

Utilization of constructed wetlands for dye removal: A concise review

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Abstract

Water discharges from the textile industry are the main environmental concern and the chemicals it carries. Industrial fields such as textile, rubber, paint, leather, paper, cosmetics and dyeing systematically use toxic dyes, causing severe pollution of water and environmental problems, which in turn threaten human health, aquatic life and the environment. Constructed wetlands (CWs) are low-energy, environmentally friendly, and natural treatment systems. CWs are well known for their ability to remove suspended solids, nutrients, and biological oxygen demand from domestic wastewater. It has been demonstrated that CWs can remove dye from textile wastewater. CWs harbour a great variety of microbial communities that enhance the efficacy of removing contaminants from wastewater. This chapter reviewed the classification of dye and the role of phytoremediation in the decontamination of dye-containing wastewater. Overall, this chapter essentially presents an overview of the concepts of different kinds of CW for dye removal.

Keywords: Constructed wetland, Dye, Phytoremediation, Textile industry, Wastewater



1. Introduction

Industrial development and swift population growth have heightened the need for textile materials, resulting in the dramatic upsurge of textile industries and indiscriminate disposal of their effluents. Textile dyeing processes are the most environmentally unfriendly waste-producing industries because they generate colored wastewaters that are severely polluted with several dyes, textile auxiliaries, and chemicals.^{1,2} In the textile industry, the effluents contain high concentrations of total suspended solids (TSS), color, chemical oxygen demand (COD), total dissolved solids (TDS), total suspended solids (TSS), and biological oxygen demand (BOD), which are capable of negatively impacting the water quality, causing odours, and threatening economic activities.^{3,4} The properties of textile effluent are determined by the manufacturing process, technology, and chemicals used. Most textile wastewater consists of dye wastes, which are toxic to the biosphere and block sunlight, causing serious ecological problems.^{5,6} These textile dye wastewaters directly threaten living creatures because of their highly toxic, mutagenic, and carcinogenic contents.^{4,7,8} Moreover, due to their complex structure and synthetic origin, these dyes are designed to withstand degradation over time, exposure to sunshine, soap, water, and oxidizing

agents. Traditional wastewater treatment techniques cannot easily remove them.⁹ This situation necessitates the development of simple, cheap, and viable technology for the treatment of textile dye wastewater. In recent years, dye-containing wastewater has been treated with a variety of methods, including membrane filtration, precipitation, ultrasonication, adsorption, photocatalysis, chemical oxidation, bioremediation, and constructed wetland (CW).^{10–19} CW has been greatly preferred for dye contaminants degradation in wastewaters due to its pollutant removal efficiency, high reusability, ease of operation, low energy, and cost requirements without any adverse environmental effects. The chapter is structured to provide an outline of CW in dye removal. Firstly, the description, characteristics, applications, and examples of different dye classes were enumerated. Also, the phytoremediation efficiency of various macrophytes for dye removal was explained. Moreover, the advantages of CW systems were expounded. More importantly, the removal processes of dye in CW systems were expounded. Lastly, future research needs were put forward.



2. Dye

Dyes are colored compounds that can be fixed to fabrics, usually in solution. They are also referred to as substances containing chromophore and auxochrome groups. Due to their saturation, the chromophore group determines the dye color, while the auxochrome group controls the dye fiber reaction. Dyes are classified as natural dyes (extracted from natural or plant sources, e.g., carmine, orcein, haematoxyline etc.) and synthetic dyes (derived from organic or inorganic compounds, e.g., direct, basic, acid, mordant, reactive, metal complex, disperse, vat, sulfur, etc.). In a broader sense, dye classifications depend on some factors based on source (natural and synthetic), chromophoric groups (triarylmethane, azo, nitro and nitroso, anthraquinone, indigo), and ionic nature as illustrated in Fig. 1. The chemical structure of dyes is complex and dyes are used for many industrial purposes. Dyestuffs, especially synthetic dyes, have stable structures due to the presence of complex aromatic structures and the resonance and to the π conjugated bond characteristic; also, they are deliberately intended to be recalcitrant with poor biodegradability.²⁰

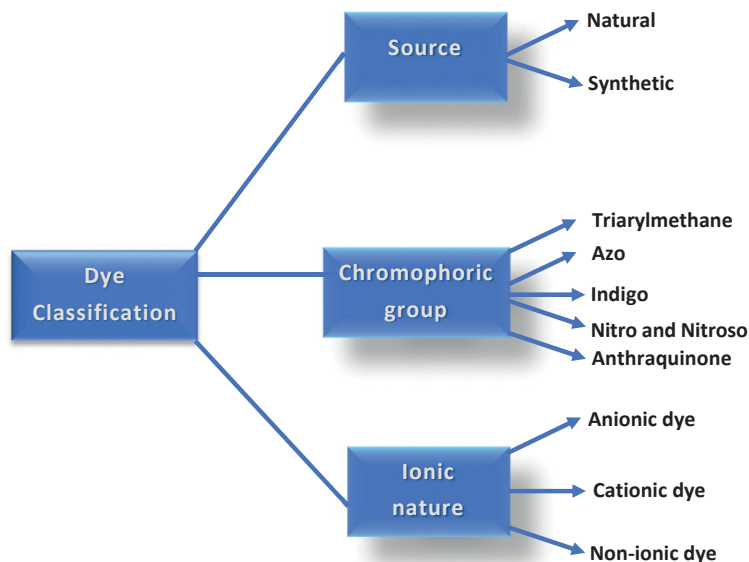


Fig. 1 The significant classifications of dye.

Though colored products provide joy to the eye, indiscriminate disposal of dye effluent in receiving water bodies poses a considerable risk, even with low concentrations, since it interferes with solar penetration, consumes dissolved oxygen and hinders breathing, thereby disrupting photosynthetic and biological activities in waters.^{8,21} As a result of long-term exposure to dye contaminants, including cationic, reactive, and direct dyes, aquatic and terrestrial organisms, including humans, can develop carcinogens and mutagens and exhibit high toxicity.^{22,23} The toxicological and environmental impacts of textile dyes are increasingly being considered, mainly because of their increased use in the current era. Fig. 2 illustrates the chemical structure of important dyes, and Table 1 discusses the description of different types of dyes.

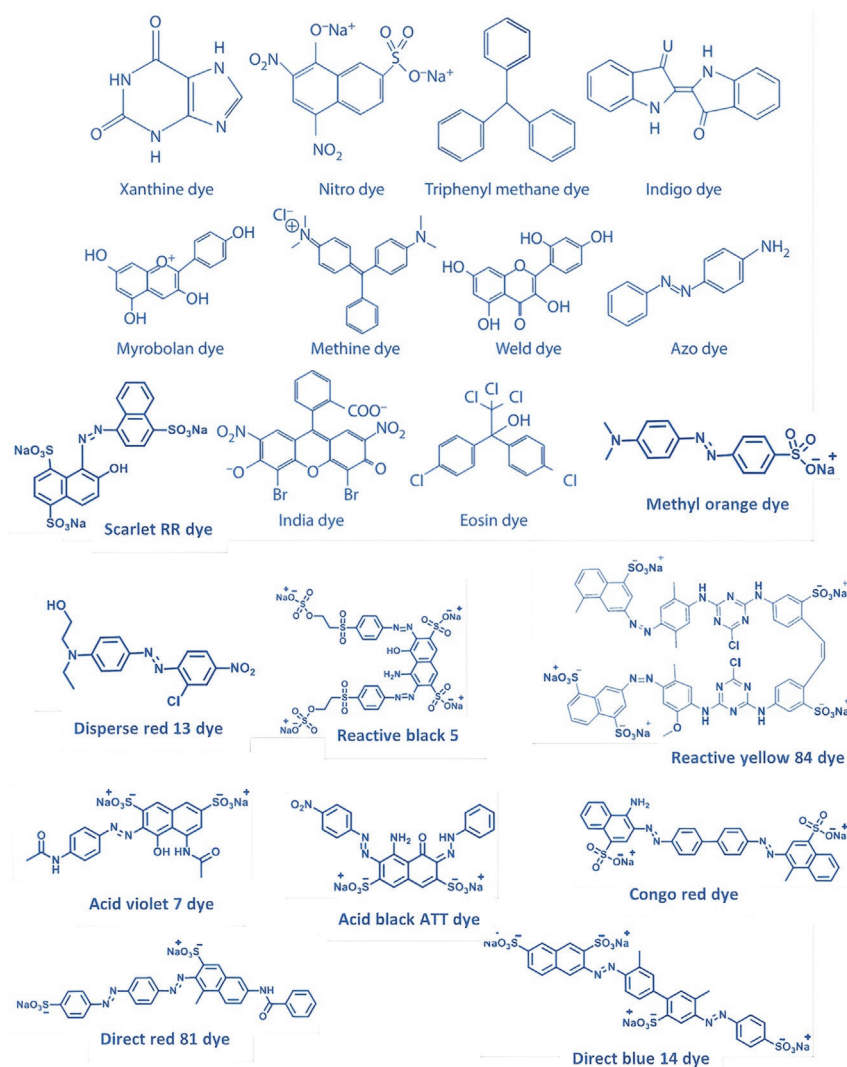


Fig. 2 The chemical structures of selected dyes.

Table 1 The description, characteristics, application and examples of different classes of dyes.

Classes of dye	Characteristics	Application
Acid dye	As a result of the presence of sulfonic acid groups, acid dyes are extremely soluble in water. They are used both in acidic and neutral conditions. They are also known as anionic (–ve) dyes. They possess molecular structures with large aromatic rings and sulfonyl and amino groups.	They are utilized in the coloring of nylon, wool, and silk, except for cotton. E.g., Nigrosine, eosin, India ink, and picric acid.
Basic dye	Basic dyes are positively charged (cationic) dyes with functional groups such as ($-\text{NH}_2$) or ($-\text{NR}_2$) groups. They are soluble in alcohol and methylated spirit. However, they are insoluble in water. They react with negative sites and are attached to fabrics used under acidic conditions.	Besides being used for dyeing and printing jute, they are also used in wool and acrylic fiber processing. E.g., Malachite green and crystal violet.
Direct dye	Direct dyes are soluble in water. They are anionic and can be used both in neutral and alkaline solutions. They are colorful, but; they fade with washing. They are applied as pH indicators and as biological stains.	Coloring applications in cotton, rayon, nylon, wool paper, leather, and silk.
Disperse dye	Non-ionic and no ionizing groups are present. They are organic synthetic dyes suitable for dyeing hydrophobic fibers. They are less soluble in water.	They are used for dyeing nylon, polyester, and polyacrylonitrile.
Reactive dye	Reactive dyes develop covalent bonds between dyes molecules and end sites ($-\text{NH}_2$, $-\text{OH}$, $-\text{SH}$ and $-\text{Cl}$) of substrates such as fiber. They are anionic, soluble in water, and can be used in neutral and alkaline media. They are available in several kinds, such as liquid, print paste, and powder. They have an excellent wash, light fastness and are relatively cheap.	They are used for coloring cotton, rayon, flax, cellulose, polyamide, and wool fibers.
Vat dye	Vat dyes are sourced naturally from vegetables and animals. They are insoluble in water. Under alkaline conditions, they give excellent and stable colors to fibers. They have poor robbing characteristics. They are expensive and cause skin diseases in contact with human skin.	They are used for coloring cellulosic fiber, such as cotton.

Table 1 The description, characteristics, application and examples of different classes of dyes.—cont'd

Classes of dye	Characteristics	Application
Solvent dye	Solvent dyes are highly soluble in nonpolar organic solvents. Used in textile coloring processes, they are insoluble in water. They found applications as color lubricants in cutting operations in the automotive and industrial sectors.	Acrylics, PVC, polyester, PMMA, PETP, acetates, nylon, polystyrene, and styrene monomers are used for coloring materials, as well as identifying cell structural components in medical studies and research.
Mordant dye	Mordant dyes have the unique capability to form insoluble color lakes when bound to metals. They may be of natural and synthetic nature. They are also known as chrome dyes, thus commonly applied as inorganic chromium. Cold water is the preferred solvent, and they have good color durability.	A variety of fibers are made using them, including modacrylic fibers, protein fibers, and nylon.



3. Phytoremediation of dye-containing wastewater

As a green and reliable technology, phytoremediation has been credited for its low design and maintenance costs, independent solar power, and aesthetic appeal. In addition, it has a longer-standing potential and is, therefore, better suited for use on contaminated terrain than other costly treatment options.^{24,25} Phytoremediating plant roots can be colonized by soil-borne bacteria, which can enhance plant growth and be utilized for bioremediation.^{26–28} Some wild plants have previously been used to treat textile effluents such as *Phragmites australis*, *Blumea malcolmii*, *Rumex hydrolapathum*, *Typhonium flagelliforme*, and *Rheum rabarbarum*.^{29–33} Furthermore, macrophytes can act as dye decolorizers and detoxicators in dye-containing wastewater. Studies at a microcosmic scale and in situ degradation of dyes have been conducted with these aquatic plants.^{34,35} Plants in hydroponic systems and the phytoremediation performances they exhibit are presented in Table 2, including initial dye concentrations, removal efficiency, and treatment time. Constructed wetlands are designed and fabricated to depurate pollutants employing natural mechanisms such as vegetation (macrophytes), soil, and microbial communities.^{52–54} Among the major components of

Table 2 Phytoremediation performances of different wild/indigenous plants for textile dyes and effluents.

S/N	Macrophyte	Dye	Concentration (mg/L)	Decolorization time (h)	% Decolorization	Reference
1	<i>Alternanthera philoxeroides</i>	Remazol Red	70	72	100	Rane et al. ³⁴
2	<i>Pogonatherum crinitum</i>	Effluent	NA	288	74	Watharkar et al. ³⁶
3	<i>Nasturtium officinale</i>	Acid Blue 92	20	96	78	Torbati et al. ³⁷
4	<i>Ipomoea hederifolia</i>	Scarlet RR	50	60	96	Rane et al. ³⁸
5	<i>Typha angustifolia</i>	Reactive Blue 19	75	144	70	Mahmood et al. ³⁹
6	<i>Bouteloua dactyloides</i>	Effluent	NA	24	92	Vijayalakshmi Devi and Muthukumar ⁴⁰
7	<i>Petunia grandiflora</i>	Brilliant Blue G	20	36	86	^{41,42}
8	<i>Azolla filiculoides</i>	Acid Blue 92 and Basic Red 46	20	168 and 144	80 and 90	Vafaei et al., ⁴³ Khataee et al. ⁴⁴
9	<i>Lemna minor</i>	Acid Blue 92 and Methylene Blue	2.5 and 10	144	77 and 98	Reema et al., ⁴⁵ Khataee et al. ⁴⁶
10	<i>Portulaca grandiflora</i>	Reactive Blue 172	20	40	98	Khandare et al. ⁴⁷
11	<i>Glandularia pulchella</i>	Remazol Orange 3R and Green HE4B	20	96 and 48	100 and 92	^{48,49}
12	<i>Aster amellus</i>	Remazol Orange 3R Remazol Red	20	72 and 60	100 and 96	, ⁴⁹⁵⁰
13	<i>Typhonium flagelliforme</i>	Brilliant Blue R	20	96	65	Kagalkar et al. ³²
14	<i>Blumea malcolmii</i>	Direct Red 5B, Methyl orange, Malachite green, Red HE4B, and Reactive Red 2	20	72	80, 76, 96, 88	Kagalkar et al. ³¹
15	<i>Phragmites australis</i>	Acid Orange 7	75 and 100	Eight times a day and 144 h	68 and 98	Davies et al., ⁵¹ Ong et al. ³³

NA: Not available.

Source: Khandare R, Govindwar S. Phytoremediation of textile dyes and effluents: current scenario and future prospects. *Biotechnol Adv* 2015;**33**:1697–714.

constructed wetlands are aquatic macrophytes which absorb contaminants through their plant parts, along with enzymes that could act as catalysts for efficient pollutants degradation. Also, a variety of rhizosphere bacteria within their root zone area facilitate the removal of contaminants more effectively.⁵⁵ Specifically, aquatic macrophytes have recently been used in various artificial wetlands to decolorize and degrade colors from textile wastewater, such as *Typha angustifolia*, *Typha domingensis*, *Phragmites australis*, *Ipomoea aquatic*, *Ammannia baccifera*, *Alternanthera philoxeroides*, *Fimbristylis dichotoma*, *Salvinia molesta*, and *Paspalum scrobiculatum*.^{56–58}



4. The importance of using CW to treat wastewater containing dye and its advantages over other treatment

Conventional technologies such as biological and physicochemical (coagulation, flocculation, sedimentation, membrane filtration, and advanced oxidation) treatments have been applied to remove dye from dye-rich wastewater. However, these methods have numerous disadvantages, such as high investment and maintenance costs, low efficiency, and the formation of sludge and toxic by-products. CWs are a promising eco-friendly and more sustainable treatment technology that is energy-efficient, simple to design, and economically and environmentally friendly, with their optimal biophysicochemical treatment conditions. These have been proven from global experiences.

CWs are an excellent alternative from both an economic and environmental standpoint, and they are less expensive and have low maintenance costs (up to 90% lower) than conventional technologies. CWs have a more aesthetic appearance than conventional treatment methods. CW does not produce any by-products in practice. Biomass from plants is the only by-product that can be considered in CWs. The biomass can be further exploited as a biofuel for energy production or used as compost. In addition, CWs do not require the addition of chemical additives. Locally available resources can be sourced for the construction of CWs. In CWs, energy and water requirements are very low. CWs and physicochemical methods are compared in [Table 3](#). CWs are often designed to take advantage of many processes in natural wetlands, with more controlled environments. Hence, the reduction or removal of contaminants such as dyes is accomplished by diverse treatment mechanisms, including adsorption, filtration, sedimentation, chemical precipitation, microbial interactions, and macrophyte uptake or transformation.

Table 3 The main comparison between constructed wetlands (CWs) and physicochemical methods.

	Constructed Wetlands (CWs)	Physicochemical methods
Performance	Wholly effective and efficient in removing and mineralizing different types of dyes	Possess low dye removal efficiency. These methods don't involve the complete elimination or removal of dyes
Sustainability	The use of plants, microbial microorganisms, enzymes and the production of non-toxic end products make it eco-friendly.	Produces sludges and greenhouse gases
Energy consumption	Less	High
Water consumption	Less	Less
Use of chemicals	Not required	Always required
By-products	No sludge as a by-product	Produces large volumes of sludge
Cost investment	Low operating and maintenance costs	Economically unviable because large mechanical parts and equipment is needed.



5. Removal processes of dye in CW systems

The removal of dye from wastewater in CWs involves several mechanisms. The main mechanisms are physicochemical and biological processes occurring in the rhizosphere under aerobic, anaerobic, or anoxic conditions. These processes are induced by the interaction of the dye with plants, microorganisms, and the soil. Physiochemically, under anaerobic treatment, the cleavage of the $N=N$ in Azo dyes occurs, producing an aromatic amine that cannot be further reduced under the same anaerobic conditions. However, aromatic amines can be reduced aerobically, while azo dyes can be reduced anaerobically, anoxically, or aerobically. Biologically, microbes break the azo bond and reduce the dye into aromatic amines by secreting enzymes such as laccase, azo reductase, peroxidase, and hydrogenase. Further mineralizing these dye metabolites results in simpler non-toxic compounds that are used as a source of energy. Anaerobic and aerobic conditions are

necessary to degrade and mineralize azo dyes since they are not biodegradable under aerobic conditions. Various environmental and microbial factors have been reported to influence textile azo dyes' degradation. These factors include hydrogen ion concentration, oxygen, temperature, pH, inoculum size, carbon and nitrogen supplementation, concentration, structure, and toxicity.

Plant-associated microorganisms are potent enough to degrade and detoxify synthetic dyes and also completely mineralize them under certain environmental conditions. Shehzadi et al.⁵⁸ established the potential of 41 culturable bacterial endophytes isolated from wetlands, including *Typha domingensis*, *Pistia stratiotes*, and *Eichhornia crassipes* to degrade textile effluent and promote plant growth. Patil et al.⁵⁹ degraded Navy Blue HE2R (NB-HE2R) textile dye using adventitious roots of *Ipomea hederifolia* endophytically colonized by *Cladosporium cladosporioides*. Similarly, it has been reported that *Klebsiella aerogenes* S27 from *Suaeda salsa* is entirely able to degrade malachite green.⁶⁰ In the United States, the color removal efficiency was reported for the removal of acid blue and reactive blue from textile wastewater at 98%.⁶¹ In Portugal, acid orange was removed from dye solution at 74% removal efficiency.³⁰ Similarly, in Tanzania, Slovenia and Turkey, the color removal efficiency was reported for various dyes in real wastewater at 77%,⁶² reactive black, disperse yellow, and vat yellow at 90% removal efficiency from dye solutions,⁶³ and acid yellow at 95% removal efficiency in 90 days from textile wastewater⁶⁴ respectively.

Noonpui and Thiravetyyan⁶⁵ investigated Azo dye removal in CW, showing 97% dye removal; however, the removal efficiency of each dye molecule influenced the removal efficiency. It has been proven that using a microbial fuel cell (MFC) in combination with CWs can be an affordable treatment for textile dye wastewater. Several recent studies have shown that CW-MFC systems are more efficient at treating textile dye wastewater than conventional CWs.^{66–68} According to a study by Xu et al.,⁶⁹ the anodic microbial community plays a key role in the performance of a CW-MFC system due to its importance in understanding the microbial community structure. MFCs can be coupled with CWs because of the redox gradients in CWs, which enable anaerobic anodes and aerobic cathodes, which are essential for MFCs to operate.⁶⁹ A compilation of previous related works on the removal of dye or mixture from CWs is presented in Table 4.

Table 4 Previous studies on dye removal by constructed wetlands.

CWs system	Design characteristics	Country of operation	Plant used	Dye/Wastewater	Initial dye concentration (mg. L ⁻¹)	pH	Duration (days)	Removal efficiency	HRT (h)	Reference
VF	Gravel-sand	USA	<i>P. australis</i>	AB113, *RB171	100	7.6–7.8	70	98% color	960	61
VF	Gravel-sandy clay soil	Portugal	<i>P. australis</i>	AO7	40	5	77	64% COD, 71% TOC and 74% color	NA	Davies et al. ³⁰
					127	5	48	93% COD, TOC, and 99% color	NA	Davies et al. ⁷⁰
HF	Gravel-sand	Tanzania	<i>Typha and cocoyam</i>	Various dyes in real wastewater	NA	NA	84	72% COD, 59% sulfate, and 77% color	29.04	Mbuligwe ⁶²
VF	Gravel-sand-zeolite-peat	Slovenia	Without plant	RR22, VR13, **RB5	NA	12–7.6	90	60% EC, 70% dye, 88% COD and TOC	NA	Ojstršek et al. ⁷¹
VF-HF	Gravel-sand-tuff	Slovenia	<i>P. australis</i>	**RB5, DY211, VY46	30	7.6–7.8	60	84% COD, 93% TSS, 52% TN, 88% sulfate, 87% Norganic—331% NH4-N, 90% color, 80% anion surfactant and 93% TSS	NA	Bulc and Ojstršek ⁶³
VF	Gravel-sand	Thailand	<i>Typha</i>	RR141	20	7.8	NA	60% COD, 86% TDS, and 49% color	360	Nilratnisakorn et al. ⁷²
UF	Gravel-glass beads	Japan	<i>P. australis</i>	AO7	50, 100	7.7	365a	98% dye, 90% COD, 67% TN, 72 and 28% TP, 98% NH4-N, 100% NO ₃ -N	144	Ong et al. ³³

VF	Gravel-sludge	N/A	<i>P. australis</i>	AO7	50	NA	27	95% COD and 86% NH ₄ -N, 94% color	48	Ong et al. ⁷³
FWS-SSF	Shale	Thailand	<i>P. australis</i>	Azo Dye	NA	6.0–7.5	–	98% COD, 97% color	96	Cumnan and Yinrattanabovorn ⁷⁴
BF-MFC	Copper electrodes-sludge	India	<i>C. indica</i>	MB	2000	6.1–4.0	NA	80% color	96	Yadav et al. ⁷⁵
VF.	Coconut shavings-soil with bacteria	India	<i>Gaillardia pulchella</i>	Mixture dyes into different metabolites	NA.	NA	0.042	0% COD, 74% TOC, 70% BOD	NA	Kabra et al. ^{48,49}
VF.	Coconut shavings-sand-gravel-soil with bacteria	India	<i>Portulaca grandiflora</i>	Mixture dyes into different metabolites	NA	NA	0.05	37% TOC, 41% turbidity, 59% COD, 38% BOD, 71% TDS, 60% TSS	NA	Khandare et al. ⁷⁶
CVU-MFC	Gravel-GCA electrode	China	<i>Ipomoea aquatica</i>	ABRX3	150	NA	NA	91.24% color	72	Fang et al. ⁷⁷
VF.	Coconut shavings-gravels and soil	Pakistan	<i>Typha</i>	Various dyes in real wastewater	NA	NA	3	79% COD, 77% BOD, 59% TDS, 27% TSS	NA	Shehzadi et al. ⁵⁸
VF	Gravel-sand-zeolite	Turkey	<i>Canna and Typha</i>	AY 2G E107	250	8	90	94% PO ₄ -P, 77% NH ₄ -N, 95% color, 64% COD	90	Yalcuk and Dogdu ⁶⁴
HSF	Rice husk-gravel	Malaysia	<i>Typha latifolia</i>	AO7	300	NA	NA	100% color	120	Tee et al. ⁷⁸
CVU-MFC	Gravel-GAC	China		MO	450	NA	NA	87.6% color	72	Fang et al. ⁷⁹

Continued

Table 4 Previous studies on dye removal by constructed wetlands.—cont'd

CWs system	Design characteristics	Country of operation	Plant used	Dye/Wastewater	Initial dye concentration (mg. L ⁻¹)	pH	Duration (days)	Removal efficiency	HRT (h)	Reference
SSF	Gravel-sand	Malaysia	<i>Scirpus grossus</i>	Paper mill effluent	NA	NA	95 days	66.1% COD, 55.8% color, 87.2% suspended solid (SS.)	120	Mojiri et al. ⁸⁰
CVU-MFC	Gravel-GAC	China	<i>Ipomoea aquatica</i>	ABRX3	300	NA	NA	92.7% color	72	Fang et al. ⁸¹
AB	Gravel-activated sludge	Malaysia	<i>Phragmites australis</i>	AM	26	NA.	NA	98–91% COD, 100% color	24	Lehl et al. ⁸²
CVU-MFC	Gravels-glass beads	Malaysia	<i>T. Latifolia</i>	AR18	500	NA	463	91% color	24	Oon et al. ⁸³
CW-MFC	NA	India	<i>Fimbristylis dichotoma</i>	ADMI	NA	NA	NA	82.2% color, 70% COD	72	Rathour et al. ⁶⁷
RHF	Fine gravel	Tunisia	<i>Typha domingensis</i>	AM	10–25	7–7.7	NA	92% color, 56% COD	3.1	Haddaji et al. ¹⁴
FTWs	NA	Pakistan	<i>Phragmites australis</i>	Textile dye wastewater	NA	NA	730	92–91% BOD, 86% color	NA	Tara et al. ⁸⁴
CVU-MFC	Gravels-carbon felt electrode	Malaysia	<i>Typha latifolia</i>	AR18, AO7, CR	200			96% AR18, 67% Acid Orange 7 (AO7), 60% C.R.	24	Oon et al. ⁸³
HSSF-MFC	A dual-chamber MFC-stainless steel electrode	India	<i>Fimbristylis dichotoma</i>	ADMI	NA		120	62% COD, 90% color	96	Patel et al. ⁶⁶

AB: Acid blue; *RB: Reactive blue; VF: Vertical-flow; AO: Acid orange; COD: Chemical oxygen demand; TOC: Total organic carbon; HF: Horizontal flow, **RB: Reactive black; DY: Disperse yellow; VY: Vat yellow; TSS: Total suspended solid; TN: Total nitrogen; N: Nitrogen; NH₄-N: Ammonium nitrogen; RR: Reactive red; VR: Vat red; AM: Amaranth dye; HRT: Hydraulic retention time; EC: Electrical conductivity; UF: Upper flow; NO₃-N: Nitrate nitrogen; TDS: Total dissolved solids; FWS: Free water surface; SSF: Subsurface flow; BOD: Biochemical oxygen demand; AY: Acid yellow; PO₄-P: Ortho-phosphate-phosphorus; NA: Not applicable; HSF: Horizontal subsurface-flow; SSF: Subsurface flow; AB: Aerobic-anaerobic baffled; RHFA: Re-circulating horizontal flow; BF-MFC: Batch flow-microbial fuel cell; CVU-MFC: Continuous vertical upflow-microbial fuel cell; ABRX3: Reactive Brilliant Red X-3B; MO: Methyl Orange; GAC: Granular activated carbon; AR18: Acid Red 18; CR: Congo Red, HSCW-MFC: Horizontal sub-surface flow—microbial fuel cells; ADMI: American Dye Manufacturer's Institute, FTWs: Floating treatment wetlands.



6. Conclusion and future research needs

CWs are an environmentally friendly, cheap, simple-to-use, and effective technology widely accepted for treating a variety of municipal sewage, stormwater runoff, agricultural runoff, and industrial wastewater. This chapter reported that the high removal efficiency of dye, COD, and other contaminants was due to the interplay between plants, water, soil, and micro-organisms in CW. Using this technology, wastewater of different origins can easily be treated in a natural and low-cost manner, especially dye-containing wastewater. Biodegradation of textile dyes in CW needs to be extensively studied from a simple and applied perspective and studies should emphasize case studies that are more similar to real-world situations. This biodegradation process should focus on environmental factors, degradation rate, degradation mechanisms and degradation pathways that influence pollutant removal. Finally, it is crucial to ensure that the intermediate products from dye degradation have no toxic effects on aquatic environments.

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