Algae constitute a wide range of organisms including photoautotrophic eukaryotic algae and prokaryotic cyanobacteria, which occur both in fresh and marine environments, with a wide range of diversity in their thallus organization and habitat[65]. The biodiversity of algae is large and evaluated to be about 200,000–800,000 species, out of which about 50,000 species are only described[66]. This enormous diversity and tendency to adapt to extreme and hostile habitats has led the researchers to screen and identify promising species and develop good algae-based technologies for wastewater treatment[67]. Algae enhance the removal of nutrients, heavy metals and pathogens and provide O_2 to heterotrophic aerobic bacteria to mineralize organic pollutants, using in turn the CO_2 released from bacterial respiration[68]. The advantages of using algae in treatment of waste water are as follows:

- Cost effective
- Low energy requirement
- Production of useful biomass
- Reduction in sludge formation
- Algae contain more than 50% of oil in its biomass.
- They provide much higher yields of biomass and fuels, 10-100 times higher than comparable energycrops.
- They can be grown under conditions which are unsuitable for conventional crop production.

Several species of algae like *Chlorella, Oscillatoria, and Spirogyra* etc are capable of degrading dyes to their simpler compounds which are less toxic. Some of them are even capable of utilizing azo dyes as sole source of carbon and nitrogen. Algae can play an important role in the removal of dyes in stabilization ponds[69].Different mechanisms of dye removal by algae are reviewed in the present article.

A)BIOACCUMULATION

Bioaccumulation normally means intracellular binding by a living organism[70]. Even though both living and dead biomass are capable of dye accumulation, there are some differences in the mechanisms involved depending on the extent of metabolic differences in the live algae[71]. Accumulation of dyes by living algae occurs in two phases: a rapid surface reaction followed by much slower metal uptake over a period of hours. During initial rapid uptake, dyes would adsorb on the cell surface within a short span of time and the process is metabolism independent. A slower uptake will correspond to the metabolism dependent incorporation into the cell body[72]. Hala Yassin and Laila Abdelfattah (2014)[73]investigated the potential application of *C.*

vulgaris for the bioremediation of textile waste effluent using 2^2 central composite design. The highest colour and COD removal occurred with 17.5% of textile effluent. The results of *C. vulgaris* in textile waste effluent demonstrated the possibility of this microalga for colour and COD removal.Four native cyanobacterial species *Nostocmuscorum*, *Anabaena virabilis,Lyngbyamujuscula* and *Oscillatoriasalina* isolated by David Noel and Rajan (2014)[74] were used for the biotreatment of textile industry effluent. From the results, it was evident that the cyanobacterial species were able to effectively remediate the pollutants from the textile effluent. Pathak et al (2014)[75] investigated the potential application of microalgae *C. pyrenoidosa* for phycoremediation of textile wastewater. Decolourization of Malachite green and Methylene Blue by two microalgal species *Chlorella vulgaris* and *Dunaliellasalina* was studied by Mohamed SaadAbd-El-Kareem et al (2012)[76]. Parameters like dye concentration, algal concentration and pH were studied. The rate of dye decolourization was found to increase with increase in both algal concentration and to some extent the increase of dye concentration. pH of the media was also found to affect the dye decolourization. D. Mubarak Ali et al., (2011)[77] used marine cyanobacteria *Oscillatoria Formosa* NTDM02 for the removal of textile dye Amido black. The results showed that the alga was able to decolourize the dye in a short period of time and can be used for the bioremediation of dye effluents.S.Venkata Mohan et al., (2004)[78] examined the biological decolourization of two azo dyes (direct and reactive) in aqueous phase by algae *Spirogyra* species. The dye removal was dependent on initial algal inoculums, dye concentration and nature of the dye. Maximum dye uptake was observed on the third day for both the dyes.Biological decolourization of the triphenylmethane dye (MalachiteGreen), by three freshwater microalgae (*Chlorella, Cosmarium*and *Euglena species*) was investigated by Khataee et al (2010)[79]. Process parameters such as reaction time, initial dye concentration, algal concentration, pH and temperature were optimized. The maximum colour removal was observed as 92%, 91% and 87% for *Chlorella, Cosmarium* and *Euglena* species, respectively at an optimum condition of 45ºC temperature, contact time with 180 min, pH value of 9.0, inoculum concentration of 9×106 cells mL^{-1} and initial dye concentration of 10 mg L^{-1}. Removal of mono-azo dye (Tectilon yellow 2G) by *Chlorella vulgaris* was also investigated (Acuner and Dilek, 2004). Removal efficiencies were determined as 69%, 66% and 63%for the initial Tectilon yellow 2G concentration of 50, 200 and 400 mg L^{-1}, respectively, whereas acclimation of *C. vulgaris* caused them to increase to 88%, 87% and 88%, respectively.The removal of Malachite Green using a viable fresh water alga *Cosmarium species* was investigated[80]. The results obtained from the batch experiments were revealed the ability of algal species in removing dye. The effects of operational parameters (temperature, pH, dye concentration and algal concentration) on decolorization were examined. Optimum initial pH value was determined as 9 which showed maximum decolourization of 92.4%.Mostafa M. El-Sheekh et al (2009)[81] studied the ability of *Chlorella vulgaris, Lyngbyalagerlerimi, Nostoclincki, Oscillatoriarubescens, Elkatothrixviridis*and *Volvox aureus* todecolourize and remove methyl red, orange II, G-Red (FN-3G), basic cationic,and basic fuchsin. These algaeshowed different efficiency for colour removal; varied from 4 to 95%according to the algal species, its growth state and dye structure. Basic cationic andfuchsin dyes were the most suitable dyes for decolourization and removal byall algae being tested, and up to 82% of methyl red was also removed by*N. lincki*and *O. rubescens*. However, the algal activity to decolorize orange II and G-Red was markedly decreased. *C. vulgaris* displayed the removal efficiency as 43.7% and 59.12% for orange II and G-Red dyes, while as *V. aureus* showed the removal efficiency as 5.02 and 3.25% for the orange II and G-Red dyes, respectively. The utilization of high rate algae ponds (HRAP) is a productive technique in bioremediation of textile wastewater effluent. The system consists of shallow pond with dense algae cultures aerated with paddle wheels. The desirable features of algal species for application in wastewater treatment in HRAP are high growth rate, adaptive to seasonal and diurnal variation in outdoor growth conditions, aggregate formation and therefore enabling gravity harvest.

B)BIOSORPTION

i) BIOSORPTION USING DEAD ALGAE

Biosorption is a physiochemical process that occurs naturally in certain biomass which allows it to passively concentrate and bind contaminants onto its cellular structure. However, nowadays researchers are using wide variety of algae to efficiently remove toxic dyes from contaminated water. Rahul kumar et al., (2014)[82] utilized the de – oiled algal biomass *Microspora* sp. for the biosorption of methylene blue. It was found that de-oiled algal biomass removed 86% dye in 5 min under static conditions and nearly 100% in 24hrs when agitated at 150 rpm. Dahlia M. El Maghraby (2013)[83] studied the uptake of orange dye by red seaweed *Laurenciapapillosa* to explore its potential as a low cost adsorbent. The dye removal percentage increased from 25.92 to 67.08% and the equilibrium states were attained at almost 60 min within the experimental concentration range. Maximum removal efficiency of 65.7% was observed at pH 5. The results proved that *Laurenciapapillosa* was a promising material for removing fast orange dye from aqueous solution. Biosorption of three textile dyes, acid orange 7, basic red 46 and basic blue 3 from contaminated water by fresh water filamentous alga *Spirogyra* sp. was investigated by Khataee et al (2013)[84].The results indicated that the biosorption of dyes on dried *Spirogyra* sp. was feasible, economical and efficient. Biosorption of malachite green by naturally grown algal biomass from Girna river, jalgaon district was examined by Swapnil and Shankar (2012)[85]. Kinetic studies showed that the process requires < 45 min for > 85 % of sorption while process reached equilibrium in < 50 min of contact time. Studies also displayed that the biomass can be reused at least four times without altering the sorption properties. Kousha et al., (2012)[86] studied the potential of brown alga *Cystoseiraindica* and red alga *Gracilariapersica* for the biosorption of Acid black 1 dye using Box-Behnken design. At the optimum conditions, the maximum removal efficiencies of acid black1 for *C. indica* and *G. persica* were 90.76% and 98.18%, respectively. Therefore the results indicated that the used algal biomasses were efficient for the removal of acid black1 dye. Removal of Congo Red Dye from aqueous solution using acid activated eco-friendly low cost carbon prepared from marine algae *Valoriabryopsis* was displayed by Jayaraj et.al (2011)[87]. This adsorbent was found to be effective and economically attractive as the adsoption capacity of congo red was observed 97.77%. Biosorption of three reactive dyes namely Remazol Black B, Remazol Red RR and Remazol Golden Yellow RNL onto dried *Chlorellavulgaris* was investigated by Aksu and Tezer(2005)[88] in a batch system. The algal biomass exhibited the highest dye uptake capacity at the initial pH value of 2.0 for all dyes. The effect of temperature on maximum equilibrium sorption capacity was obtained at 35ºC for Remazol Black B and at 25ºC for both Remazol Red RR and Remazol Golden Yellow RNL. Biosorption capacity of alga was found to be increased, with increase in initial dye concentration up to 800 mg L^{-1} for both Remazol Black B and Remazol Red RR dyes, and up to 200 mg L^{-1} for Remazol Golden Yellow RNL dye. Among the three dyes,Remazol Black B was adsorbed most effectively by the biosorbent to a maximum uptake capacity of approximately 419.5 mg g^{-1}.Batch experiments were carried out for the biosorption of basic yellow dye onto the green macroalgae *Caulerpa scalpelliformis*[89]. The *Caulerpa* species exhibited a maximum uptake of 27 mg of dye per gram of seaweed. The amount of dye uptake decreased with increase in temperature. The results indicated that *C. Papillosa* constitutes a promising material for the development of a low cost biosorption technology for the removal of dyes from effluents.Hajira Tahir et al (2008)[90] observed that biosorbents*Ulva lactuca* and *Sargassum* showed good adorption capacity for basic dye methylene blue. About 96% removal was obtained by using the biosorbents.Tsai and Chen (2010)[91] studied about the *Chlorella*-based biomass as a low-cost biosorbent. The dye malachite green (MG) was removed in an agitated batch experiments with respect to various parameters such as agitation speed, initial dye concentration, biosorbent loading, initial pH and temperature. The experimental data revealed that the rapid removal of cationic solute using the dead microalgae was significantly depending on the initial MG concentration and algal loading. Furthermore, the biosorption kinetics well obeyed the pseudo-second order rate equation. This work showed that the *Chlorella* biomass can be effectively used as a low-cost biosorbent for the removal of MG from its aqueous solutions.

ii) BIOSORPTION USING IMMOBILIZED ALGAE

Muzarabani et al., (2015)[92]reported a potentially viable approach for the removal of methylene blue from aqueous solution using silica gel immobilized *Hydrodictyonafricunum*. Results from the studies showed that 124.11 mg g^{-1} of methylene blue could be adsorbed at an optimum pH of 8 and immobilization of 300 mg g^{-1} silica. Decolourization of methylene blue and malachite green by immobilized *Desmodesmus sp.* was studied by Abdullah and Mufida Abdullah (2015)[93].The results showed that the maximum decolourization of both dyes with immobilized algae after 6 days at 20 mg.L^{-1} of dye concentration was 98.6%. The outcome of experiments demonstrated that the decolourization ability of immobilized *Desmodesmus*sp. was more against the dyes compared with free one. S. Dinesh kumar et al (2014)[94] investigated the potential of various immobilized marine microalgae (*Chlorella marina, Isochrysisgalbana, Tetraselmissp, Dunaliellasalina* and *Nanochloropsis sp*) and fresh water microalga (*Chlorella sp.*) in removing dyes from textile wastewater. Highest colour removal was noticed in *Isochrysisgalbana* (55%), followed by freshwater *Chlorella sp.* (43%). The study proved to be easy to use, cost effective and devoid of any technical problems. The green microalgae *Scenedesmusquadricauda*was immobilized in alginate gel beads. The immobilized active (live) (IASq) and heat inactivated (dead) *S. quadricauda*(IHISq) were used for the removal of Reactive Blue 19 (Remazol Brilliant Blue R or RBBR) from aqueous solution[95]in the concentration range 25-200 mg L^{-1}. At 150 mg L^{-1} initial dye concentration, the IASq and IHISq exhibited the highest dye uptake capacity at 30ºC and at the initial pH value of 2.0. At the same initial dye concentration in the batch system, the adsorption capacity for IASq and IHISq was determined as 45.7 mg g^{-1} and 48.3 mg g^{-1} in 300 min, respectively. After 300 min the adsorption capacity was not increased for 24 h contact time. The Langmuir, Freundlich and Dubinin– Radushkevich equations have shown better coefficientof determination than Temkin and Flory–Huggins equation. The monolayer biosorption capacity of the biomass was found to be 68 and 95.2 mg g^{-1} for IASq and IHISq, respectively. The experimental data were also tested in terms of kinetic characteristics and it was determined that the biosorption data was well fitted with pseudo-second order kinetics.Immobilized *Chlorella vulgaris* was also used by Won loychu et al (2008)[96] for the removal of colour from textile dyes.

FUTURE PROSPECTS

Albeit, the concept of using algae in bioremediation dates back to 1990s, the improvement in the use of tools, development of method and their application is new. Several molecular tools can be used to understand the qualitative and quantitative changes in the indigenous diversity of algae present in different wastewaters with time and treatment. Different forms of consortia can be collected and developed which can acclimatize in and treat wastewater generated from textile effluents. For this purpose consortia created using native algae would be more advantageous. Also consortia of algae with bacteria or fungi can be made which further enhances the competitive ability of the consortia. This can lessen the cost the cost of process as they can cause self-flocculation, helping in the harvesting of consortia. However, the existence of pathogenic or toxic microbes should be looked into before using them as animal feed. Understanding the mechanism of nutrient uptake and their interference by other contaminants is also an important area, which is needed for the success of consortia at commercial level.

CONCLUSION

The effluents from textile industries are a major cause of pollution of water bodies. Economical removal of colour from effluents remains a key problem although a number of successful systems have been developed utilizing various physical-chemical and biological processes. Algae could be used to develop a biological treatment system to address the problem of dyes in wastewater. In case of wastewater treatment studies, various marine micro and macro algae can be used for the removal of dyes in free living, dead or immobilized forms. The available literature in reports have clearly emphasized and proved beyond doubt that algae are efficient in colour removal from textile effluent and thus can be explored for the remediation of many contaminated sites. Therefore, the effectiveness of algae as biosorbent is confirmed. These low cost biosorbents also offer a lot of encouraging benefits for commercial purposes in the future.Various researchers are working on removal of dyes using algae as a green approach,because of its low cost andno hazardous chemical formation.

ACKNOWLEDGEMENT

The authors are grateful to Amity Institute of Biotechnology, Amity University for providing the laboratory facilities.

CONFLICT OF INTEREST

There is no conflict of interest.

REFERENCES

1. Ramachandra T, Ahalya N and Rajasekara MC. Aquatic ecosystems: conservation, restoration and management, Capital Publishers. 2005; New Delhi.
2. Ramachandra TV, Kiran R and Ahalya N. Status, Conservation and Management of Wetlands— Allied Publishers (P) Ltd, 2002; India.
3. Pearce CI, Lloyd JR and Guthrie JT. The removal of colour from textile wastewater using whole bacterial cells: a review. Dyes Pigm. 2003; 58:179-196.
4. Robinson T, McMullan G, Marchant R and Nigam P. Remediation of dyes in textile effluent: a critical review on current treatment technologies with a proposed alternative, Bioresour. Technol. 2001; 77; 247-255.
5. Gupta GS, Shukla SP, Prasad G and Singh VN. China clay as an adsorbent for dye house wastewater, Environ.Technol.1992; 13: 925–936.
6. Sokolowska-Gajda J, Freeman HS and Reife A. Synthetic dyes based on environmental considerations: 2. Iron complexed formazan dyes. Dyes Pigm. 1996; 30: 1–20.
7. Tünay O, Kabdasli I, Ohron D and Ansever G. Use and minimalization of water in leather tanning processes. Water Sci.Technol. 1999; 40: 237–244.
8. Kabadasil I, Tünay O and Orhon D. Wastewater control and managementina leather tanning district. Water Sci.Technol.1999; 40: 261–267.
9. Ivanov K, Gruber E, Schempp W and Kirov D. Possibilities of using zeolite as filler and carrier for dyestuffs in paper. Das Papier.1996; 50: 456–46.
10. Bhat RV and Mathur P. Changing scenario of food colours in India. Curr.Sci. 1998; 74: 198–202.
11. Cook SMF and Linden DR. Use of rhodamine WT to facilitate dilution and analysis of atrazine samples in short-term transport studies. J.Environ.Qual. 1999; 26: 1438–1441.
12. Kross BC, Nicholson HF and Ogilvie LK. Methods development study for measuring pesticide exposure to golf course workers using video imaging techniques. Appl. Occup. Environ. Hyg. 1996;11: 1346–1351.
13. Wagner RW and Lindsey JS. 1996. Boron-dipyrro methane dyes for incorporation in synthetic multi-pigmentlight-harvesting arrays. Pure Appl. Chem. 1996; 68: 1373-1380.
14. Wrobel D, Boguta A and Ion RM. Mixtures of synthetic organic dyes in aphotoelectronic cell. J.Photochem . Photobiol.A Chem. 2001; 138: 7–22.
15. Scarpi C, Ninci F, Centini M and Anselmi C. High-performance liquid chromatography determination of dir. Arch. Environ. Contam.Toxicol.1998; 29: 845-853.
16. Surbhi S, Rachana S, Akhilesh KC andSubhasha N. Self-sustainable Chlorella pyrenoidosa strain NCIM 2738 based photobioreactor for removal of Direct Red-31 dye along with other industrial pollutants to improve the water-quality, J. Hazard. Mat.2015; 386-394.
17. Palanivelan R, Rajakumar S, Jayanthi P and Ayyasamy PM. Potential process implicated in bioremediation of textile effluents: A review. Advan.Appl. Sci. Res. 2013; 4: 131-145.
18. Weber EJ and Wolfe NL. Kinetics studies of reduction of aromatic azo compounds in anaerobic sediments/water systems. Environ Toxicol Chem. 1987; 6: 911-920.
19. Chung KT, Fulk GE and Egan M. 1978. Reduction of azo dyes by intestinal anaerobes.Appl . Environ. Microbiol.1978; 35: 558-562.
20. Anliker R, Clarke EA and Moser P. Use of the partition coefficient as an indicator of bioaccumulation tendency of dyestuffs in fish. Chemosphere.1981; 10: 263-274.
21. Baughman GL and Perenich TA. Fate of dyes in aquatic systems: I. Solubility and partitioning of some hydrophobic dyes and related compounds. EvironToxicol and Chem 1988; 7(3): 183-199.
22. Clarke EA, and Anliker R. Organic dyes and pigments. In Anthropogenic compounds 1980; (pp. 181-215). Springer Berlin Heidelberg.
23. Zollinger H. Synthesis, Properties of Organic Dyes and Pigments. In: Color Chemistry. New York, USA: VCH Publishers; 1987. p. 92-102.

24. Mishra G, and Tripathy M.A critical review of the treatments for decolourization of textile effluent.Colourage.1993; 40: 35-35.
25. Banat IM., Nigam P, Singh D, and Marchant R. Microbial decolorization of textile-dyecontaining effluents: a review. Bioresour. technol. 1996; 58(3): 217-227.
26. Fu Y and Viraraghavan T. Fungal decolorization of dye wastewaters: a review. Bioresour.Technol. 2001; 3: 251-262.
27. MacGregor JT, Diamond MJ, Mazzeno LW and Friedman M. Mutagenicity tests of fabric-finishing agents in Salmonella typhimurium: fiber-reactive wool dyes and cotton flame retardants. Environ. Mutagen. 1980; 2(3): 405-18.
28. Costan GN, Bermingham C, Blaise and Ferard JF. Potential ecotoxic effect probe (PEEP); a novelindex to assess and compare the toxic potentialofindustrialeffluents. Environ. Toxic. Water Qual. 1993; 8: 115-140.
29. Souza SM, De AGU, De KAS, Bonilla and De Souza AAU. Removal of COD and color from hydrolyzed textile azo dye by combined ozonation and biological treatment. J. Hazard. Mat. 2010; 179: 35-42.
30. Wang A, Qu J, Liu H and Ge J. Degradation of azo dye Acid Red 14 in aqueous solution by electrokinetic and electooxidation process. Chemosphere.2004; 55: 1189-1196.
31. Golab V, Vinder A and Simonic M. Efficiency of the coagulation/flocculation method for the treatment of dye bath effluent. Dyes Pigm. 2005; 67: 93-97.
32. Alinsafi AF, Evenou and Abdulkarim EM. Treatment of textile industry wastewater by supported photocatalysis. Dyes Pigm. 2007; 74: 439-445.
33 .Arslan-Alaton I. Degradation of a commercial textile biocide with advanced oxidation processes and ozone. J. Environ. Manage. 2007; 82: 145-154.
34. Dos-Santos AB, Cervantes FJ and Van Lier JB. Review paper on current technologies for decolourisation of textile wastewaters perspectives for anaerobic biotechnology. Bioresour.Technol. 2007; 98: 2369-238.
35. Wang H, Su JQ and Zheng WX. Bacterial decolourization and degradation of the reactive dye reactive red 180 by Citrobacter sp. CK3. Int. J. Biodeter. Biodegr.2009; 63: 395-399.
36. Hao OJ, Kim H and Chiang PC. Decolorization of wastewater. Criti. Rev. Environ. Sci. Technol. 2000; 30; 449–505.
37. Rao NN, Bose G, Khare P andKaul SN.Fenton and Electro-Fenton Methods for Oxidation of H-Acid and Reactive Black 5. J. Environ. Engg. 2006; 132(3): 367-376.
38. Robinson T, McMullan G, Marchant R and Nigam P. Remediation of dyes in textile effluent: a critical review on current treatment technologies with a proposed alternative. Bioresour.Technol. 2004; 77: 247-255.
39. Akbar E and Mona K. Bioremoval of an azo textile dye, Reactive Red 198, by *Aspergillus flavus,* World J. Microbiol.Biotechnol. 2011; 28(3): 1125-1131.
40. Kaushik P and Malik A. Process optimization for efficient dye removal by Aspergillus lentulus FJ172995. J. Hazard. Mat. 2011; 185: 837-43.
41. Selvam K, Swaminathan K and Chae KS. Decolourization of azo dyes and a dye industry effluent by white rot fungus Thelephorasp. Bioresour.Technol. 2003; 88: 115-119.
42. Yesiladal SK, Pekin G, Bermek H, Arslan-Alaton I, Orhon D and Tamerler C. Bioremediation of textile azo dyes by Trichophyton rubrum LSK-27. World J. Microbiol.Biotechnol.2006; 10: 1017-1031.
43. Vitor V and Corso CR. Decolourization of textile dye by Candida Albicans isolated from industrial effluents. J.Ind. Microbial.biotechnol. 2008; 35: 1353-1357.
44. Aksu Z. Reactive dye bioaccumulation by *Saccharomyces cerevisiae*. Process Biochem. *2003; 38 (10): 1437-1444.*
45. *Babita R*, Vivek K, Jagvijay S, Sandeep B, Priyanka T, Shivesh S, andRitu K. Bioremediation of dyes by fungi isolated from contaminated dye effluent sites for biousability, Braz J Microbiol. 2014; 45(3): 1055–1063.
46. Mahmoud MS. Decolorization of certain reactive dye from aqueous solution using Baker's Yeast (*Saccharomyces cerevisiae*) strain, HBRC Journal ,Available online 27 August 2014 In Press, Corrected Proof.
47. Martorell MM, Pajot HF and De Fiegueroa LIC. Dye decolourizing yeast isolated from Las Yangas Rainforest. Dye assimilation and removal as selection criteria. Int. Biodeterbiograd. 2012a; 66: 25-32.
48. Maulin PS. Biodegradation of Azo Dyes by Three Isolated Bacterial Strains: An Environmental Bioremedial Approach, Microbial BiochemTechnol, 2014; 1948-5948.
49. Harshad L, Avinash K, Diby P and Sanjay D. Biodegradation and detoxification of textile azo dyes by bacterial consortium under sequential microaerophilic/aerobic processes, EXCLI J, 2015; 14: 158–174.
50. Wang ZW. Liang JS and Liang Y. Decolorization of Reactive Black 5 by a newly isolated bacterium Bacillus *sp.* YZU1.Int. Biodeter. Biodegrad.2013; 76: 41–48.
51. Leyla Ç, Ayten ÖM and Abdullah I. Biodegradation of reactive red 195 azo dye by the bacterium RhodopseudomonasPalustris 51ATA. African J.Microbiol.Res. 2012; 6: 120-126.
52. Mabrouk MEM and Yusef HH.Decolorization of Fast Red by Bacillis subtilis HM. J. Appl. Sci. Res. 2008; 4: 262-269.
53. Cengiz Y, Emrah A, Asim O, Necip A, Semra I and Ferdag K. Biosorption studies of anionic dyes from aqueous solution using Bacillus amyloliquefaciens. Eng. Life. Sci. 2010; 10(3): 233-241.
54. Won SW and Yun YS. Biosorptive removal of Reactive Yellow 2 using waste biomass from

lysine fermentation process, *Dyes Pigm*. 2008; 76: 502-507.
55. Vijayaraghavan K, Won SW, Mao J and Yun YS. Chemical modification of *Corynebacterium glutamicum* to improve methylene blue biosorption, *Chem. Eng. J*. 2008.
56. Willmott NJ, Guthrie and Nelson G. The biotechnology approach to color removal from textile effluent.J. Soc. Dye Colour.1998; 114: 38-41.
57. Chen H. Recent advances in azo dye degrading enzyme research. Curr Protein Pept Sci. 2006; 7:101–111.
58. Khalid A, Arshad M and Crowley DE. Biodegradation potential of pure and mixed bacterial cultures for removal of 4 nitroaniline from textile dye wastewater.Wat.Res. 2009; 43: 1110-1116.
59. Prasad A, Venkata K and Rao B. Pysico chemical analysis of textile effluent and decolorization of textile azo dyes by Bacillus endophyticus strain VITABR 13. IIOAB J. 2011; 2: 55–62.
60. JadhavJP, ParshettiGK, Kalme SD and Govindwar SP. Decolourization of azo dye methyl red by *Saccharomyces cerevisiae* MTCC 463, Chemosphere, 2007; 68(2): 394-400.
61. Khan MS, Zaidi A, Wani PA and Oves M. Role of plant growth promoting rhizobacteria in the remediation of metal contaminated soils. Environ. Chem. Lett. 2009; 7: 1–19.
62. Dresback K, Goshal D and Goyal A. Phycoremediation of trichloroethylene. Physiol. Mol. Biol. Plants. 2001; 7(2):117-123.
63. Olguin EJ. 2003. Phytoremediation: Key issues for cost effective nutrient removal processes. Biotechnol.Adv. 2003; 22: 81-91.
64. Sen B, Alp MT, Sonmez F, Kocer MAT and Canpolat O. Relationship of algae to water pollution and waste water treatment. In: Elshorbagy W (ed) Water treatment. 2013. ISBN: 978-953-51-0928-0, InTech
65. Lee RE. 2008. Phycology, 4th edn. Cambridge University Press, New York.
66. Starckx S. 2012. A place in the sun—algae is the crop of the future,according to researchers in Geel, Flanders Today.
67 .Fouilland E. Biodiversity as a tool for waste phycoremediation and biomass production. Rev Environ SciBiotechnol. 2012; 11:1–4.
68. Munoz R and Guieysse B. Algal-bacterial processes for the treatment of hazardous contaminants: a review. *Water Res. 2006; 40*: 2799-2815.
69. Banat IM, Nigam P, Singh D and Marchant R. Microbial decolorization of textile- dye-containing effluents: a review. Bioresour.Technol. 1996; 58: 217–227.
70. Davis TA, Volesky B and Mucci A. *Wat. Res., 2003;*37: 4311.
71. Webster EA and Gadd GM.*Biometals*.1996; 9: 241.
72. Crist RH, Oberholser K, Macgarrity J, Crist DR, Jhonson JK and Brittsan JM *Environ. Sci. Technol*. 1992; 26: 496.
73. Hala YEK and Laila AM. Bioremediation of the textile waste effluent by *Chlorella vulgaris*, Egyp. J. Aqua. Research, 2014; 40 (3) : 301–308.
74. David NS and Rajan MR. Cyanobacteria as a Potential Source of Phycoremediation from Textile Industry Effluent.Bioreme.Biodegrad. 2014.
75. Vinayak VP, Richa K, Chopra AK and Singh DP. Experimental and kinetic studies for phycoremediation and dye removal by Chlorella pyrenoidosa from textile wastewater.J. Environ. Manage. 2015; 1-8.
76. Mohamed SA andHala MT. Decolorization of Malachite Green and Methylene Blue by Two Microalgal Species, Int. J. Chem. Environ. Eng. 2012; 3(5).
77. Mubarak Ali D, Suresh A, Praveen KR, Gunasekaran M and Thajuddin N. Efficiency of Textile Dye Decolorization by Marine Cyanobacterium, Oscillatoria Formosa NTDM02, African J. Basic Appl. Sci. 2011; (1): 09-13.
78. Mohan SV, Bhaskar YV and Karthikeyan J. Biological decolourisation of simulated azo dye in aqueous phase by algae Spirogyra species. Int. J. Env. Poll.2004; 21: 211-222.
79. Khataee AR, Dehghan G, Ebadi A, Zarei M and Pourhassan M. Biological treatment of a dye solution by macroalgaeChara sp. : Effect of operational parameters, intermediates identification and artificial neural network modeling. Bioresour. Technol. 2010; 101(7): 2252—2258.
80. Daneshvar N, Ayazloo M, Khatae AR and Pourhassan M. Biological decolorization of dye solution containing malachite green by microalgae Cosmarium sp. Bioresour. Technol. 2007; 98: 1176-1182.
81. Mosatafa MS, Gharieb MM and Abou-El-Souod GW. Biodegradation of dyes by some green algae and cyanobacteria.Biodeter.Biodegrad.2009; 63: 699-704.
82. Rahul KM, Tonmoy G, Chetan P, Anupama S, Kaumal C, Imran P, Arup G, and Sandhya M. Biosorption of Methylene Blue by De-Oiled Algal Biomass: Equilibrium, Kinetics and Artificial Neural Network Modelling, PLoS One. 2014; 9(10).
83. Dahlia MM (2013)Evaluation of non-viable biomass of Laurenciapapillosa for decolorization of dye waste water, African J. Biotechnol.2013; 12: 2215-2223.
84. Khataee AR, Vafaei F and Jannatkhah M. Biosorption of three textile dyes from contaminated water by filamentous green algae spirogyra Sp.: Kinetic, Isotherm and thermodynamic Studies. Int. Biodeter. Biodegr.2013; 83: 33-40.
85. Swapnali M, Gajare and Shankar M. Biosorption of malachite green by naturally grown algal biomass from Girnariver ,Jalgaon District, Maharashtra, J. Algal Biomass Utln. 2012; 3(4): 60–65.
86 .Kousha M, Daneshvar E, Sohrabi MS, Koutahzadeh N and Khataee AR. Optimization of C.I. Acid black 1 biosorption byCystoseiraindica and Gracilariapersicabiomasses from aqueous

solutions, Int.BiodeterBiodegrad. 2012; 67: 56-63.
87. Jayaraj R, JeyasinghThanaraj P, Thillai Natarajan S and Martin Deva Prasath P. Removal of Congo red Dye from Aqueous solution using Acid Activated Eco-Friendly Low Cost Carbon prepared from marine algaeValoriabryopsis, J. Chem. Pharm. Res. 2011. 3(3):389-396.
88. Aksu Z and Tezer S. Biosorption of reactive dyes on the green alga Chlorella vulgaris. Process Biochem.2005; 40: 1347–1361.
89. AravindhanR,Rao JR and Nair BU. Removal of basic yellow dye from aqueous solution by sorption on green alga Caulerpascalpelliformis. J. Hazard. Mater.2007; 142: 68–76.
90. Hajira T. Removal of basic dye methylene blue by using biosorbents Ulvalactuca and Sargassum. African J. of Biotechnol. 2008; 7 (15): 2649-2655.
91. Tsai WT and Chen HR. Removal of malachite green from aqueous solution using low-cost chlorella-based biomass.J. Hazard. Mater. 2010; 15 : 175(1-3).
92. Muzarabani N, Mupa M, Gwatidzo L and Machingauta C. Silica gel matrix immobilized Chlorophytahydrodictyonafricanum for the removal of methylene blue from aqueous solutions: Equilibrium and kinetic studies, African J. Biotechnol. 14(31): 2463-2471.
93. Abdullah TAF and Mufida A (2016) Decolorization of Methylene Blue and Malachite Green by Immobilized Desmodesmus sp. Isolated from North Jordan, Int. J. Environ. Sci. Develop. 2016; 7.
94. Dinesh Kumar S, Santhanam P, Nandakumar R, Ananth S, BalajiPrasath B, Shenbaga Devi A, Jeyanthi S, Jayalakshmi T and Ananthi P. Preliminary study on the dye removal efficacy of immobilized marine and freshwater microalgal beads from textile wastewater. African J. Biotechnol. 2014; 13(22): 2288-2294.
95. Ergene A, Ada K, Tan S and Katircioğlu H. Removal of Remazol Brilliant Blue R dye from aqueous solutions by adsorption onto immobilized Scenedesmusquadricauda: Equilibrium and kinetic modeling studies. Desalination. 2009; 249: 1308–1314.
96. Wan-Loy C ,Yike-Chu S and Siew-Moi P. Use of immobilised Chlorella vulgaris for the removal of colour from textile dyes. J. Appl. Phycol. 2009; 21:641–648.