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Decolourization of dye wastewater by microbial methods- A review

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Waste water originating from textile processing and dyestuff manufacturing industries contain varying amounts of dyes, metals/metalloids, salts and organic pollutants out of which dyes are the visible toxic contaminants. Presence of dyes in water bodies causes several problems including decreased photosynthesis and higher BOD and COD load, apart from their displeasing appearance. Dyestuffs are organic molecules, which may be toxic or mutagenic. In the last few years, environmental legislation about the presence of colour in discharges, coupled with the increasing cost of water for the industrial sector, has made the treatment and reuse of dyeing wastewaters increasingly important to the industry. A variety of approaches are available for treatment, out of which the biological treatment is the genuinely ecofriendly and cost effective method. The decolourization efficiencies of different biological methods are discussed in this review along with the detailed discussion on bacterial treatment and their relative merits and drawbacks.

Keywords: Azo dyes, Bacteria, Biological treatment methods, Decolourization, Dye degrading Enzymes

Introduction to textile and dye waste water

Textile industries consume large volumes of water and chemicals during wet processing[1]. The chemicals used during manufacture and processing are diverse in chemical composition ranging from dyes, inorganic compounds to polymers and organic products[2]. The main visible pollutant is dye, which is aesthetically unpleasant and hazardous to human and aquatic life. Synthetic dyes, based on azo chromophore account for nearly 80% consumption in textile colouration out of all the types of dyes available[3,4]. By design, majority of the dyes are recalcitrant so that they can confer colour onto the designated materials and resist fading on exposure to perspiration, soap, water, light or oxidizing agents[5]. Amongst a variety of dye classes available for colouring cellulosic fibres, the azo chromophore based reactive dyes are the most utilized ones. As the name suggest, these dyes react covalently with the cellulosic –OH in the fibre, thereby providing the highest level of wash fastness. The amount of dyestuff that does not bind to the fibres, enters into wastewater during textile processing. There are more than 10,000 dyes available commercially, and more than 7×10^5 tons of dyestuffs are produced annually[6]. Therefore, textile and dyestuff industry waste waters are characterized by their high levels of visible colour and large chemical oxygen demand (COD), biological oxygen demand (BOD) and total dissolved solids (TDS) at alkaline *p*H (9 –11)[7].

Ecotoxicity of dyes

Dyes are generally photolytically stable and can be detected by naked eye even in trace levels (<1 ppm)[8]. Release of dyes can be ecotoxic and can also affect human beings although their acute toxicity low. Azo dyes are the most commonly used dyes for cotton fabric dyeing. In their pure form, they are seldom directly mutagenic or carcinogenic. Reduction of azo based dyes, i.e., cleavage of azo linkage, however, leads to the formation of primary aromatic amines which are mutagens and sometimes carcinogens. The acute toxic hazard of aromatic amines can be cancer, especially bladder cancer in humans if it enters the human body through food chain. Moreover, numerous reports indicate that textile dyes and wastewaters have toxic effects on the germination rates and biomass of several plants species which have important ecological functions, such as providing habitat for wildlife, protecting soil from erosion and providing the organic matter that is so significant to soil fertility[9]. The wastewater containing azo dyes is often used to irrigate crops, which adds harmful azo dyes to agricultural soils and also absorbed by the crop. These dyes may alter the biological properties of soil, including the composition of microbial communities and enzyme activities[10].

Environmental legislation on coloured wastewater

In last few decades, environmental legislation about the appearance of colour in water discharges has made treatment and reuse of dyeing wastewaters increasingly obligatory to the industry[11]. Wastewater discharge from textile processing and dyestuff industries into main water bodies and into the treatment plants, is currently causing significant concerns to the environmental regulatory agencies.

The municipalities calculate the charges of wastewater treatment based on the organic load of the wastewater (usually determined by COD), and therefore the discharge of desizing and scouring wastewaters usually results in extremely high wastewater treatment costs. The textile industry, a 24×7 industry with huge production capacities, feels the wastewater treatment as a burden and a cut into the profits, and hence prefers to provide less attention at the expense of the environment. There is a need to develop easy to operate and cost effective methods for removal of these contaminants from wastewater before its discharge[12-14].

Physico-chemical characteristics of coloured waste water

Dye containing wastewater contains a variety of structurally different azo dyes, salts and metal ions, along with other organic and inorganic compounds that make raw wastewater very difficult to decolourize[3]. Colour is the first contaminant to be recognized and it has to be removed before discharging the wastewater into the water bodies or onto the land. Salt is the second pollutant, which increases electrical conductivity of wastewater. Salts like NaCl, Na_2SO_4 are generally added to dye baths for improving the fixation of dyes on fabrics and toad just the ionic strength of the dye baths during the dyeing process. Third significant contaminant is the heavy metal ions. The amount of heavy metals present in wastewater is largely associated with the use of acid-mordant and metal complex dyes or chemicals containing metals that are used during the after treatments of dyeings. According to one estimate, about 30% metal complexed dyes are used in dyeing of wool and 40% for dyeing of nylon[15].The other contaminants are, organic and inorganic pollutants of much diverse nature present in variable quantities[16].

Treatment techniques available

Although many techniques are available for dye removal, there are several factors that determine their technical and economic feasibility. Such factors include: chemical nature of dye, composition and volume of the dye containing wastewater, dose and cost of required chemicals to be added for dye decolourization, equipment necessary, operational and maintenance costs, environmental fate and handling costs of generated waste, etc. Each dye removal technique has its own limitations and one single process may not be sufficient to achieve complete decolourization as desired for reuse (Table 1). Several chemical and physical decolourization methods that are available include: coagulation/ flocculation, precipitation, adsorption, oxidation and advanced oxidation processes, electrolysis and membrane extraction[17,18]. These techniques are more or less effective for colour removal from the wastewater but are also chemical/ energy intensive and most importantly, the chemical intensive processes further introduce chemicals that are unwanted in the first place. They also concentrate the pollutants into solid or liquid streams requiring additional treatment or

Table 1 — Advantages and disadvantages of various decolourization methods

S. No	Decolourization method	Stage of treatment	Advantages	Major disadvantages
1	Activated carbon	Pre/post treatment	Good removal of wide variety of dyes	Very expensive; regeneration essential
2	Irradiation	Post treatment	Effective removal for a wide range of colourants at low volumes	Dissolved oxygen requirement is high; Ineffective for light resistant colourants
3	Coagulation and precipitation	Pre/main treatment	Less time and low capital costs. Good removal efficiencies	High cost of coagulants and chemicals for *p*H adjustment; Dewatering and sludgehandling problems.
4	Membrane filtration	main treatment	Removes all dye types	Concentrated sludge Production; membrane fouling
5	Electrochemical	Pre treatment	Breakdown compounds are non-hazardous	High cost of electricity
6	Oxidation (with H_2O_2)	Pre/main treatment	Removes dye by oxidation of azo ring resulting into aromatic rings	Agent needs to be activated by some means (e.g., UV)
7	Fenton's reagent	Pre/main treatment	Decolourizes both soluble and insoluble dyes	Heavy sludge formation
8	Ozonation	Main treatment	Decolourizes most of the azo dyes	High cost; handling safety issues

disposal, thus escalating the cost of wastewater treatment[19]. Due to such drawbacks of the various conventional methods, the biological methods are currently viewed as specific, less energy intensive, effective and environmentally safe since they result in partial or complete bioconversion of organic pollutants to stable and nontoxic end products[20]. Many bacterial, fungal and algal species have the ability to adsorb and/or degrade azo dyes[13,14,21].

Bioremediation of dye containing wastewater using microbial community

Microbial decolourization and degradation is an eco-friendly and cost-competitive technique compared to the conventional physicochemical treatment methods. Biological processes possess the potential to convert the pollutants into water and carbon dioxide. It is the best suited greener method for the removal of colour from textile wastewater. Biological methods such as microbial degradation, adsorption by (living or dead) microbial biomass and bioaccumulation by growing cells are commonly applied to the treatment of industrial wastewaters since many microorganisms such as bacteria, yeast, algae and fungi are able to absorb, accumulate and degrade different organic pollutants[22-25] (Fig. 1). Fungi, bacteria, yeast and algae are the types of microbes used for decolourization of dyes among which the major research appears to have been conducted on fungi and bacteria as they have the ability to decolourize dyes almost completely. A microbe is chosen based on the factors like the structure and concentration of the dye to be decolourized, absorbance of the dye at cell wall and its cell permeability, biomass concentration, presence of redox mediator i.e., electron donor species (NADH, FAD), *p*H, temperature, salt concentration, oxygen concentration as well as the presence of other chemicals[26].

Fig. 1 — Bioremediation using microbial community

Over the past two decades, a number of azo dye-degrading microbial strains belonging to different genera of fungi have been isolated and studied. The reason behind these studies is that the fungi possess extracellular, nonspecific and non-stereo selective enzyme system, including lignin peroxidase (LiP), laccase and manganese peroxidase (MnP) (Table 2). Fungal cultures belonging to white rot fungi have been extensively studied to develop bioprocesses for the mineralization of azo dyes. White rot fungi are a class of microorganisms that produce efficient enzymes capable of decomposing dyes under aerobic conditions. They produce various oxidoreductases that degrade lignin and related aromatic compounds[27]. However, application of white rot fungi for the removal of dyes from textile wastewater has some inherent drawbacks such as a long growth cycle and the need for nitrogen limiting conditions. White rot fungi are not naturally found in wastewater and therefore, the enzyme production may be unreliable[26]. During decolourization, long hydraulic retention time is required for complete decolourization and the preservation of fungi in bioreactors is also a matter of concern[28].

Algae are photosynthetic organisms, which are distributed in nearly all parts of the world and in all kinds of the habitat. Recently, the application of algae has been receiving increasing attention in the field of wastewater decolourization. Algae can degrade number of dyes, assuming that the reduction appears to be related to the molecular structure of dyes and the species of algae used [34]. Colour removal by algae is

Table 2 — Decolourization of dye- containing waste water using fungi.

Fungi	Dye	Decolourization (%)	Incubation period (days)	References
Phanerochaetechrysosporium	Methyl Violet, Congo Red, Acid Orange, Acid Red 114, Vat Magenta, Methylene Blue and Acid Green	88-98	3-10	29
Trametes (Coriolus) versicolour	Reactive Blue 4 (50 mg/L)	98	16	30
Aspergillus ochraceus	Reactive Blue-25 (100 mg/L)	100	20	31
Aspergillus flavus	Malachite Green (18 mg/L)	97	6	32
Lentinuspolychrous	Methyl Red (20 mg/L)	35	16 h	33

caused due to three intrinsically different mechanisms of assimilative utilization of chromophores for the production of algal biomass, CO_2 and H_2O transformation of coloured molecules to non-coloured ones and adsorption of chromophores on the algal biomass. Moreover, this biosorption process could be adopted as a cost effective and efficient approach for the decolourization of wastewater, and it may be a viable alternative to costlier chemicals/ materials[35,36]. Table 3 presents a summary of some studies on biodegradation of dyes by algae.

Research also focusses on use of yeast, mainly for biosorption. Compared to bacteria and filamentous fungi, yeast has many advantages; they not only grow rapidly like bacteria, but like filamentous fungi, they also have ability to resist unfavourable environments[39]. Table 4 presents a summary of some studies on biodegradation of dyes by yeasts.

In comparison to other microbial community, bacterial decolourization is normally faster[42]. Other advantages are, ease to cultivate, rapid growth under aerobic or anaerobic conditions and can be facultative. They are adapted to survive in extreme conditions of salinity and temperature and express different types of oxidoreductases. Dye decolourizing bacteria can be isolated from soil, water, human and animal excreta and even from contaminated food materials. However, other potential ecological niches for isolating such bacteria are coloured wastewaters arising from dye manufacturing and textile industries. The details about bacterial treatment are discussed below.

Bacterial biodegradation with whole biomass

Studies have been carried out to determine the role of diverse groups of bacteria in the decolourization of azo dyes. The bacterial decolourization and degradation of the dyes has been of considerable interest since it can achieve a high degree of biodegradation and mineralization and is applicable to a wide variety of azo dyes. The process is inexpensive and environment friendly and produces less sludge after the treatment[43]. The biotransformation of dyes by bacteria has been mainly focused on the most abundant class of dyes (azo). The electron withdrawing nature of the azo linkages obstructs the susceptibility of azo molecules to oxidative reactions[44]. A number of bacterial strains (Table 5), has been reported to decolourize textile dyes efficiently under controlled conditions. Degradation metabolites formed as a result of dye decolourization were found to be less toxic compared to untreated waste waters.

Table 3 — Biodegradation of dyes by algae.

Algae	Dye	Decolourization (%)	Incubation period (days)	References
Cosmarium sp.	Malachite Green (10 mg /L)	87	1	35
Scenedesmusbijugatus	Tartrazine (5 mg /L)	68	6	37
Gloeocapsapleurocapsoides	Acid Red 97 (100 mg /L)	83	26	38

Table 4 — Biodegradation of dyes by yeasts.

Yeast	Dye	Decolourization (%)	Incubation period (days)	References
Trichosporonbeigelii	Navy Blue HER (50 mg /L)	100	24	40
	Malachite Green (50 mg /L)	90	24	
Galactomyces geotrichum	Methyl Red (100 mg /L)	100	1	41
	Scarlet RR (50 mg /L)	100	18	
	Malachite Green (50 mg /L)	97	9	

Table 5 — Biodegradation of dyes by bacteria

Sr. No.	Azo dye	Bacteria	Reference
1	Reactive Orange 16	*Bacillus sp.* ADR	45
2	Reactive Yellow 107, Reactive Red 198, Reactive Black 5	*Staphylococcus arlettae*VN-11	46
3	Textile azo dyes	*Pseudomonas aeruginosa Strain* PFK10,	47
4	Reactive Red 195	*Georgenia*CC-NMPT T-3	48
5	Reactive Red 195	*Micrococcus glutamicus*NCIM 2168	49
6	Reactive Red 141, Reactive Red 2	*Bacillus lentus*BI377	50
7	Azo Acid Red B	*Staphylococcus cohnii*	51
8	Reactive Blue 19	*Enterobacter sp.F*NCIM 5545	52
9	Acid Black 210	*Providencia sp.* SRS82	53
10	Reactive Red 2	*Pseudomonas sp.* SUK1	42

Anaerobic dye decolourization using bacteria

Anaerobic digestion of textile wastewater is a very promising technique. Azo-reactive dyes decompose under anaerobic conditions due to the cleavage of the azo bond. The reductive products (aromatic amines) are further treated aerobically. Dye decolourization under anaerobic conditions requires an organic carbon/energy source such as lactate, glucose, starch, ethanol etc. In anaerobic condition, the azo bond undergoes cleavage to generate aromatic amines and it is further mineralized by non- specific enzymes through ring cleavage. However, the rate of decolourization is dependent on the added organic carbon source as well as the dye structure[28]. *S. oneidensis* MR-1 showed a high capacity for decolourizing Napthol Green B even at a concentration of up to 1000 mg/ L under anaerobic conditions[54]. Under anaerobic conditions, in a fixed-bed column using glucose as co-substrate, the azo dyes were reduced and amines released by the bacterial biomass[55] (Table 6).

Aerobic dye decolourization using bacteria

Azo dyes are generally resistant to bacterial attack under aerobic conditions[59] because the presence of oxygen usually inhibits azo bond reduction activity[40]. However, some selected aerobic bacterial strains possess the ability to reduce the azo linkage by oxygen-insensitive or aerobic azoreductases[59], meaning that colour removal depends on oxygen-rich environments. These bacteria cleave –N=N– bonds reductively and utilize amines as the source of carbon and energy for their growth. Azo dyes are not solely metabolized under aerobic condition due to which complete mineralization is not achieved[60]. An interesting example is *Micrococcus* sp., which decolourises reactive dyes under anaerobic conditions in 24 h, but in aerobic environments the decolouration time is reduced to 6 hr[61]. The presence of aromatic amines was observed after decolouration in microaerophilic but not aerobic conditions, indicating that in aerobic systems, the azo bond is first cleaved by an azoreductase and then the aromatic amine can be mineralised to less toxic products by an oxidative process[61] (Table 7).

Treatment using mixed bacteria

Single microbial strains are able to decolourize azo dyes, but the degradation products can be toxic aromatic amines or metabolites that are more difficult to biodegrade than the parent dye. They are often specific to a type of dye, and due to the chemical complexity of wastewater from the textile industry, there is a need for an approach where complete degradation of dyes is achieved with a non-specific technique. This may become possible by the use of mixed consortium of bacteria. A significant advantage of such consortia over the use of single strains in the degradation of azo dyes is that different strains can attack the colour molecule at different positions or can use the metabolites produced by another strain for further decomposition, in some cases even attaining the mineralization of azo dyes. The proposed mechanism for dye degradation can involve anaerobic step where the reductive cleavage of the azo bond leads to decolouration and under aerobic conditions complete mineralisation of aromatic amines can be achieved. Microaerophilic treatment of Orange II using the consortium of *E. casseliflavus* and *E. cloacae* (NAR-1) yields sulphanilic acid, which is degraded by the same consortium under aerobic conditions. In contrast, the individual strains cannot degrade the acid even after 5 days[66] (Table 8).

Role of enzymes in bioremediation of coloured waste water

Application of microbial enzymes could be another effective way to remove toxic dyes from textile

Table 6 — Biodegradation of dyes by anaerobic bacteria

Anaerobic Bacteria	Dye	Decolourization (%)	Incubation Period (h)	References
Pseudomonas sp.	Reactive Blue 13 (200 mg/L)	83	70	56
Shewanella oneidensis MR-1	Napthol Green B (100 mg/L)	95	24	54
Pseudomonas aeruginosa	Remozol Orange; (200 mg/L)	94	24	57
Rhodopseudomonaspalustris	Reactive Red 195 (1000 mg/L)	100	-	58

Table 7 — Biodegradation of dye using aerobic bacteria

Bacteria	Dye	Decolourization (%)	Incubation Period (h)	References
P. aeruginosa	Navitan Fast blue S5R (100 mg/L)	90	24	62
Aeromonas hydrophila	Reactive Red 141 (300 mg/L)	80	24	63
Sphingomonaspaucimobilis	Methyl Red (850 mg/L)	98	10	64
Micrococcus sp	Orange MR (100mg/L)	93	48	65

wastewater for their safe release into the environment. Microbial enzymes are very effective to degrade dyes in the wastewater. The oxidoreductive enzymes are responsible for generating highly reactive free radicals that undergo complex series of spontaneous cleavage reactions. Azo dye decolourizing microorganisms have been reported to produce a variety of enzymes including azoreductase, laccase, peroxidases, NADH–DCIP reductase, tyrosinase, MG reductase and aminopyrine N-demethylase[72,73,45]. Among these, azoreductases, laccases and lignin peroxidases are the main enzymes responsible for the decolourization of azo dyes (Table 9).

Current progress in using bacterial bioremediation for wastewater treatment

Decolouration of azo dyes using advanced oxidation processes (AOPs) combined with microbiological processes

Microbiological treatment for the degradation of azo dyes has advantages and disadvantages, which have been previously described in this review. Whereas AOPs depends on the use of chemical reagents, they are efficient in the degradation of azo dyes. However, a substantial decrease in COD is only observed with significant amounts of reagents, such as hydrogen peroxide and ferrous ions[80] and the inputs of energy for ozonation, photochemical and electrochemical processes[81], thereby increasing the cost of AOPs. It is possible to improve the advantages and minimize the disadvantages of AOPs and microbial methods by combining them to develop a robust and economic alternative for azo dye degradation. The goal of coupling AOPs and microbial processes is to allow partial degradation of the dyestuff by minimally using the costlier advanced oxidation process followed by the relatively inexpensive microbial process for further organic compound removal[82]. Thus, the main aim of AOPs is not to mineralize the dyes but rather to convert those recalcitrant dyes into smaller intermediates that are vulnerable to degradation by biological processes[81]. The microorganisms for biodegradation may be isolated from the wastewater of textile or municipal plants[83] or from soil contaminated with dye housewastewaters[84]. With this approach, COD removal is significant and also it can be accomplished in less time. Various such combinations are possible as listed in Table 10.

Table 8 — Biodegradation of dyes by mixed bacteria

Consortium	Dye	Decolourization (%)	Incubation period	References
Alcaligenes sp., Bacillus sp. BAB2731, Escherichia sp. BAB2734, Pseudomonas sp. BAB3054, Providencia sp. BAB2749, Acinetobacter sp. BAB2750, Bacillus sp. BAB2751and Bacillus sp. BAB3055	Reactive Blue 160	100	4 h	67
Bacterial consortium AR1	Reactive Red 195	100	14 h	68
Bacterial mixed culture- SB4	Reactive Violet 5		18 h	69
Bacillus vallismortis, Bacillus pumilus, Bacillus cereus, Bacillus subtilis, Bacillus megaterium	Congo Red, Direct Red 7, Acid Blue 113, Direct Blue 53,	96 89 81 82		70
Proteus vulgaris and Proteus mirabilis	Reactive Red 195-A, (30-99 mg/L) Reactive Red 2, Reactive Blue 4, Reactive Blue 19	60-100	12 h	71

Table 9 — Biodegradation of dyes by enzymes

Species	Enzyme	Dye	Decolourization (%)	Time	Reference
Alcaligenes sp. AA09	Azoreductase	Reactive Red BL	100	24 h	74
Bacillus lentus BI377	Azoreductase	Reactive Red 141	99.11	6h	50
Trametes versicolour	Lacasse	Reactive Black 5	43	30 min	75
Pseudomonas aeruginosa and Serratiamarcescens	Lignin peroxidase	Textile effluent	50-58	-	76
Pseudomonas desmolyticum NCIM 2112	Tyrosinases	Direct Blue-6	98	72 h	77
Serratia marcescens	Mn peroxidases	Ranocid Fast Blue and Procion Brilliant Blue-H-GR	90	8 days 5 days	78
Pleurotus ostreatus	Laccase	Synozol Red HF6BN	96	24 days	79

Table 10 — Biodegradation of dyes by combined processes

AOPs and Biological treatment	Dye	Decolourization (%)	Incubation period (days)	References
Sonolysis/*Pseudomonas putida*	Tectilon Yellow 2G	-	18min	84
Ultrasound/*Rhodotorula mucilaginosa*	Reactive Red 2, Reactive Blue 4, Basic Yellow 2	93	-	85
Ozonation/Aerobic treatment	Reactive Brilliant Red X-3B	100	120 min	86
Aspergillus niger, Penicillium sp. from tannery yard/ozonation	Acid Black 1	94.5	-	87

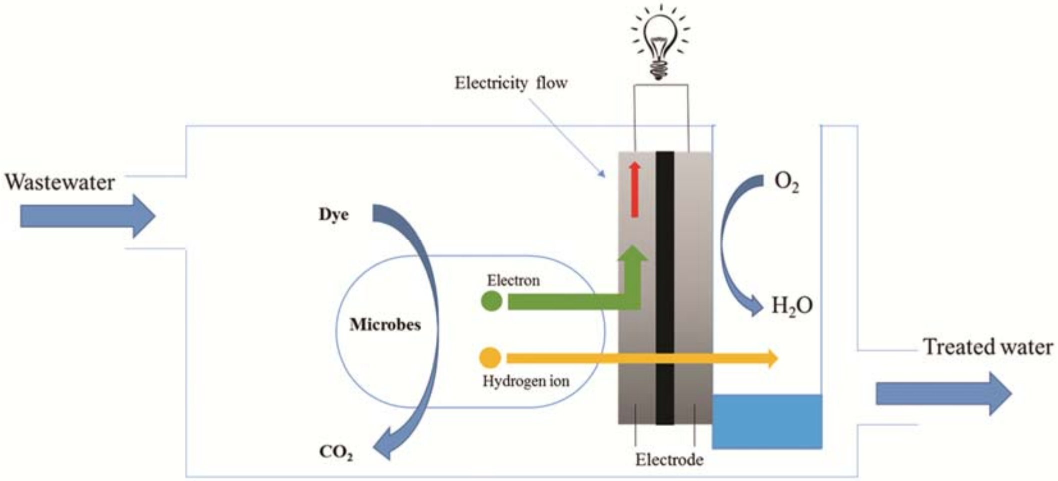

Fig. 2 — Schematic mechanism of MFCs

Decolouration of azo dyes using microbial fuel cells

The use of Microbial Fuel Cells (MFCs) is a promising sustainable technology that takes advantage of the microbial oxidation of organic matter to generate bioelectricity simultaneously with wastewater treatment[88]. The generation of bioelectricity is accomplished through at least three mechanisms: (1) electron shuttling via cell-secreting mediators (e.g., phenazine, quinones), (2) membrane-bound redox proteins (e.g., mobile electron carriers, such as cytochromes), and (3) conductive pili (or nanowires)[89-91] (Fig. 2). The advantages of MFC use are: the electrons generated in an MFC are utilized *in situ* for the degradation of azo dyes; the electricity produced can be harnessed from the system without an extra electricity supply; the degradation rate of azo dyes can be significantly increased with a simple modification of the method, such as by adding redox mediators[88]; the use of a biocathode as a catalyst to assist in the electron transfer helps to eliminate the use of noble metals[92]; the increased power generated by the MFC will partly offset the energy consumed for aeration in the biocathode and can also potentially be used to power other electrical devices by binding several MFCs for higher voltage outputs[93]. However, one serious disadvantage of using MFCs is the production of toxic amines during cleavage of the azo bond[88].

Conclusion

Presence of dyestuffs in textile wastewater creates not only the environmental pollution but also medical and aesthetic problems associated with human health and society. During the past two decades, several conventional methods have been adopted, which are either costly or less effective. Their selection depends on the wastewater characteristics like type and concentration of dye, *p*H, salinity and presence of other chemicals.

Biological treatment systems are known to be capable of reducing the BOD and COD as well as colour through anaerobic, aerobic and combined anaerobic–aerobic degradative techniques. Recent literature survey indicates that the decolourization using microorganisms has unambiguously proved their decisive role in the decolourization. Degradation and mineralization of dye and removal of dye waste from the environment are still at a somewhat immature stage. For the effective pre-treatment, better understanding of microbiology and enzymology is essential, which includes a suitable combination of aerobic, anaerobic, pure culture and mixed culture methodologies. It is necessary that the products originating from biodegradation process should not further contaminate the environment and therefore a meaningful and successful process with suitable organism along with optimized conditions needs to be designed. The solution for complete dye decolourization may be the use of biological treatment along with other pre or post conventional methods, as the biological means of dye degradation may not alone tackle the problem effectively from the point of view of the variety and number of dyestuffs and also the time required. Application of modern molecular biological techniques for cloning and overexpression or exploitation of salt and thermo-tolerant microorganisms in biotreatment system for dye and textile wastewater would be a great improvement and is expected to enter the field of dye degradation by biological means, with significant impact on it. The development of innovative methodologies, such as AOPs or MFCs combined with microbiological processes for treating wastewater containing azo dyes, and the addition of new efforts and approaches in this direction are the future of this field and will play a critical role in increasing the environmental protection.

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Conflict of Interest

“The authors declare no financial or commercial conflict of interest.”

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