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Textile Wastewater Treated by Constructed Wetlands – A Critical Review

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ABSTRACT

Textile industries are among the most environmentally unsustainable businesses, releasing large amounts of effluent that endangers ecosystem health. Constructed wetlands (CWs) are low-cost eco-technical treatments for industrial wastewater control. The CWs are self-contained remediation systems that do not require external energy and have basic mechanisms for pollutant removal, such as biological, chemical, and physical processes. For more than sixty years, constructed wetlands have been utilized to clean wastewater. Most applications have been developed to treat municipal or household wastewater, although CWs are now successfully used to treat a wide range of wastewater types. Constructed wetlands were also employed to treat textile industry effluents in the 1990s. The survey indicated that textile manufacturing wastewaters were treated using subsurface and surface-flow wetlands. Both horizontal and vertical flow systems have been designed within subsurface flow-created wetlands. In addition, many hybrid-built wetlands have recently been documented in the literature for textile industrial wastewater treatment. According to the survey, textile industrial wastewater is treated in constructed wetlands on all continents, and this research includes the data from 65 constructed wetlands in 21 nations worldwide. This paper examined the latest improvements and discoveries in CWs and the many types of CWs used for textile wastewater treatment. The paper also demonstrated state-of-the-art integrated technologies for improving the performance and sustainability of CWs, such as CW-MFC systems.

Keywords: azo dye, constructed wetlands, textile wastewater, treatment.

INTRODUCTION

The textile industry sector is one of the most critical and largest industrial sectors in many countries; India (Sivakumar et al., 2013), Turkey (Yalcuk and Dogdu, 2014), European countries, and the USA (Yaseen and Scholz, 2019). It is estimated that globally 280, 000 tons of textile dyes are discharged in textile industrial effluent every year (Jin et al. 2007). They affect the economic development worldwide due to the growing environmental pollution from these industries (Hossain et al., 2018). Large quantities of pure water will be consumed. The textile dyeing industry will produce a large volume of wastewater from various processing of dyeing and finishing (Ojstršek et al., 2007; Hussein and Scholz, 2017), as shown in Table 1. The majority of chemical substances, including dyes, are only partially metabolized (Bidu et al., 2021). Because the textile effluent wastewater is being discharged into the river without having any effect of degradation or reduction on the water environment, the river's water is unfit for irrigation, drinking, and aquatic life (Hussein, 2017, Hussein and Scholz, 2018). In addition, a significant number of the dyes that are utilized in the textile industry are carcinogenic and toxic (Dos Santos et al., 2007). Additionally, hazardous materials known as aromatic amines will be released because of the use of azo dyes in textiles (Hussein, 2017). This category of wastewater can be treated using a variety of approaches, including physicochemical and biological methods. The first approach is not only expensive, but it also generates significant amounts of sludge and discharges some dyes (Costa et al.,

Table 1. List of some of the pollutants generated at each stage of textile processing (Holkar et al., 2016)

<table>
<tr><td colspan="8">Desizing stage</td></tr>
<tr><td colspan="2">Sizes</td><td colspan="2">Enzymes</td><td colspan="2">Starch</td><td colspan="2">Waxes</td></tr>
<tr><td colspan="8">Scouring stage</td></tr>
<tr><td>NaOH</td><td>Surfactants</td><td>Soups</td><td>Fats</td><td>Pectin</td><td>Oils</td><td>Sizes</td><td>Waxes</td></tr>
<tr><td colspan="8">Bleaching stage</td></tr>
<tr><td colspan="2">H2O2</td><td colspan="2">Sodium Silicate</td><td colspan="2">Organic stabilizer</td><td colspan="2">Alkaline pH</td></tr>
<tr><td colspan="8">Dyeing stage</td></tr>
<tr><td>Colors</td><td>Metals</td><td>Salts</td><td colspan="2">Surfactant</td><td colspan="3">Alkaline / Acidic</td></tr>
<tr><td colspan="8">Printing stage</td></tr>
<tr><td>Colors</td><td colspan="2">Metals</td><td colspan="2">Urea</td><td colspan="2">Formaldehyde</td><td>Solvents</td></tr>
<tr><td colspan="8">Finishing stage</td></tr>
<tr><td colspan="2">Softeners</td><td colspan="2">Solvents</td><td colspan="2">Resins</td><td colspan="2">Waxes</td></tr>
</table>

2012). In contrast, the second method, which may involve the creation of constructed wetlands, is not only significantly cheaper than the methods that came before it, but also friendly to the environment and do not result in the production of a significant amount of sludge (Tee et al., 2015; Shenoy et al., 2022).

Constructed wetlands mimic the treatment that occurs in real wetlands. Constructed wetlands are classified into horizontal, vertical, and hybrid flow constructed wetlands, depending on the direction of water movement (Vymazal, 2014). CWs consist of a properly designed basin that contains plant, water, substrate, and microorganisms. substrate, such as sand, soil, and gravel, plays a major role in supporting plants' growth and micro-organisms (Hussein and Scholz, 2017). The plants provide many benefits and contribute to the creation of the conditions that affect the efficiency of constructed wetlands (Stefanakis et al., 2014); they can release oxygen from their roots into the rhizosphere (Brix, 1994); This process is essential for assisting subsurface flow CWs in aerobic degradation and nitrification. In addition, numerous kinds of research have proven that plants play a crucial role in nutrient absorption (Vymazal, 2007; Hussein and Scholz, 2017, 2018). Microorganisms are one of the primary factors on which constructed wetland functions for wastewater treatment rely heavily (Brix, 2003). Numerous researchers have noted that micro-organism communities exist in aerobic and anaerobic wetlands (Scholz et al., 2001; Meng et al., 2014) and that artificial wetlands provide the optimal habitat for micro-organism growth (Saeed and Sun, 2012). Due to the interaction of physical, biological, and chemical processes that occur in CWs during the purification of wastewater and the transformation of phosphorus and nitrogen, microorganisms play a significant factor in reducing the organic pollutants of textile wastewater (Kayombo et al., 2005).

Many researchers treated textile wastewater by constructed wetlands through different conditions, such as; hydraulic loading rates (Davies et al., 2006; Yalcuk and Dogdu, 2014), dye concentration (Yadav et al.; 2012, Hussein and Scholz, 2017), hydraulic retention time (Saba et al.; 2014, Chandanshive et al.; 2018), type of plant (Yalcuk and Dogdu, 2014; Fang et al., 2015), type of media (Oon et al., 2018; Jayalakshmi et al., 2022), period of experimental work (Fibbi et al.; 2012, Almaamary et al.; 2022), with/without bacteria (Kabra et al., 2013, Hussein and Scholz, 2018), with/without aeration (Masi et al.; 2019, Sethulekshmi and Chakraborty 2021), and enhancing the media by adding extra materials (Yalcuk and Dogdu, 2014).

During the last decade, many researchers have been working on integrating Microbial Fuel Cell (MFC) in constructed wetlands. Yadav et al. (2012) treated synthetic wastewater containing textile dye (Methylene Blue) with different concentrations (2000, 1500, 1000, 500) mg/l by VF-CWs integrated with Microbial Fuel Cell (MFC); this experimental work is the first one to integrate MFC with CWs. Fang et al. (2013) investigated the combination between up-flow constructed wetlands and microbial fuel cells on color removal of azo textile dye (reactive brilliant red, 150 mg/l) contaminated in synthetic wastewater. The system consists of three constructed wetlands the medium of which was gravel. The first was open-circuit CW-MFC, the second was Non-planted CW-MFC, and the third was planted CW-MFC with *Ipomoea Aquatica* and operated with 3-day as HRT. The maximum removal percentage rates for color and COD were obtained in the third reactor, planted WC-MFC, 91 and 86 percent, respectively. Furthermore, the obtained results confirmed that microbial fuel cells enhanced pollutant removal in a constructed wetland.

Fang et al. (2015) investigated the treatment of azo textile dye (Reactive brilliant red, 500 mg/l) contaminated in synthetic wastewater using a combination of CW-MFC. The system consists of UFCW planted with *Ipomoea Aquatica* and used gravel as a medium; both polarization behavior and coulombic efficiency evaluated the MFC performance. The system operated under different HRTs (1.5, 2, 2.5, 3, 3.5, 4) days. Fang et al. (2016) used unplanted UFCWs-MFC to treat Methyl Orange (MO), 450 mg/l, in synthetic wastewater with gravel and activated carbon as a substrate. The total duration for the experimental work was 60 days, and the samples were collected every 3 days (HRT). MFC operated in two cases, open and closed circuits. Fang et al. (2017) treated azo textile dye (brilliant red X-3B in synthetic wastewater, 300 mg/l) using a combination of VFCWs-MFC planted with *Ipomoea aquatic*.

Kurniadie et al. (2020) treated the wastewater from the textile industry in two stages. The first stage consisted of chemical pre-treatment, and the second stage consisted of VFCWs, continuous feeding, and a drainage system that was spread over the entire bed area. In order to treat the synthetic textile wastewater that contained three azo textile dyes, Oon et al. (2020) utilized a combination of chemical wastewater treatment (CWs) and microbial fuel cells (MFC) (Acid Red 18, Acid Orange 7, and Congo Red). The analyses conducted with high-performance liquid chromatography (HPLC) and a gas chromatograph–mass spectrometer (GC–MS) both yielded the same results, which substantiated the findings. When treating textile wastewater with CW-MFC, the anaerobic anodic region has a high capacity for decolorizing azo dyes, and the aerobic cathodic region has a high capacity for mineralizing dye intermediates into less harmful or non-toxic products. Both of these processes take place simultaneously.

Patel et al. (2021) treated natural textile wastewater using a system combination of HF-CWs-MFC consisting of two reactors. The first was planted with *Fimbristylis ferruginea,* and the second was planted with plant consortium *(Fimbristylis ferruginea* and *Elymus repens*). The total period for the experimental work was 120 days, with 4-day as an (HRT) and; 2-day in each reactor. The system operated in batch mode with a closed circuit. The bacterial community (DC5) was inoculated in the culture medium, increasing the percentage of pollutant removal. Sethulekshmi and Chakraborty (2021) treated azo textile dye (Reactive Red 22, ranging from 10 to 50 mg/l in concentration) in synthetic textile wastewater using the HFCWs system planted with *Typha*. The gravel was used in three different sizes as a wetland medium, starting from the bed, then firmly soiled to the plants. The system consists of two wetland filters, one baffled and one non-baffled, with (3-day to 7-day) as an HRT.

Saket et al. (2022) used a combination of CW-MFC on treated azo textile dye (Congo Red, 50 and 750 mg/l) contaminated with synthetic wastewater. Unplanted chambered CW was used and filled with gravel as a medium. The samples were taken every 24 h (HRT) during the experimental work (140 days). The obtained results showed the maximum color removal percentage rate was achieved at dye concentration (50 mg/l) with a value of 90 percent. In comparison, the COD removal percentage rate got at dye concentration (750 mg/l) with a value of 96 percent. These results stated that using CW-MFC leads to higher pollutant removal percentage rates.

This review aimed to collect the information regarding treating textile wastewater by subsurface flow CWs. The objective is to summarize the papers that treated this type of wastewater regarding the physical and chemical parameters of different types of constructed wetlands; horizontal, vertical, and hybrid flow.

VARIABLE PARAMETERS

Physical parameters

The physical parameters included dye concentration, color, Turbidity, Total Suspended, Total Dissolved Solids, Electrical, and Total Organic Carbon.

Dye concentration

Any increase in dye concentration leads to an increase in textile wastewater physical and chemical parameters. Furthermore, dye compounds are one of the major environmental sources of aromatic amines. Human blood continues to be associated with the current concentration of aquatic-toxic aromatic amines (Snyderwine et al., 2002; Kirandeep et al., 2015). Each colorant contains at least one aromatic amine (Pielesz et al., 2002). CWs can degrade aromatic amine under aerobic conditions (Ong et al., 2011). The presence of plants has significantly affected dye removal percentage, as confirmed by many researchers, such as Keskinkan and Lugal (2007) and Zhou and Xiang (2013). Many researchers work on dye concentration removal in both low concentrations such as (Hussein and Scholz, 2017) and (Ong et al., 2009); and high concentrations, such as (Davies et al., 2005) and (Hussein and Scholz, 2018). The removal efficiency finds to be a function of the structure and size of the dye molecule (Noonpui and Thiravetyyan 2011).

Color

The production of color in dye-pollutant water by azo dye, which blocks sunlight and is therefore harmful to the many photo-initiated chemical reactions that are essential for the survival of aquatic life in water bodies, results in the use of more dye (Yadav et al., 2012; Hussein and Scholz, 2017, Hussein, 2018). The dark color of effluent materials prevents the sunlight from reaching the surrounding area, which results in severe issues for the surrounding biological communities. When azo dyes are exposed to anaerobic conditions, they lose their color, which results in the release of aromatic amine. O'Neill et al. (2000) and Ruddon (2007) all found that the current level of aromatic amines in human blood continued to be linked with one another. The decolorization of textile dyes can be accomplished in aerobic, anaerobic, or oxygen-free environments (Van der Zee, 2002).

Turbidity, total suspended, and total dissolved solids

It is possible to interpret the degree of water clarity based on its turbidity. It is a variable that is frequently used to indicate the number of microorganisms in the water that are more significant or the number of sediments in suspension. A high level of turbidity in the water surface may also indicate an elevated level of total suspended solids (TSS), a reduction in the number of algae populations, and the possibility of damage to aquatic life (Postolache et al., 2007). In addition, a higher range of turbidity can cause an increase in the surface water temperature due to an increase in the amount of heat absorbed from the sun. This can also cause a reduction in the amount of light that can penetrate the water, which can have an effect on photosynthesis (Hkanson, 2006). The acronym TSS stands for total suspended solids, which refers to all the particles in wastewater that can be filtered out. They are made up of inorganic and organic particles of a solid nature, such as sewage, silt, and waste products from industry (Zhang et al., 2013). A high total suspended solids concentration prevents light from reaching plants, which slows photosynthesis and reduces the amount of dissolved oxygen that plants release into the water (Bilotta and Brazier, 2008).

This is not the only physical factor that contributes to variations in temperature. Because of the higher concentration of TSS, chemical reactions will also cause the release of pollutants like heavy metals, as well as nutrients like phosphorus into the stream that is receiving the water (Bilotta and Brazier, 2008; Haygarth et al., 2006). In addition, a higher concentration of TSS may have an effect on the biological characteristics of organisms, such as their rate of growth or population size (Shaw and Richardson, 2001). According to the findings of a large number of researchers, engineered wetlands have a significant amount of capacity for the mechanical removal of TSS. In most cases, the total suspended solids are reduced through the processes of physical settling and filtering (Kadlec and Wallace, 2008).

According to Manios et al. (2003), the physical and chemical structure of a gravel bed makes it more effective than any other substrate bed in removing total suspended particles. This finding was based on a comparison of gravel beds to other substrate beds (soil, sand, and other compost). Gravel is not as compact as the other substrate materials that have been described, which are compactable, and the pressure that is applied to these compactable substrates minimizes the considerable porosity that they have. The presence of plants significantly influences the reduction of TSS by increasing the amount of time that the water is retained (Kadlec and Wallace, 2008).

Electrical conductivity

The electrical conductivity (EC) of the wetland outflow can be used as a proxy for the charge (or the ion-carrying species) that exists there (Islam et al., 2011). The electrical conductivity value can be applied to the task of locating additional water quality problems. In a wetland filter, the presence of a source of dissolved ions can be inferred from any unexpected rise in EC readings (Kumar and Chopra, 2012).

Total organic carbon

An increase in organic carbon decreases the nitrification rate, while denitrification is observed after an increase in organic carbon (Ding et al., 2012). Khehra et al., 2005 found that the presence of organic carbon is very important as a source to reduce textile dyes. Some dyes, such as Basic Red 46 and Acid Blue 113 (Hussein and Scholz, 2017), contain carbon as part of their chemical structure. This contributes to the ability of a dye to improve the capacity of constructed wetland to reduce nitrogen in high percentages. These results have been backed up by the research carried out by (Lavrova and Koumanova 2014).

Chemical parameters

The chemical parameters included chemical and bio-chemical oxygen demands, nitrogen, phosphate, and other chemical compounds.

Chemical and bio-chemical oxygen demands

The chemical oxygen demand (COD) is a crucial index that is used to measure the amount of organic pollution that is present in textile wastewater (Li et al., 2018). Biochemical oxygen demand, also known as BOD, refers to the amount of dissolved oxygen that aerobic biological organisms in a given wastewater sample require in order to decompose organic material. The presence of a high BOD in wastewater has the potential to reduce the amount of oxygen in receiving waters, which may result in the demise of certain organisms (Bhateria and Jain, 2016).

The accumulation of organic matter is an absolutely necessary component of man-made wetland areas. Microorganisms benefit from it in two ways: first, it supplies the energy necessary for their growth, and second, it supplies long-term carbon. Denitrification, or the reduction of nitrogen, is facilitated by the addition of carbon, as numerous researchers have demonstrated (Songliu et al., 2009). In contrast, the accumulation of organic matter is one of the most important contributing factors in the formation of clogging (Fu et al., 2013).

When attempting to determine the level of organic contamination that is present in textile wastewater, one of the most important measurements that should be taken is the chemical oxygen demand. The amount of oxygen equivalent that must be present in order to oxidize the organic components of the textile wastewater is called the oxygen equivalent loading (Chai et al., 2006). Numerous researchers, such as Joseph et al. (2019), Almaamary et al. (2022), and Benny and Chakraborty (2023), have investigated the COD and BOD concentrations in the textile wastewater treated by subsurface flow CWs. The amount of organic matter in constructed wetlands can be decreased through the processes of adsorption, filtration, and aerobic metabolism, anaerobic metabolism, and microbial metabolism (Vymazal et al., 1998; Stefanakis et al., 2014).

Nitrogen compounds

Nitrogen, either organic or inorganic, can be dissolved in water and delivered to the wetland (Sumner, 1999). According to Vymazal and Kropfelová (2009), the origin of the effluent influences the proportional proportions of nitrogen that are present in the effluent. Nitrate, nitrite, ammonia and ammonium are the inorganic nitrogen compounds that are found in the greatest abundance (Likens, 2010). The most common types of organic nitrogen compounds are amines, urea, amino acids, and purine (Kadlec and Wallace, 2008). Plant uptake and soil accumulation are the two primary methods for reducing nitrogen levels in the environment (Obarska and Gajewska, 2003). Microbial nitrification and denitrification are also important (Lee et al.; 2009). In the process of nitrification, ammonia or ammonium is first oxidized to nitrite, and then the nitrite is converted to nitrate (Kessel et al., 2015). The process of converting nitrate into nitrogen gas is referred to as denitrification (Schaechter, 2009). The wetland is fed dissolved organic and/or inorganic nitrogen, depending on the type of nitrogen (Sumner, 1999). The relative amounts of the nitrogen composition change depending on the source of the effluent, as stated by Vymazal and Kropfelová (2009). The inorganic nitrogen compounds that are most common include nitrite, nitrate, ammonium, and ammonia. The organic nitrogen compounds that are most common include amines, urea, amino acids, and purine (Likens, 2010). Several papers have reported additional strategies for reducing nitrogen in constructed wetlands, including nitrogen fixation, ammonification, ammonia adsorption, anammox, and ammonia volatilization (Mustafa, 2010).

On the other hand, the most important step in the process of removing nitrogen is a combination of nitrification and denitrification (Scholz, 2011).

It is necessary to have both aerobic and anaerobic conditions for the processes of nitrification and denitrification to take place. The conditions that are anaerobic are necessary for the conversion of ammonia and/or ammonium to nitrite during the nitrification process. On the other hand, aerobic conditions are necessary for the conversion of nitrite to nitrate (Kadlec and Knight, 1996; Kyambadde, 2005). This process requires a carbon source, which can be supplied by decaying plant detritus or the COD that is present in the textile wastewater that is being processed. Denitrification necessitates the presence of both aerobic and anaerobic conditions in order to convert the nitrogen-containing compounds (nitrite or nitrate) to nitrogen gas (Winkler et al., 2015). C stands for organic carbon, and N refers to inorganic nitrogen. The rate of nitrification decreases whenever there is an increase in the amount of organic carbon, whereas denitrification is discovered after there is an increase in the amount of organic carbon. Ding et al. (2012) provided additional evidence that supported these findings.

Changes in temperature influence the rate of nitrogen reduction. A number of studies demonstrate that the reduction rate declines throughout winter (Mietto et al., 2015). USEPA (2000) claimed that temperatures greater than 12.9 degrees Celsius are optimal for nitrification and denitrification. The temperature is a crucial consideration when planning CWs (Chapanova et al., 2007). According to Vymazal (2007), the influence of temperature on nitrification is stronger than on denitrification. Developing countries (especially when temperatures above 40 degrees Celsius) will have an effect on plant life, which is dependent on their growth cycle and requires consultation with ecologists. Songliu et al. (2009) demonstrated that the created wetland has a strong capacity to maintain an optimal pH for denitrification, and winter temperature may impact nitrate removal.

Phosphate compounds

Phosphorus, in both its organic and inorganic forms, can be found in CWs as organic and inorganic phosphate. Phosphorus can also be found in its organic form (Vymazal, 2007). The vast majority of phosphorus is converted into orthophosphate through the process of biological oxidation (Cooper et al., 1996). Vymazal (2007) demonstrated that the removal mechanisms for phosphorus in CWs include desorption, leaching, fragmentation, microbial and plant absorption, dissolution, mineralization, adsorption, sedimentation, precipitation, burial, and precipitation. Additionally, in natural wetlands, the removal mechanisms for phosphorus include mineralization, adsorption, precipitation, burial, and sedimentation (Vymazal, 2007). Despite this, the processes that contribute the most significantly to reduction are precipitation, adsorption, as well as microbial and plant uptake (Cooper and Findlater, 2013). This points to the fact that the combination of biological, chemical, and physical treatments is likely to be the most successful strategy for phosphorus reduction (Mazumder, 2013). In a marsh, orthophosphate can quickly accumulate in the vegetation and the medium, leading to an increase in the natural uptake as well as the chemical bonding that occurs.

According to Kayombo et al. (2004), the way in which wetland ecosystems are designed to function is what determines whether or not they have the capacity to store or reduce phosphorus. Phosphorus may leave the wetland through the water body, if the anaerobic condition in the wetland, which is caused by a deficiency in oxygen demand, is not remedied. This condition is caused by a deficiency in the demand for oxygen (Reddy et al., 1999). The capacity of the filter media to reduce phosphorus is dependent on the content of metal of the textile wastewater (Vohla et al., 2011), as well as the pH value (Cui et al., 2008), via precipitation and adsorption mechanisms. This is due to the contaminants that the wastewater contains. The reactions that take place when the pH is greater than 6 are sorption onto iron and aluminum oxide as well as the precipitation of calcium phosphates. Both of these reactions require a pH greater than 6. When the pH level reaches 6, the iron and aluminum phosphate that precipitates becomes more significant (Priya and Urmila, 2013). These methods have the potential to cause blockage in CWs (Knowles et al., 2011), which is especially likely when the textile wastewater in question contains significant quantities of a number of different industrial contaminants (Kadlec and Wallace, 2008).

Heavy metals

Heavy metals are any of a variety of metallic elements that have a density that is significantly higher than that of water (Fergusson, 1990), and some examples of these metals include mercury (Hg), cadmium (Cd), lead (Pb), arsenic (As), and thallium (Tl) (Martin, 2011). The vast majority of heavy metal ions are known to be carcinogenic or poisonous, they are not biodegradable, and they are accumulated by living beings, as stated by a number of sources (Barakat, 2011; Fu and Wang, 2011; Lakherwal, 2014). Heavy metals can cause a variety of adverse health effects in humans, including irritated skin, anemia, cirrhosis, and stomach cramps (Oyaro et al., 2007). As a consequence of this, removal of heavy metals is absolutely necessary.

In CWs, heavy metals are removed from the environment through the physical processes of sedimentation, settling, and adsorption; the chemical processes of adsorption, sorption, precipitation, and co-precipitation and oxidation; metal carbonates; and metal sulfides; and the biological activities of microbial uptake and plant uptake (Sukuma-ran, 2013; Arivoli et al., 2015). Because of the dynamic transformation that takes place in wetland systems regardless of whether or not the water is moving, the levels of heavy metals that are linked to particulate matter are greatly reduced during the settling and sedimentation processes (Ellis et al., 2003; Sheoran and Sheoran, 2006). It is possible for heavy metals to be transported from influent wastewater to the material of wetlands or bacteria (Matagi et al., 1998). According to Sheoran and Sheoran (2006), the primary method for removing heavy metals is the process of sedimentation.

The type of heavy metal, its concentration, and the conditions of the medium all play important roles in the adsorption process (Zeb et al., 2013). The vast majority of trace metals, such as lead, cadmium, nickel, zinc, and copper, are found in their cation forms. Their capacity to hold water is directly proportional to the type of wetland substrate present (Sheoran and Sheoran, 2006). Mengzhi et al. (2009) conducted the research to determine the effect that gravel and coke have on the rate at which heavy metals are reduced. The findings indicated that different levels of absorption efficiency existed. Sahu (2014) studied how lowering the retention time from one to eight days affected the amount of dissolved Cr, Ni, Fe, and Hg. The decrease rates increased along with the retention time increased.

The process of reducing heavy metals through the uptake of those metals by microbes and plants is known as a biological process, and it is the most important pathway for reducing heavy metals (Liu et al., 2015). The plant's type, the concentration of heavy metals, the pH of the sedimentation, the temperature, the chemical characteristics of the sediment, and the amount of organic matter in the sediment all have an impact on the number of heavy metals that are removed from artificial wetlands as a result of plant uptake. According to Allende et al. (2014), the rate of reduction of heavy metals by plant uptake was found to be 3%, while the reduction rate by wetland media was found to be >85%. According to the findings of Sinicrope et al. (1992), *Scirpus lacustris* had a significant impact on the reduction of Zn and Cd. According to the findings, there was approximately a 13% decrease in the amount of Zn and a 35% decrease in the amount of Cd that was found in the fine root of the plant. According to the findings of Cooper and Findlater (2013), an increase in the concentration of heavy metals inhibits the development of plants. According to the findings of Li et al. (2015), a few acidic inflow, with a pH equal to 5.6-6.5, makes it easier for the plant to take in heavy metals, whereas an alkaline inflow, with a pH equal to 7.5-8.5, makes it more difficult for the plant to take in heavy metals.

CLASSIFICATION OF SUB-SURFACE CONSTRUCTED WETLANDS FOR TEXTILE WASTEWATER TREATMENT

Subsurface flow systems are characterized by the fact that the influent travels under the surface of the gravel or soil substrates. The purification process happens when the substance comes into contact with the substrate surfaces and plant roots, both of which are oxygen-limited and water-saturated. Because the litter layer and overlying vegetation acts as a thermal insulator under these conditions, the performance of the wetland does not significantly degrade over the course of the winter. Horizontal flow, vertical flow, and hybrid flow are the three types of flow (Vymazal, 2013).

Horizontal flow constructed wetlands (HFCWs)

The HFCWs are equipped with an inlet that allows for the discharge of wastewater from the textile industry. It makes its way slowly through the substrate that is located beneath of the bed surface, through the pores of the porous substrate, and through the plant roots until it reaches the outlet, at which point it is collected. The outlet is located at the bottom of the bed (Vymazal et al., 1998). It is not possible to see the flow at the surface, and the level of the water is somewhere between 5 and 15 centimeters under the surface of the susbtrate (Vymazal et al., 2006). In addition, the breeding of mosquitoes is discouraged, which lowers the likelihood of disease transmission in human populations as well as in wildlife habitats (Kadlec and Wallace, 2008). As a rule, gravel or a combination of gravel and sand is used as the substrate, and the depth of the layer can be anywhere from 30 to 80 centimeters deep. This medium is beneficial to the growth of plants and should be used (Vymazal et al., 2006). The depth of the plant roots will determine the depth of the substrate, and an impermeable geo-membrane will cover the base of the bottom to prevent water from leaking through the base. The slope at the bottom, which ranges from 1% to 3%, is designed to encourage the flow of wastewater based on gravity (Kadlec and Wallace, 2008). The wastewater coming from the textile industry is put through anoxic, aerobic, and anaerobic zones while it is being processed in this section, which is located around the rhizomes and roots of plants. These zones make it possible for oxygen to be released into the substrate, which results in the formation of aerobic zones (Cooper et al., 1997; Vymazal, 2014). HFCWs are extensively used not only in Europe but also in the United States of America (Vymazal et al., 2006).Table

Table 2. Relevant studies (in chronological order) on textile dye wastewater treatment by horizontal flow CWs

Textile used	Type of wetland	Design characteristics	Plants used	Removal percentage rate	Period (d)	Country of operation	References
Real wastewater	HF	Soil	*Phragmites communis Trin.*	76% COD and 82% total Sulpher	N/A	Germany	Winter and Kickuth (1989)
Natural wastewater	HF	Gravel	*P. australis*	88% TSS	N/A	Australia	Davies and Cottingham (1994)
Many dyes in real wastewater	HF	Sand-gravel	*Cocoyam and Typha*	77% color, 72% COD, and 59% sulfate	84	Tanzania	Mbuligwe (2005)
Real wastewater	HF	Gravel	*P. australis*	50% TCr and 71% Hexavalent Cr	1460	Italy	Fibbi et al. (2011)
Reactive Red 2, Reactive Red 120, and Reactive Red 141	HF	Soil	*Echinodorus cordifolius L.*	97% dye, 42% TDS, 50% EC		Thailand	Noonpui and Thiravetyyan (2011)
Real wastewater	HF	Gravel	*P. australis*	72% hexavalent and 26% trivalent chromium	730	Italy	Fibbi et al. (2012)
Reactive black in synthetic wastewater	HF	Gravel-soil-rice husks	*Prescaria barbata*	79% color, 95% COD	60	Pakistan	Saba et al. (2014)
Acid orange 7	HF	Gravel-rice husks	*Typha latifolia*	100% dye	562	Malaysia	Tee et al. (2015)
Natural wastewater	HF	Gravel-sand	*Leptochloa fusca*	90% Color, 86% COD, 78% BOD, and 35% TDS	365	Pakistan	Hussain et al. (2018a)
Amaranth dye	HF	Gravel	*T. domingensis*	92% color, 56% COD, 92% NO_3, and 97% NH_4	30	Tunisia	Haddaji et al. (2019)
Acid black 10B in synthetic wastewater	HF	Sediment-Sand	*Eichhornia Crassipes-Hydrilla verticillata-Water thyme-Pistia stratiotes*	76% Color and 87% COD	90	India	Kumar et al. (2019)
Real wastewater	HF	Gravel-Sand	*P. australis+ Gambusia fish*	57% TSS, 74% COD, and 70% NO_3-N	6	Iran	Saharimoghaddam et al. (2019)
Real wastewater	HF-HRTS	Soil	*V. zizanioides, s, I. Aquatica and in Consortium*	76% color, 79% COD, 84% BOD, 83% TDS, and 51% TSS	5	India	Chandanshive et al. (2020)
Real wastewater	Ash filter-HF	Gravel-Soil	*Monochoria aginalis Echinodorus palaefolius*	99% TSS, 27%TDS, 74%COD, and 95%Cr	N/A	Indonesia	Daris et al. (2020)
Real wastewater	HF	Gravel-Sand	*Hymenocallis littoralis*	87% COD, 98% TSS, and 90% FOG	18	Indonesia	Rahmadyanti et al. (2020)
Real wastewater	HF-MFC	Gravel-Soil	*Fimbristylis ferruginea, Elymus repens, and Fimbristylis ferruginea*	97% color and 74% COD	120	India	Patel et al. (2021)
Reactive Red 22 in synthetic wastewater	HF	Gravel-Soil	*Typha*	73% color, 85% COD, and 34% Sulfate	96	India	Sethulekshmi and Chakraborty (2021)
Artificial mixed methylene blue and methyl orange	HF	Gravel-Sand	*Scirpus grossus*	79% Color, 62% COD, 70% BOD, and 78% TOC	72	Malaysia	Almaamary et al. (2022)

Note: COD, chemical oxygen demand; BOD, bio-chemical oxygen demand; FOG, oil and grease; TOC, total organic carbon; HRTS, high-rate transpiration system; TSS, total suspended solids; TDS, total dissolved solid; TN, total nitrogen; N, nitrogen; NH_4-N, ammonium nitrogen; PO_4-P, ortho-phosphate-phosphorus; N/A, not.

2 provides a summary of relevant previous studies on the reduction of textile wastewater. The survey is broken down into categories based on the dye that was used, the different kinds of wetlands and design characteristics that went into their creation, the plant that was utilized, the reduction performance, the amount of time that the experiment lasted, its location, and its reference.

Vertical flow constructed wetlands (VFCWs)

VFCWs are constructed with a structure that is made up of numerous layers of substrate (sand and gravel), and they are planted with macrophytes in a pattern that depth-grades from the surface to the depths of the structure (Vymazal et al., 2006). After being dosed on the top of the media surface, the wastewater from the textile industry is collected by an underdrain located at the bed of the substrate surface. The result of this is that the wastewater will flow in a direction that is orthogonal to the direction that the wetland extends in (Tousignant et al., 1999). Both the depth of the substrate (which can be anywhere from 45 centimeters to 120 centimeters) and the slope of the bottom (which can be anywhere from one percent to two percent) have an impact on the amount of effluent that is collected (Vymazal et al., 2006).

In VFCWs, wastewater is allowed to distribute over the surface of the CW substrate, creating an aerobic environment (Scholz, 2006) by displacing the air that was previously contained and drawing in the fresh air that is located at the base of the substrate (Stefanakis et al., 2014). The nitrification process and the decomposition of organic materials are both facilitated more efficiently as a result of this, as compared to a horizontal subsurface flow system (Kadlec and Wallace, 2008). According to the research by Ye et al. (2012), the top layer of media receives around fifty percent of the atmospheric oxygenation that is present. In addition, a large number of studies have demonstrated that VFCWs can lessen the levels of pollutants in wastewater, such as BOD and COD, as well as suspended particles (Ong et al., 2010). Stefanakis and Tsihrintzis (2007) found that this type of operation does not help denitrification, and the removal of phosphorus is limited in comparison to the removal of other pollutants due to insufficient retention time between the substrate and the wastewater. Hussein and Scholz (2017) demonstrated that VFCWs with tidal loading were able to achieve a greater phosphorus reduction by treating azo textile dye wastewater without modifying or supplementing the gravel medium that was used in their study. This was accomplished through the treatment of azo textile dye wastewater. In addition, several authorities assert that vertical-flow constructed wetland systems which operate on an intermittent basis are able to denitrify well with the addition of amendments (Song et al., 2015). When there is a high concentration of nitrate in the effluent, the wastewater is contaminated with only modest levels of organic chemistry, a wetland that has been developed with the vertical flow cannot provide enough organic carbon sources to reduce the nitrate (Songliu et al., 2009).

The majority of VFCWs are utilized throughout Europe, particularly in the countries of Austria, Denmark, United Kingdom, Germany, and France. However, they are also utilized in the United States, as indicated by Stefanakis and coauthors in their study (Kadlec and Wallace, 2008). (2014). This artificial wetland has been developed below the surface, and it is now being used by other countries in Asia and Africa (Gargi Sharma et al., 2014). VFCWs are able to be further categorized based on flow direction, saturation level, and saturation length (Stefanakis et al., 2014). These additional categories include VFCWs with intermittent loading (down-flow), recirculating VFCWs, saturated vertical (down-flow,up-flow), tidal flow, and integrated VFCWs. It is common practice to combine VFCWs with tidal loading, notably in European countries. The production of temporary wastewater ponding on the media surface of 3–5 centimeters in depth is the principal advantage brought about by this way of operation. This state is referred to as an anaerobic mode (Stefanakis et al., 2014), and the amount of time that the aerobic mode is present is referred to as the contact time or the retention time. Because of the pressure exerted by the wastewater, the entrapped air moves at a speed that is significantly slower than normal. The wastewater is forced by gravity to drain vertically through the porous media, where it is replaced by air from the surrounding atmosphere and the period span during which it is present is called the resting period. Bed aeration in this kind of operation encourages and accelerates the proliferation of microorganisms (Du et al., 2016), which improves the oxidation of organic materials nitrification process to prevent obstruction (Stefanakis et al., 2014). The decrease in the number of different azo dyes analyzed in the prior study is summarized in Table 3.

Table 3. Relevant studies (in chronological order) on textile dye wastewater treatment by vertical flow CWs

Textile used	Type of wetland	Design characteristics	Plants used	Removal percentage rate	Period (d)	Country of operation	References
AB113, *RB171	VF	Gravel-sand	*P. australis*	98% color	70	USA	Pervez et al. (2000)
AO7	VF	Gravel-sandy clay soil	*P. australis*	74% dye, 71% TOC, and 64% COD	77	Portugal	Davies et al. (2005)
AO7	VF	Gravel-sandy clay soil	*P. australis*	99% color, 93% TOC, and COD	48	Portugal	Davies et al. (2006)
**RB5,VR13, RR22	VF	Gravel-Sand-Zeolite-Peat	Without plant	70% dye, 88% COD, 60% EC, and TOC	90	Slovenia	Ojstršek et al. (2007)
BB41	VF	Sand	C. demersum / M. spicatum	96 dye	50	Turkey	Keskinkan and Lugal Göksu (2007)
AO7	VF	Gravel	P. australis	68% dye, 67% TOC, and 69% COD	8	Portugal	Davies et al. (2009)
Methyl Red	UF and VF	Gravel	*P. australis*	Reasonably practical and competitive for decolorization	N/A	India	Goyal et al. (2009)
RR141	VF	Sand-Gravel	Typha	49% color, 86% TDS, and 60% COD	N/A	Thailand	Nilratnisakorn et al., (2009)
AO7	UF	Gravel- glass beads	*Manchurian wild rice / P. australis*	98% dye, 96% NH_4-N, 86% COD, 86% NO_3-N, 26% TP, and 67% TN	42	Japan	Ong et al. (2009)
AO7	UF	Gravel-glass beads	*P. australis*	98% dye, 67% TN, 90% COD, 28% TP, 100% NO_3-N, and 98% NH_4-N	365	Japan	Ong et al. (2010)
AO7	VF	Sludge-Gravel	*P. australis*	94% color, 95% COD, and 86% NH_4-N	27	N/A	Ong et al. (2011)
Methylene blue	VF	Glass wall-Gravel	*Canna indica*	93% dye and 75% COD	4	India	Yadav et al. (2012)
reactive brilliant red in synthetic wastewater	UF	Gravel	*Ipomoea Aquatica*	91% Color and 86% COD	N/A	Chine	Fang et al. (2013)
Natural wastewater	VF	Soil with- coconut shavings bacteria	*G. pulchella*	70% BOD, 74% TOC, and 70% COD	4	India	Kabra et al. (2013)
Natural wastewater	VF	Coconut shavings-soil-sand-gravel with bacteria	*Portulaca grandifora*	59% COD, 37%TOC, 38% BOD, 41% turbidity, 60% TSS, and 71% TDS	3	India	Khandare et al. (2013)
Natural wastewater	VF	Soil-gravel	*Eichhornia crassipes*	87% EC, 90% TDS, 83% Cl, 87% Sulphate, 79% Phenol, 91% BOD, and 93% COD	7	India	Sivakumar et al. 2013
DR81	VF	No Media	*P. australis*	96% color, 90% COD, and 90% TOC	123	Portugal	Ferreira et al., 2014
Real wastewater	VF	Gravel-soil-sand-Coconut shavings	*Typha*	79% COD, 59% TDS, 77% BOD, and 27% TSS	3	Pakistan	Shehzadi et al. (2014)
AY 2G E107	VF	Sand-gravel-zeolite	*Typha and Canna*	95% color, 60% COD, 77% NH_4-N , and 94% PO_4-P	90	Turkey	Yalcuk and Dogdu (2014)
Reactive brilliant red X-3B	UF	Gravel-activated carbon	*Ipomoea Aquatica*	95% Color and 86% COD	180	Chine	Fang et al. (2015)
Methyl Orange (MO) in synthetic wastewater	UF	Gravel-activated carbon	Without Plant	87% Color and 56% COD	60	Chine	Fang et al. (2016)
Real wastewater	VF	Eucalyptus leaves, sawdust, and fly ash	*T. angustifolia,and Paspalum Scrobiculatum*	76% color, 70% COD, 75% BOD, 75% TDS, 47% TSS, and (28-77)% arsenic, cadmium,and chromium	2	India	Chandanshive et al. (2017)

brilliant red X-3B in synthetic wastewater	UF	Gravel-screes-glass beads-biological ceramics	*Ipomoea aquatica*	93% Color and 61% COD		Chine	Fang et al. (2017)
BR46 And AB113	VF	Gravel-sand	*P. australis*	67% COD,	360	UK	Hussein and Scholz (2017)
Real wastewater	VF	Gravel-sand	*Brachiaria mutica*	74% Color, 81% COD, 72% BOD, 32% TDS, 84% N, 79% P, 97% Cr, 89% Fe, 88% Ni, and 72% Cd	365	Pakistan	Hussain et al. (2018b)
BR46 and AB113	VF	Gravel-sand	*P. australis*		360	UK	Hussein and Scholz (2018)
Acid Red 18 in Synthetic wastewater	UF-MFC	Glass-gravel	*T. latifolia*	97% Color and 95% COD	463	Malaysia	Oon et al. (2018)
Real wastewater	VF	Gravel-Sand	*Alternanthera sessilis Zea mays*	52% EC, 6% TS, 60% TDS, 83% TSS, 60% Cl, 81% BOD, 72% COD, 53% Th, and 68% T-Alkalinity	1	India	Joseph et al. (2019)
Real wastewater	VF-MFC	Gravel	*Fimbristylis dichotoma)*	82% Color and 70% COD	4	India	Rathour et al. (2019)
Reactive Black 5	VF	Gravel with bacteria	*Juncus acutus*	50% dye	27	Morocco	Riva et al. (2019)
Congo Red in Synthetic wastewater	VF	Gravel-Sand	*P. australis and T. domingensis*	93% dye and 86% COD	210	Iraq	Bedah and Faisal (2020)
Real wastewater	VF	Eggshells-gravels-wood husk and activated charcoal	*Canna indica*	40% COD and 40% BOD	N/A	India	Jayabalan et al. (2020)
Real Wastewater	VF	Gravel-Sand	*Phragmites karka*	95% color and 88% COD	120	Indonesia	Kurniadie et al. (2020)
Acid Red 18, Acid Orange 7, and Congo Red in Synthetic wastewater	UF-MFC	Glass-Gravel	*Typha latifolia*	96% Color (AR18), 67% Color (AO7), 60% Color (Congo Red), and 74% COD	45	Malaysia	Oon et al. (2020)
Congo Red in Synthetic wastewater	VF	Gravel	*P. australis and T. domingensis*	98% Dye and 82% COD	5	Iraq	Faisal et al. (2022)
Methylene Blue dye in Synthetic wastewater	VF	Sand-Zeolite-Gravel	*Canna indica*	99% Color, 93% COD	30	India	Jayalakshmi et al. (2022)
Methyl orange dye in	VF-MFC	graphite granules	Seeds of *(C. arietinum, T. aestivum, and V. radiata)*	94% color and 94% COD	250	India	Mittal et al. (2022)
Real wastewater	VF	Sediment	*Water Hyacinth*	70% COD, 80% BOD, and 90% TDS	13	India	Shenoy et al. (2022)
methyl orange dye in Synthetic wastewater	VF-MFC	Sand-rice husk	*Canna indica*	97% color, 85% COD	60	India	Sonu et al. (2022)

Note: AB, acid blue; *RB, reactive blue; AO, acid orange; VF, vertical flow; MFC, microbial fuel cells; COD, chemical oxygen demand; BOD, bio-chemical oxygen demand; TOC, total organic carbon; **RB, reactive black; DY, disperse yellow; TSS, total suspended solids; TN, total nitrogen; N, nitrogen; P, phosphorus; Cr, chrome; Fe, iron; Ni, nickel; Cd, cadmium; Cl, chlorine; Th, thorium; NH_4-N, ammonium nitrogen; PO_4-P, ortho-phosphate-phosphorus; AY, acid yellow; N/A, not.

The survey is broken down into categories based on the dye that was used, the different kinds of wetlands and design characteristics that went into their creation, the plant that was utilized, the reduction performance, the amount of time that the experiment lasted, its location, and its references.

Hybrid flow constructed wetlands

In this type of CW systems, the benefits of different constructed wetland types (both of surface flow CWs and subsurface flow CWs) can be combined to complement one another (Vymazal, 2013), primarily VFCWs and HFCWs (Vymazal, 2013). This combination was created with the intention of maximizing the benefits of one type while mitigating the drawbacks of the other type. For instance, HFCWs, which have a restricted oxygen transfer capacity, have a low nitrification process, whereas VFCWs, which have a larger oxygen transfer capacity, have a greater efficiency in this process due to their larger capacity. On the other hand, the denitrification process used in HFCWs is significantly more effective than that used in VFCWs. By utilizing a hybrid system that combines HFCWs and VFCWs, it is possible to generate the conditions that are conducive to the nitrification and denitrification processes (Vymazal, 2013). As reported by Stefanakis et al. (2014), Seidel was the first person to attempt to combine the various constructed wetlands in Germany in the 1960s; this laid the groundwork for the hybrid CWs, which were revitalized at the end of the 20th century.

The most common types of hybrid systems are stages of VFCWs filters followed by HFCWs filters in sequence and stages of HFCWs filters

Table 4. Relevant studies (in chronological order) on textile dye wastewater treatment by hybrid flow CWs

Textile used	Type of wetland	Design characteristics	Plants used	Removal percentage rate	Period (d)	Country of operation	References
*RB5, DY211, VY46	VF-HF	Gravel-sand-tuff	*P. australis*	90% color, 84% COD, 66% BOD, 93% TSS, 52% TN, -331% NH_4-N, 87% $N_{organic,}$ 88% sulfate, and 80% anion surfactant	60	Slovenia	Bulc and Ojstršek (2008)
Dye in Synthetic wastewater	1. FWS-VF 2. VF-FWS	shale	*P. australis*	1. 97% color and 98% COD 2. 99% color and 90% COD	n/a	Thailand	Cumnan and Yimrattanabovorn (2012)
Real wastewater	VF-HF	(1): Sugarcane Bagasse (2): Sand	*P. australis,* *D. sanderiana, and A. platyneuron*	(1): 90% Turbidity, 81% NH_4-N, 87% NO_2-N, 72% NO_3-N, 89% COD, 95% BOD and 63% SS (2): 83% Turbidity, 70% NH_4-N, 87% NO_2-N, 77% NO_3-N, 89% COD, 97% BOD and 38% SS	105	Bangladesh	Saeed and Sun (2013)
Real bleaching	HF-VF	No	*P. australis*	89% COD, 91% BOD, and 96% TOC	N/A	Pakistan	Hussain et al. (2019)
Acid Red 27	VF-HF	Gravel	*P. australis*	100% color, 88% COD, and 98% NH_4-N	241	Malaysia	Lehl et al. (2019)
Real wastewater	HF-FWS	Gravel	*P. australis, T. Latifolia, and Miriophyllum sp.*	46% TCOD, 33% SCOD, 73% TSS, 50% TP, 32% TN, 33% TKN, 37% N-NO_3	323	Italy	Masi et al. (2019)
Real wastewater	HF-VF	Gravel-Sand	*Canna indica*	99% TSS, 90% COD, and 90% FOG	7	Indonesia	Rahmadyanti and Audina (2020)
Reactive Yellow 145 in Synthetic wastewater	HF-VF	Cow manure- wood chips- gravel	*Typha angustifolia.*	90% color, 37% COD, 69% NH_4-N, and 39% organic-nitrogen	198	India	Benny and Chakraborty (2023)

Note: AB, acid blue; COD, chemical oxygen demand; TCOD, total COD; SCOD, soluble COD; TOC, total organic carbon; *RB, reactive black; DY, disperse yellow; VY, vat yellow; HV, horizontal flow; TSS, total suspended solids; TP, total phosphorus; TN, total nitrogen; TKN, total kjeldahl nitrogen; N, nitrogen; NH_4-N, ammonium nitrogen; PO_4-P, ortho-phosphate-phosphorus; FOG, oil and grease.

followed by VFCWs filters (Vymazal, 2013). The first combination includes VFCWs units, which work to reduce the amount of organic matter and suspended particles in the water in order to boost nitrification. VFCWs units are then followed by HFCWs units, which offer an alternative method for reducing organic matter and suspended solids as well as fostering favorable circumstances for denitrification. The second combination consists of HFCWs units, which are responsible for the reduction of organic matter and suspended solids, as well as the creation of the conditions that are conducive to denitrification. These are followed by VFCWs units, which are responsible for nitrification as well as the further reduction of organic matter and suspended solids. If there is an increase in the content of nitrate in the textile wastewater effluent after VFCWs due to oxidate ammonia nitrogen, the outflow must be fed back as an inflow in HFCWs or to another HFCWs unit depending on the results of the outflow analysis. This is necessary if the effluent contains an excess of nitrate. Table 4 provides a summary of the reduction of a number of different types of azo dyes. The survey is broken down into various categories according to the dye that was used, the different kinds of wetlands and their design characteristics, the plant that was used, the reduction performance, the amount of time that the experiment lasted, its location, and its references.

CONCLUSION

The textile industry is one of the larger consumers of potable water and, consequently, produces a huge amount of wastewater. It is one of the most critical and largest industrial sectors in many countries. Constructed wetland systems are utilized frequently due to their qualities, which include low energy, convenience, mechanical simplicity requirements, environmental friendliness, and low operating costs. Subsurface flow constructed wetland is one type of constructed wetland utilized extensively to treat textile industry effluents and wastewater. This article summarized and reported all applied research that dealt with the efficiency of such types of subsurface flow CWs (horizontal flow, vertical flow and hybrid flow) which are used to treat textile wastewater. Furthermore, the article reported the applied research which included integrated Microbail Fuel Cell (MFC) with these types of constructed wetlands.

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