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Removal of methylene blue from wastewater using constructed wetland: performance and operation

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ABSTRACT

The utilization of vertical constructed wetlands (CWs) as a means of reusing textile wastewater for non-potable purposes is a unique step in the dissemination of this environmentally friendly method. The performance of unplanted and planted CW units was examined in relation to dye concentration (10–750 mg/L), hydraulic retention time (1–3 d), and substrate type (either filter-sand or waste foundry sand). With time, the used plants (*Phragmites australis* and *Canna indica*) have grown significantly in height and density. The results of the experiments showed that the pH of the effluents from these units was within the range of 6.5–8.5 that is considered acceptable by environmental regulations. The COD was removed from these effluents after 3 d, with removal efficiencies ranging from 46.8% to 80.5%. With a decrease in dye concentration and an increase in contact time, COD removal rates may be increased; Additionally, NH_4–N and NO_3–N removals did not exceed 65.5%. All units can remove color with an efficiency of 98% at the chosen dye concentrations. Findings demonstrated that WFS-packed units have efficacy values comparable to or higher than those of FS-packed units; as a result, WFS by-product can be utilized in CWs in place of FS.

Keywords: Constructed wetland; *Phragmites australis*; *Canna indica*; Methylene blue dye; Waste foundry sand

1. Introduction

Improper disposal of industrial effluents especially the wastewater resulted from textile, tannery, pulp and paper, and others can form the main cause for deterioration of ecological system in the natural water resources [1]. With the growth of demand on the textile products, there is a rapid increase in the number of textile industries. Bleaching, dyeing, printing, and stiffening of these products are major operations required in the manufacturing process. Each operation is water-intensive and forms a big challenge for sustainability of environment. Consequently, huge amounts of coloured wastewater that contained complicated and stable compounds like inorganic salts, dyes and heavy metals can be emitted. Thus, the textile industry is one of the big sources for pollutants in the world. The World Bank estimates that approximately 20% of all global industrial water pollution comes from textile dyeing and treatment [2,3].

Methylene blue (MB) is selected in this work to be the target contaminant because it classifies as toxic, mutagenic, and carcinogenic compound that remains for long period in industrial effluent and can cause severe environmental and public health problems. The MB has the same effect of the other dyes when they discharged in water bodies without being treated properly through disturbs the life cycle of aquatic animals and plants by obstructing the penetration of sunlight.

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Dye treatment is associated with many problems because most dyes are not biodegradable, stable to light and oxidation as well as cannot be remedied by traditional methods. Several physical and chemical methods have been suggested to treat dye-polluted wastewater such as flocculation with lime, coagulation, adsorption, ultrafiltration and reverse osmosis. These methods are limited in use due to the low efficiency, high cost and lack of applicability to avoid a variety of dyes in addition to the forming of toxic and secondary pollution that can produce by excessive use of chemicals. The adsorption method can be implemented using bark, rice husk, activated carbon, peanut shell, charcoal, cotton waste, clay, banana waste, coconut shell, clay gas residue and others [4–9]. Biological approach is considered to treat coloured wastewater especially this method gained more importance nowadays due to their low cost, efficiency and environmentally friendly nature. The efforts of researchers were directed for finding more efficient and sustainable technique; in this regard, constructed wetlands (CWs) were presented as suitable engineered systems for treating rural and urban wastewater.

The CWs are utilized due to their characteristics like appropriateness, low energy requirements, simplicity, low operating cost and environmental friendliness. These systems have been used to obtain wastewater treatment objective through the use of natural processes and components that significantly decrease the usage of mechanical devices, energy-intensive and technical sophistication. Previous publications revealed the efficacy of CWs in treating different types of wastewater; including urban runoff, animal wastewater and mine disposal [10], petroleum wastewater [11], textile wastewater [12] and domestic sewage [13]. Treatment by CWs mainly depends on the application of different aqueous plants such as *Phragmites australis*, *Eichhornia crassipes*, *Typhonium flagelliform*, *Typha*, *Azolla caroliniana*, and *Lemnaetc* for removing of dye and other pollutants from wastewater [14]. Microbial metabolism, adsorption, filtration, aerobic and anaerobic reactions are common processes that governed the removal of organic compounds from wastewater [15–18]. The adsorption has significant role in the elimination of such compounds because it depends on transferring the dye from the liquid to the solid phase; so, different materials like manufactured sorbents or by-products from industrial sector can be applied as substrate for CWs units [19–22].

The ability of vertical subsurface flow constructed wetlands units for the treatment of simulated wastewater contaminated with Congo red dye has been studied. The units were packed with Iraqi sand bed that unplanted and planted with *P. australis* or *Typha domingensis*. The efficacy of these units was evaluated by monitoring the pH, DO, Temperature, COD and Congo red dye concentration in the effluents under the variation of detention time (1–5 d) and dye concentration (10–40 mg/L). The maximum reductions for dye and COD were equal to 99.34% and 86.0%, respectively for 10 mg/L of Congo red dye after five-day hydraulic contact time. Results proved that the removal of dye concentration and COD increased dramatically with increase of contact time and decrease of dye concentration [23]. The VF CW was used to treat wastewater by mixing fertilizer with tap water and using textile dyes such as direct orange 46, AB113, reactive blue 198 (RB198), and basic red 46 (BR46) at low (7 mg/L) and high (215 mg/L) concentrations. This wetland can remove the BR46 and AB113 dyes with efficiency ranging from 68% to 96%, according to the findings [24].

For arid and semi-arid regions, the recycling of wastewater for non-potable uses by sustainable methods like CWs has gained high attention from economic and environmental view point. This technology would have a positive impact on the quality of treated water; making this water a reliable complementary option to the surface water; so, it can be used for irrigation process especially in the rural regions. Hence, the experimental investigation of the vertical configuration of CWs packed with either waste foundry sand (WFS) or filter-sand (FS) for the treatment of artificial wastewater containing Methylene blue dye and the presence of *P. australis* and *Canna indica* plants in comparison to unplanted units represents the significance of this work.

2. Materials and methods

This study was conducted in the period extended from 10 October 2020 to 11 April 2021. Experimental constructed wetlands systems for treating simulated wastewater contaminated with MB dye were manufactured and operated under natural environmental conditions within Baghdad city, Iraq (33° 16′ 12″ N 44° 22′ 54″ E). The experimental work was intended to evaluate the performance of CWs in the pilot-scale units by simulating the removal processes that occur. The operational conditions used to specify their influences on the performance of CWs units in the reclamation of adopted wastewater included contact time, dye concentration, plant type, and utilized substrate. Six VSSF CW units were included in the system, which allowed wastewater to drain vertically and increased aerobic biodegradation of organic matter. For the purpose of contaminating the aqueous solution, Methylene blue, whose properties are listed in Table 1, was chosen. The CWs units must receive the prepared wastewater—MB dissolved in tap water to prepare various dye concentrations of 10, 20, 30, 40, and 750 mg/L. The concentration of MB can measure at wavelength corresponded to the maximum absorbance (λ_{max}) of 665 nm [25].

Filter-sand (FS) is substrate used as "reference medium" for wetlands units constructed in this work. The FS was purchased from Alnawafith company (NSGF Co., Ltd.) for the production of sand and gravel filters Ltd, Najaf/Iraq. This sand is known as "Golden Sand" with particle size distribution ranged from 0.6 to 1 mm and specific gravity of

Table 1
Main characteristics of the MB dye used in the experimental tests of the present CWs units

Parameter	Value/Description
Molecular formula	$C_{16}H_{18}ClN_3S{\cdot}3H_2O$
Source	India
CAs No.	7220-79-3
Assay	99%–103%
Molecular weight	373.90

1.363. Waste foundry sand is a by-product of the metal casting industry that is produced in large quantities. There are roughly 35 × 10^3 foundries worldwide, producing 69 million tons of casting annually. Foundries can generate a variety of wastes, including waste sand, waste chemicals, slug, wastewater, and particulate emissions. WFS makes up the most of these wastes, and the American Foundry Society estimates that this makes up 6.8 million tons that end up in landfills. Additionally, European regulations deemed the WFS to not be a hazardous substance and consequently, it is important from an economic standpoint. The WFS byproduct was chosen as an alternative to filter-sand in the current study which represents real application for concepts of sustainability.

The WFS, which had a bulk density of 1.44 g/cm^3, was collected from plumbing workshops in the Sheikh Omar area of Baghdad, Iraq. Unfortunately, this waste has a very low coefficient of hydraulic conductivity (≈1 × 10^{-6} cm/s). Preliminary tests were carried out to determine whether the utilized plants, *Canna indica* and *P. australis*, were able to grow within this substrate; plant growth and root extension were extremely limited. The WFS (ranging from 0.075 m to 1 mm) was mixed with fine gravel with gradations of approximately 10 mm to improve plant growth and increase substrate permeability. The appropriate proportions of mixing were 60% WFS and 40% gravel, as determined by numerous tests. The usage of gravel can enhance the hydrological process through reducing evaporation, improving infiltration and temperature, enhancing biological activity and soil fertility.

3. Description of CW experimental set-up

Six plastic tanks used as VSSF CW with top and bottom lengths of 60 and 53 cm are depicted schematically in Fig. 1.

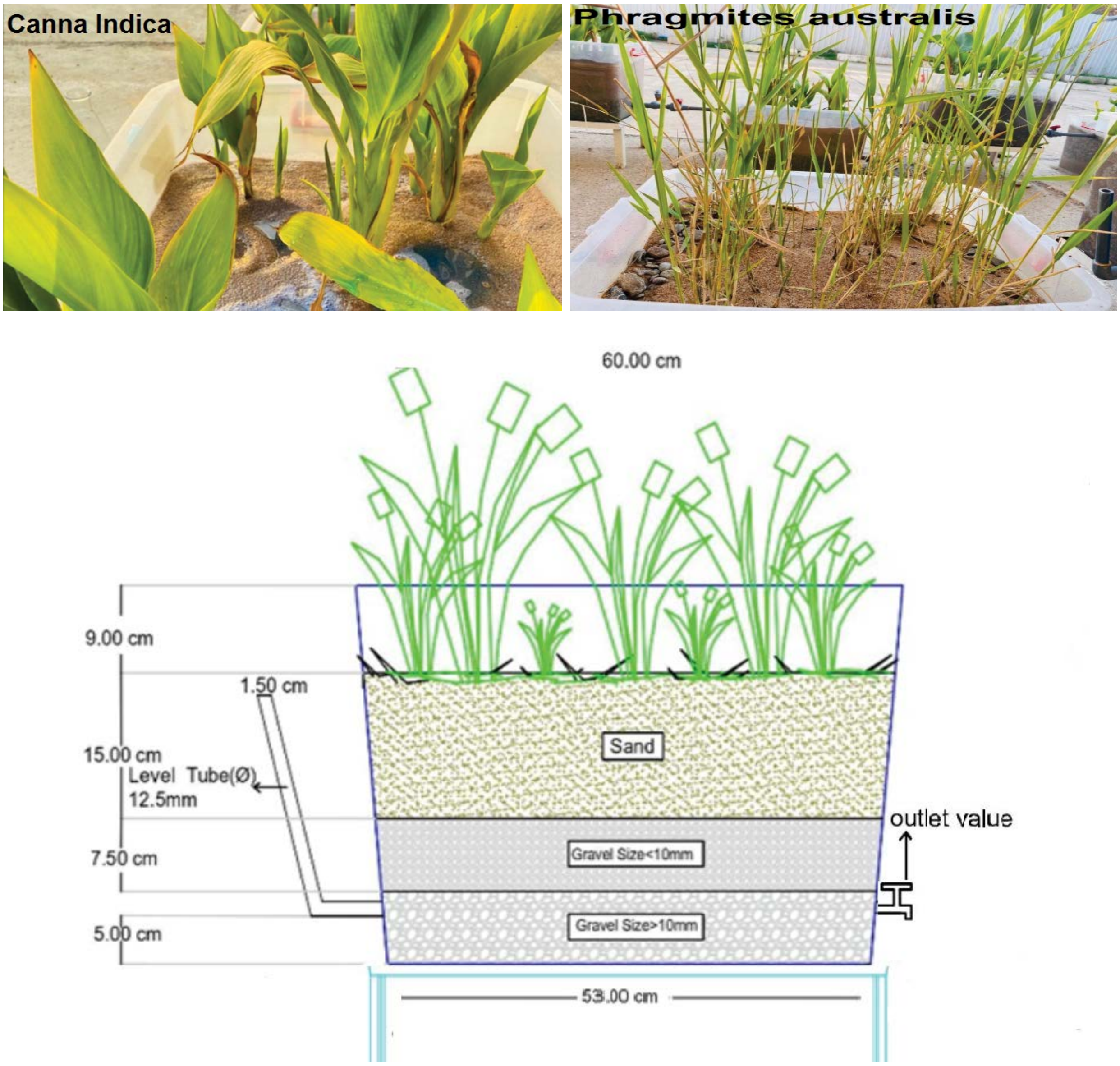


Fig. 1. Details of the pilot-scale unit used in the vertical subsurface flow CWs for treatment of wastewater.

Each container has a width of 37 cm and a depth of 39 cm. The VSSF CW tanks were loaded with two various layers of gravels; to prevent clogging of the outlet, coarser gravel (size > 10 mm) forms the bottom layer, and smaller gravel (size < 10 mm) is placed above the previous layer. With a total volume capacity of approximately 89 L, all CW units are the same size and shape. Each tank had an outlet valve that was positioned at 5 cm above its base. This valve connected to a PVC pipe with a diameter of 12.5 mm is used to drain treated water and sampling. During operation, the wastewater level in VSSF CW units must be at 1.5 cm below the media surface to prevent algal growth and reduce evaporation from the free surface of the wastewater.

The FS, which is packed above the aforementioned gravel layers and has a depth of 15 cm, is the primary substrate in the first row. As an alternative to FS, the CW units in the second row were packed with a mixture of WFS and fine gravel. The 1st unit in each row was unplanted to be the "control unit" while the other two units should be planted with *P. australis* and *Canna indica*. By combining the letter "P" with the first letter of plant, the planted units can be distinguished from the unplanted ones. CWWFSGPC stands for vertical flow constructed wetland packed with waste foundry sand-gravel and planted with *Canna indica*, while CWFSPP stands for vertical flow constructed wetland packed with filter-sand and planted with *P. australis*. Other units can be defined in the same way, and all of them must be supplied with water contained MB dye.

4. Vegetation

Constructed wetlands must be vegetated because the plant will enhance the performance of the treatment process and also improve the aesthetical of the environment. The presence of *P. australis* or *Canna indica* (living all around the year) in the manufactured CWs has an important role in the supporting of sedimentation and avoidance of erosion by reducing the water velocity due to increase of hydraulic pathway [26].

The plants are submerged in the pot and flooded with tap water for 2 d. Initially, the heights of the *P. australis* and *Canna indica* were approximately equal to 0.3 m; however, first plant must be trimmed to height of 0.15 m to ensure its rapid growth. Thereafter, the selected plant must be cultivated in the CW units with density of 5 plants/container and the distances between the species prefer to be ranged from 0.14 to 0.25 m. The plantation was established in the first half of November 2020, and the plants were irrigated with tap water from the second half of November 2020 to 16 January, 2021. The acclimation (or stabilization) period is very important to create a compact bed suitable for wastewater treatment by ensuring the appropriate growth of roots and micro-organisms. The density and height of the *P. australis* and *Canna indica* in the experimental units were increased dramatically with time. The plant's densities are not exceeded 55 plants/unit and their heights not exceeded 1.52 m for all CWs units after 5 months from plantation process. Many parts of adopted plants were suffered from yellowing which may be due to the decreasing of temperature during winter season.

5. Operation of the system

The wetland system was operated in a batch approach to avoid expenses like pumping and automatic control. The "detention time" refers to the amount of time that the wastewater had to remain in the treatment unit after being poured directly into it. The "outlet valve", depicted in Fig. 1, is collected the treated water from the wetland unit. Between any two tests, the wetland units must be free of wastewater for a certain amount of time, known as the "resting time". The VF CW system's entire operating cycle in this work was equivalent to 3 d. Initially, the wastewater was fed to the VSSF tank in the first day with closing the outlet valve. This valve was opened at the end of each day for 3 d to collect the water samples (50 mL). The outlet valves were opened at the conclusion of the operation cycle, allowing treated water to leave the CW throughout the day; lastly, the system rests for 10 d, reaching partially saturated conditions. Air is drawn into the bed as it drains, re-aerating the microbes. The previous working plan was used for the unplanted subsurface flow CW units.

The laboratory tests include the measurements of dye concentration, colour, DO, Temp., pH, COD, NO_3–N, and NH_4–N. Samples were collected from each of the tap water, prepared polluted water (influent) and treated water (effluent) at the end of operation cycle. The UV-VIS spectrophotometer was used to determine the dye concentration after the filtration of samples using 0.45 μm filter. The DO (mg/L) and temperature (°C) of water were measured using a hand-held mi 605 portable dissolved oxygen, MARTINI (Italy). The pH of all samples was measured by a hand-held E-1 portable the pH electrode Digital Meter (Chine). The closed reflux 5220 C method described in "Standard Methods for the Examination of Water and Wastewater" was applied to measure COD by Colormeter DR 5000, Hach (USA), Selected Analytical Methods, UNESCO-IHE. The NH_4–N and NO_3–N were measured by [high performance liquid chromatography (HPLC)] DR 2800, SYSEL, (UK).

6. Results and discussion

6.1. Variation of pH, DO and temperature

According to WHO standards in 2004, the pH is the most important factor for water quality and must be within the range 6.5–8.5. The value of this factor has an effect on microbial populations that degrade the pollutants in the CW system [13,27]. Measurements signified that the pH values for the treated wastewater were increased for CWs packed with FS that planted with *P. australis* or *Canna indica* in comparison with unplanted units under different dye concentrations; however, these values still in the acceptable limits specified by WHO. This rise in effluent pH may be caused by the formation of basic aromatic amine metabolites [28]. Increase in pH could also refer to organic matter biodegradation [29] or algal activity, which can rise the pH and encourage the formation of calcium rich solids when calcium ions are present in water, increasing the dissolved solids [30].

For same systems, the DO had been measured because it is essential for the aerobic respiration of microorganisms controls the oxidation-redox potential in wastewater. Fig. 2 illustrates that the measured values of DO in the prepared simulated wastewater were varied from 7.76 to 7.96 mg/L due to change of initial dye concentration (C_o) from 10 to 750 mg/L; however, this difference is expected due to changes in the tap water used in the preparation and may not be related to the dye concentration. It is clear that the DO values have decreased with increase of detention time due to the consumption of this oxygen by microbial community in the degradation of an organic chemicals presented in the simulated wastewater. It is observed that the values of DO are ranged from 5.44 to 6.31 mg/L for planted and unplanted vertical systems at adopted MB concentrations beyond 3 d. Also, it seems that the DO in the planted units was less than in the unplanted ones with the time because more concentrations of organic material (measured in COD) can be oxidized and, consequently, more oxygen will be consuming.

Slight changes in water temperature can be detected in the range from 23.1°C to 26.4°C for vertical CWs packed with FS under different dye concentrations as plotted in Fig. 2. It appears that the measured temperature in each unit is greater than the temperature value for influent water, and that this is proportional inversely to the DO values. Increases in temperature may be caused by the activity of the microbial community, which promotes the oxidation of chemicals and, as a result, water quality can be improved [31].

Results obtained from CWs packed with WFS for pH, DO and temperature proved that the used bed can produce treated water with quality satisfied the previous regulations. Fig. 3 demonstrates that the variation trend of DO and temperature is identical to the variation of these parameters in the CWs packed with FS. This means that the WFS by-product can be used as alternative for FS to obtain treated wastewater with acceptable values of pH, DO and temperature. The current experimental investigation's temperature, pH, and DO measurements concur with those of previous studies like [30,32,33].

6.2. Removal of organic content

The measurement of COD in textile wastewater must be conducted because it represents the critical indictor for assessing organic matter in wetland units. The COD removal efficiency in CWs is accomplished through physical, chemical, and biological steps. According to USEPA specifications in 2006, the prescribed limit of COD for surface water courses must be in the range 8–10 mg/L [34]. For dye C_o = 10, 20, 30, 40 and 750 mg/L, corresponding COD values are equal to 23.8, 33.1, 62.8, 73.2 and 510 mg/L; thus, the prepared samples have organic content that exceeded the acceptable limits.

Fig. 4 demonstrates that there is a remarkable reduction in the concentrations of COD for both planted and unplanted CWs units packed with filter sand. This reduction is resulted from the presence of biofilms that can be enhanced the oxidation (i.e., biodegradation) of organic chemicals and, consequently, this improves the water quality. For dye C_o of 10 mg/L, the final removal efficiencies of COD after 3 d for CWFSPC and CWFSPP have values equal to 63.8% and 61%, respectively in comparison with removal in the CWFS (i.e., unplanted unit) that reach to 49.5%. The figure shows that there is an increase in COD removal for all concentrations after 3 d of treatment time because sufficient time can allow the occurrence a proper contact between wastewater and microorganisms. It is clear that the achieved removal efficiencies of COD in the unit planted with *P. australis* (i.e., CWFSPP) approaches from efficiencies of the one planted with *Canna indica* (i.e., CWFSPC). For influent COD concentrations ≤40 mg/L, these concentrations in the treated water produced from units packed with FS are acceptable in comparison with European Union (EU) prescribed limit for surface water courses that equal to 125 mg/L. However, COD concentrations in the effluents were exceeded this limit for influent concentration of 510 mg/L identical to dye concentration equal to 750 mg/L.

Fig. 5 states the residual concentrations of COD in the wastewater treated by unplanted and planted CWs packed with WFS for different times ranged from 1 to 3 at 10, 20, 30, 40 and 750 mg/L MB concentrations. It is clear that the removal percentages of this dye under adopted operation conditions have taken the same variation of efficiencies in the CWs packed with FS; however, these percentages are greater than that obtained from containers packed with FS and this support the use of WFSG as alternative to FS. The findings of organic matter follow the same pattern that has been demonstrated in previous studies like [23,27,35].

6.3. Removal of nitrogen compounds

The concentrations of NH_4–N detected in the influent wastewater for CW units packed with FS have values of 0.0625, 0.0582, 0.0401, 0.0340 and 0.0524 mg/L due to dissolve of MB dye in tap water at 10, 20, 30, 40, and 750 mg/L, respectively. In addition, the detected values of nitrate–nitrogen (NO_3–N) were 16.27, 14.59, 15.54, 6.15 and 5.99 mg/L for same influent wastewater. It is expected that the tap water quality utilized in the preparation of wastewater samples may be the cause for recorded differences in the values of NH_4–N and NO_3–N regardless the concentration of MB dye especially the present experiments have implemented in different dates. The experiments of 10, 20, 30, 40 and 750 mg/L dye concentrations were conducted on 17 Jan., 31 Jan., 14 Feb., 28 Feb. and 5 Apr.–2021, respectively.

Measurements signified that the removal efficiencies of NH_4–N and NO_3–N were improved with higher contact time for each unit under certain concentration of MB dye. The obtained results are attributed to the ability of VSSF CWs to oxidize nutrient compounds due to the high oxygen transport that resulted from existence of tidal conditions in such type of constructed wetland. This oxygen can promote the growth of different microorganisms that aid in the nitrification and denitrification processes, which are the prime mechanisms for nitrogen reduction in the CWs units. These mechanisms include two-steps; nitrification process (1st step) includes the oxidation of ammonium to nitrites and then to nitrates while denitrification process (2nd step) converts the nitrate to the gaseous nitrogen [36,37]. The removal percentages of nutrients in CWs packed with WFSG were greater than that removals achieved in units packed with FS under the same conditions and this can support the usage of WFS as alternative to FS.

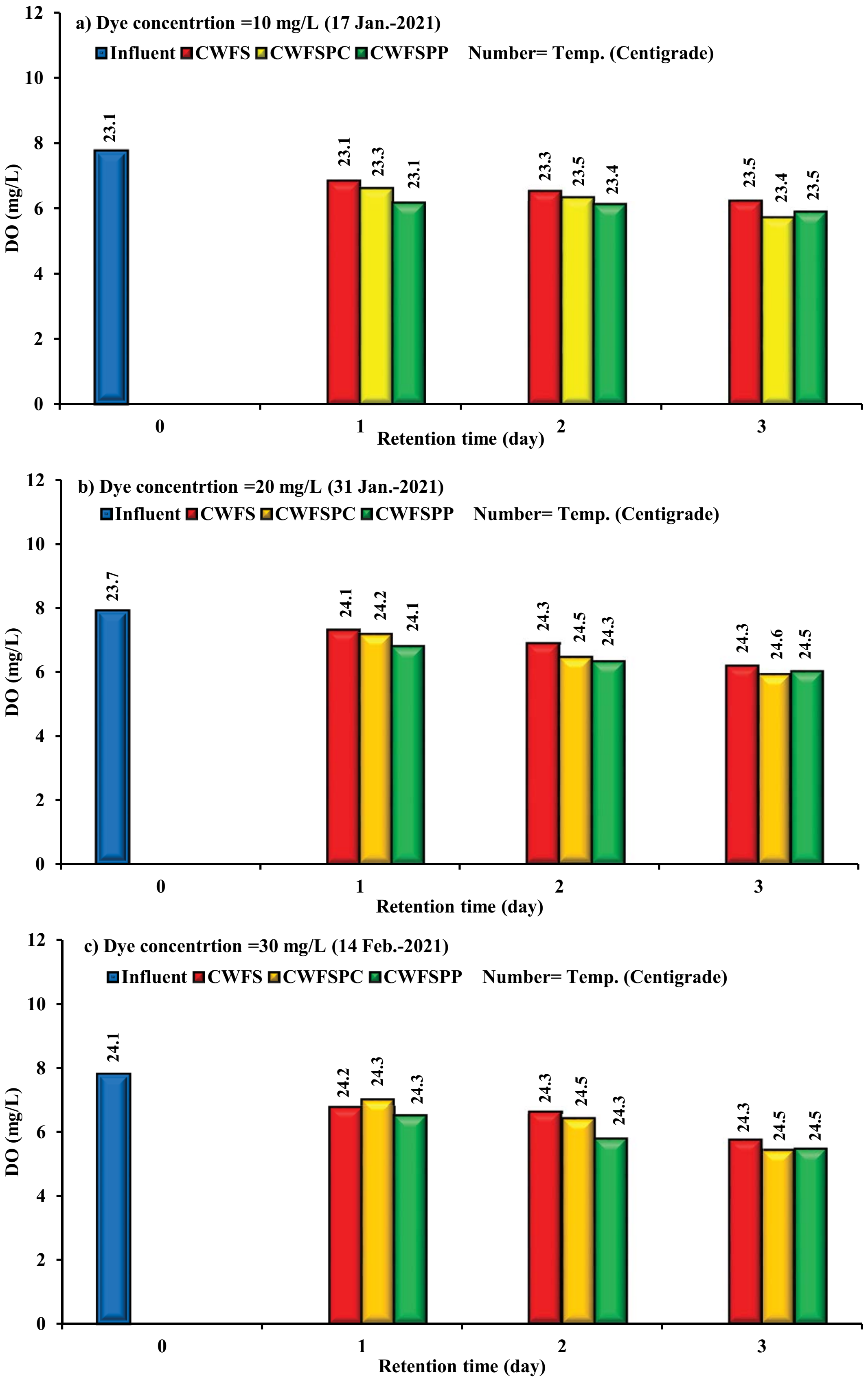


Fig. 2. (Continued))

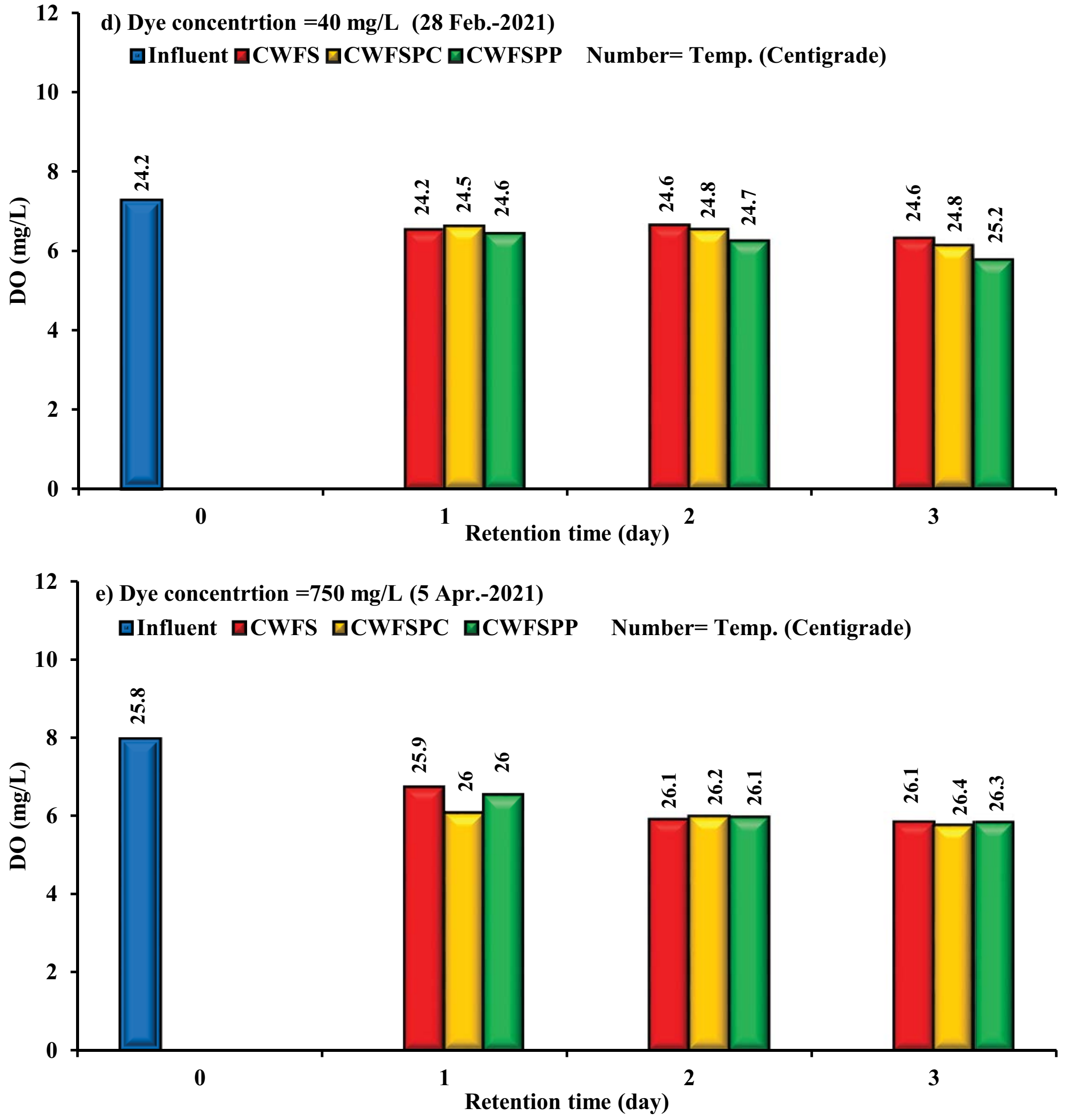


Fig. 2. Values of DO for effluent and influent with water temperature vs. the time in the planted and unplanted vertical units of CW filled with filter sand for various concentrations of MB dye.

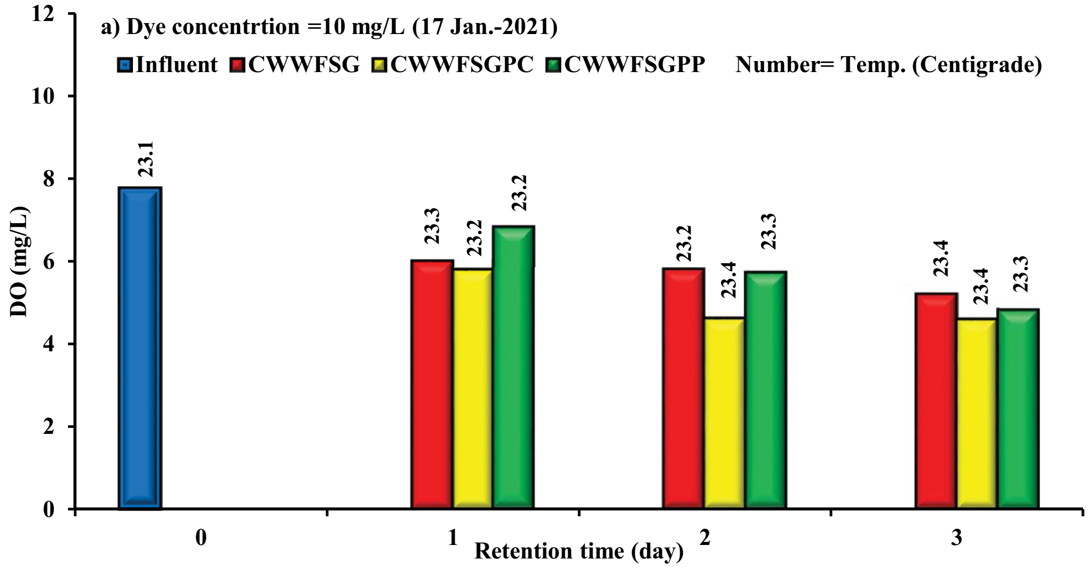
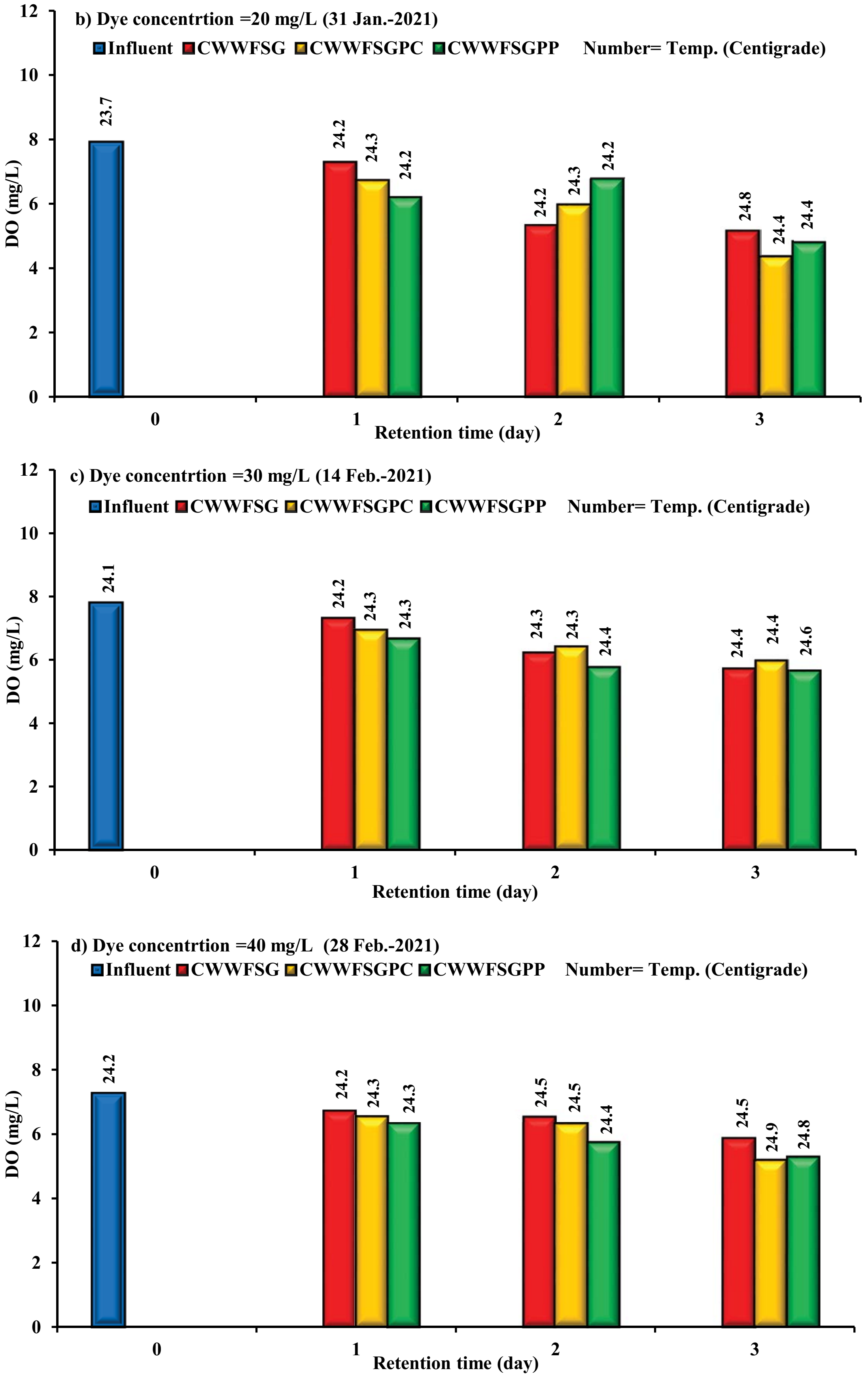


Fig. 3. (Continued))



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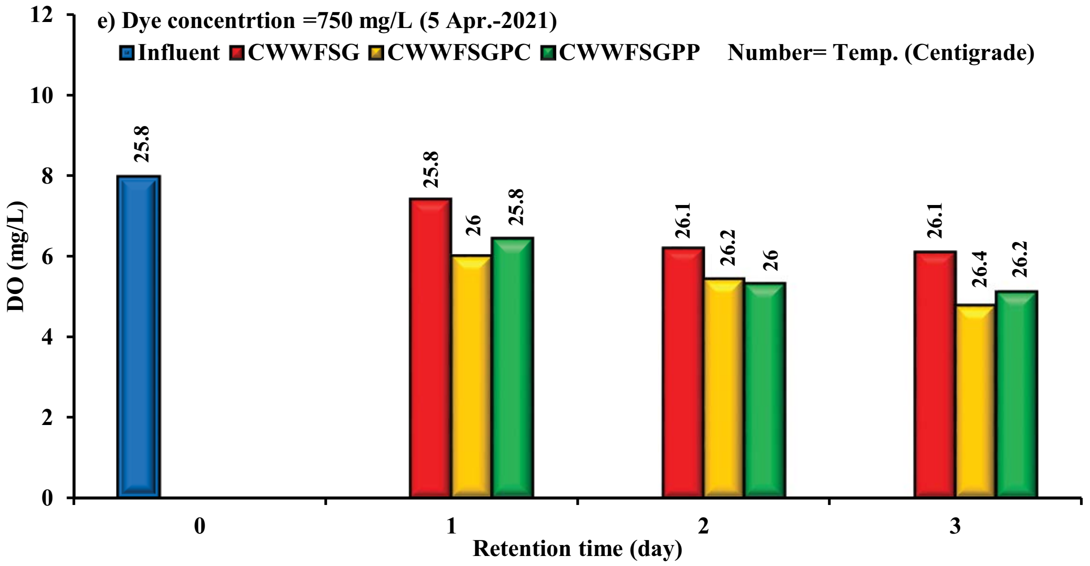

Fig. 3. Values of DO for effluent and influent with water temperature vs. the time in the planted and unplanted vertical units of CW filled with waste foundry sand for various concentrations of MB dye.

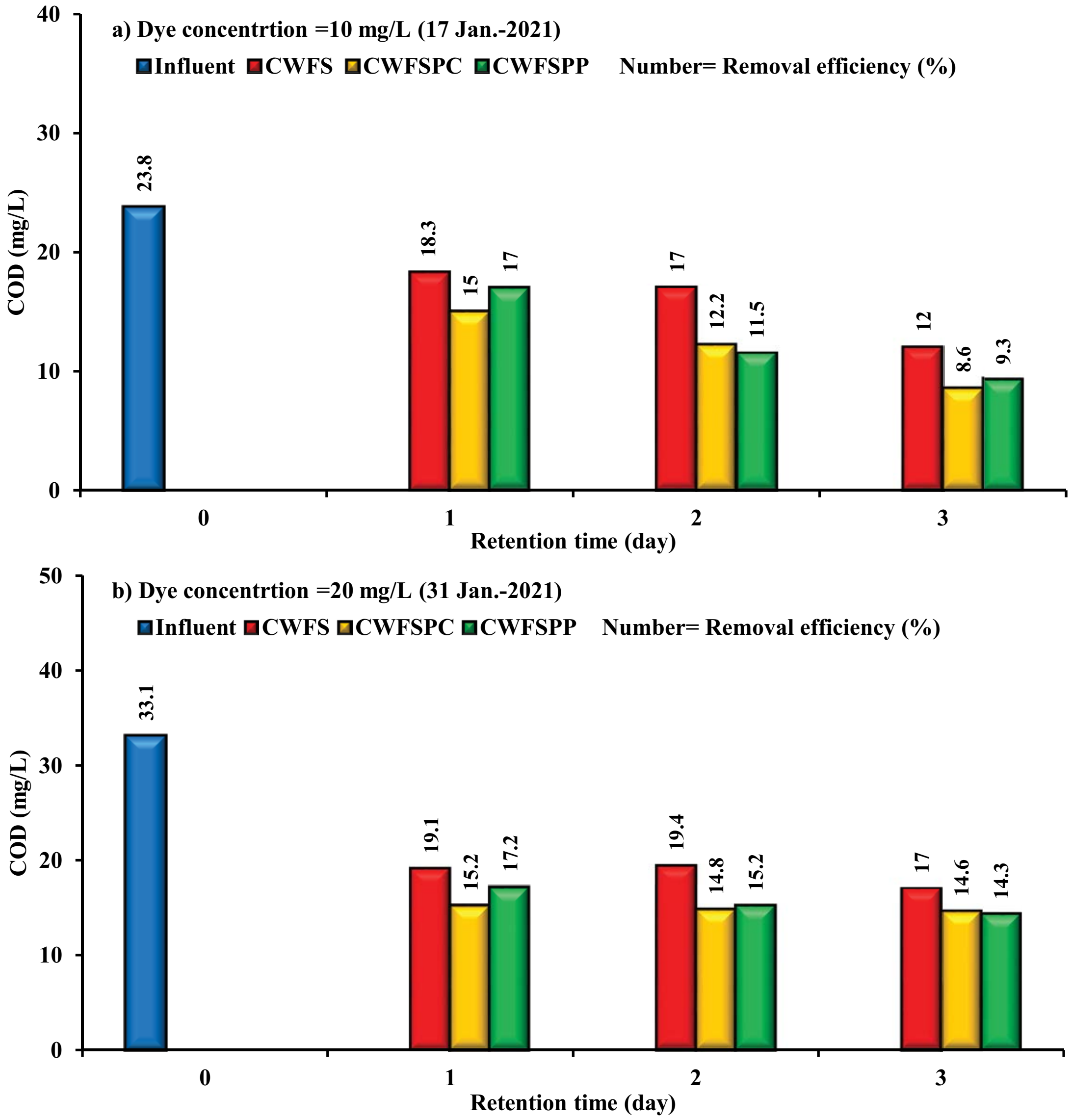

Fig. 4. (Continued))

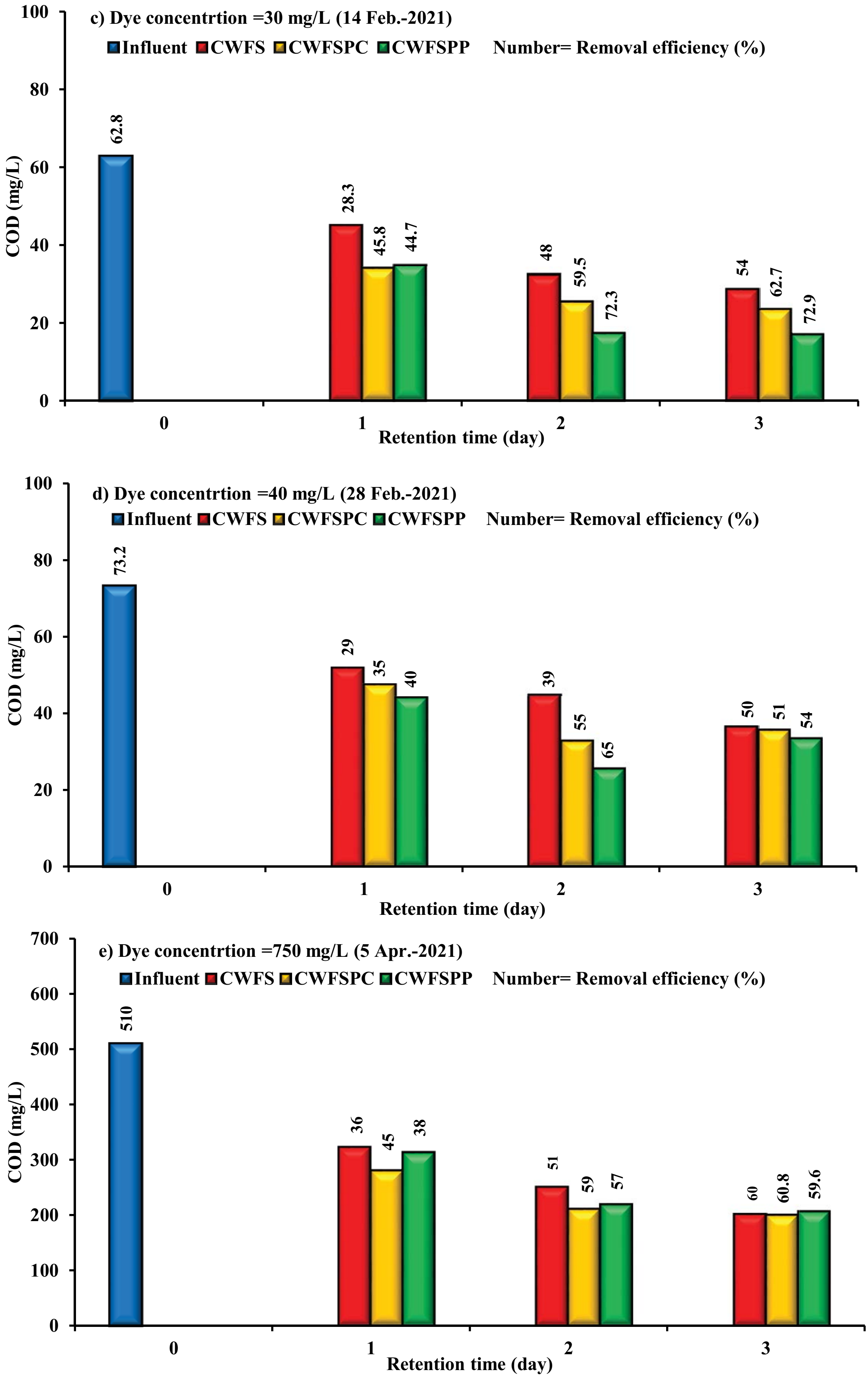

Fig. 4. Values of COD with efficiencies of removal for effluent and influent vs. the time in the planted and unplanted vertical units of CW packed with filter sand for various concentrations of MB dye.

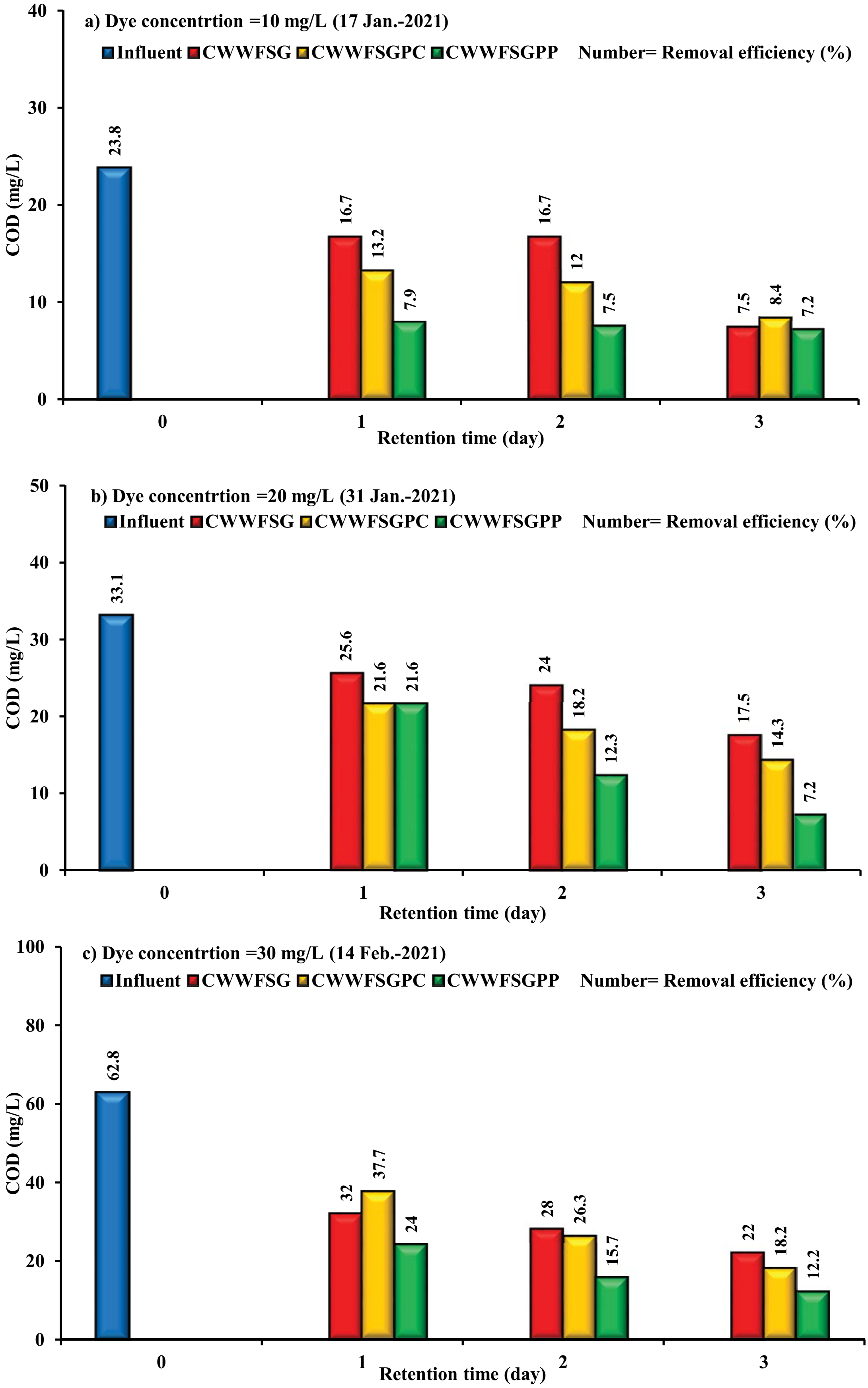

Fig. 5. (Continued))

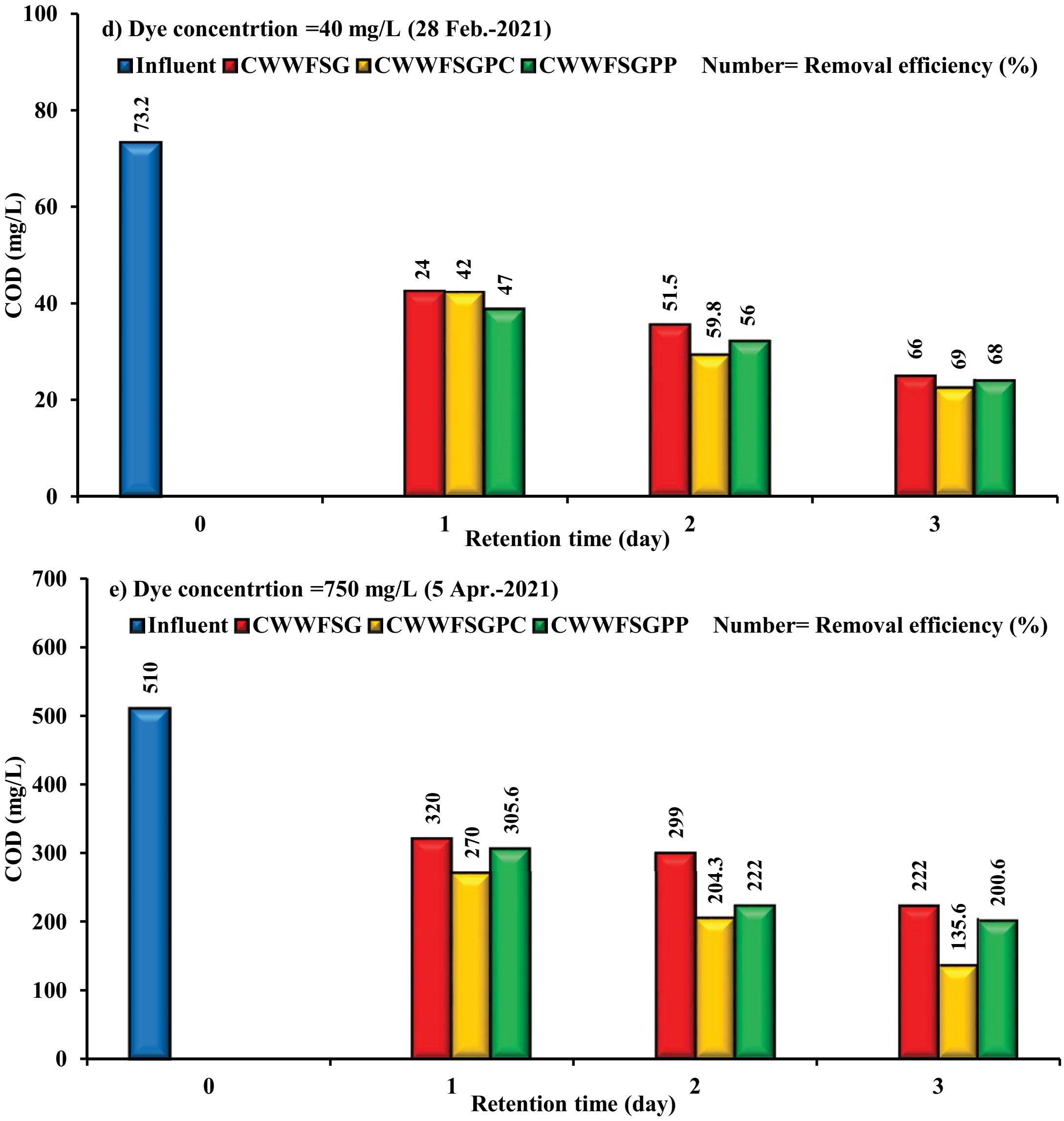

Fig. 5. Values of COD with efficiencies of removal for effluent and influent vs. the time in the planted and unplanted vertical units of CW packed with waste foundry sand for various concentrations of MB dye.

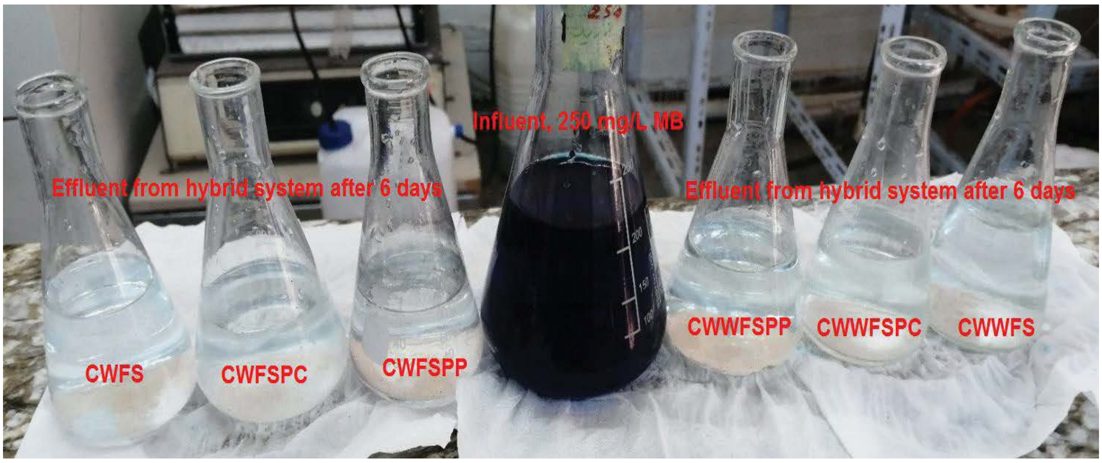

Fig. 6. Appearance of effluent treated by CW units filled with FS and WFS beds after 3 d in comparison with influent for dye C_o of 250 mg/L.

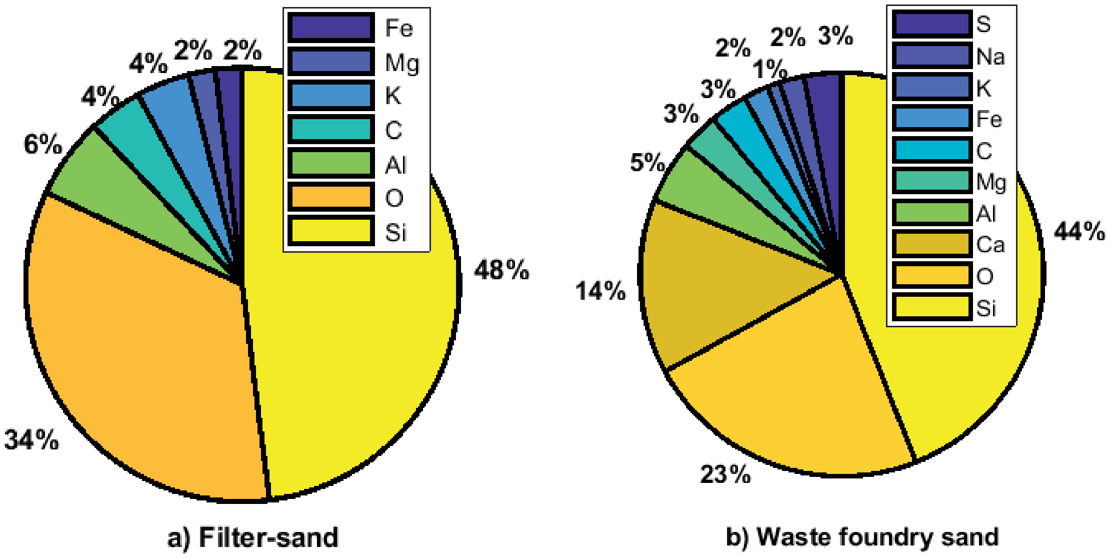

Fig. 7. Percentages of elements in composition of FS and WFS as determined by EDX analysis.

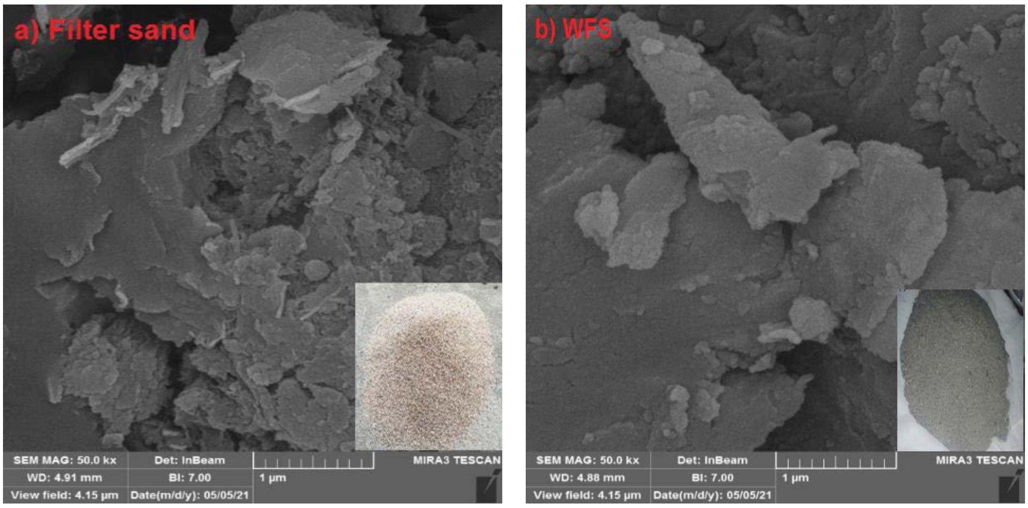

Fig. 8. Scanning electron micrographs (SEM) for (a) filter sand and (b) waste foundry sand.

6.4. Removal of MB dye

The color considers the familiar property for wastewater resulted from textile industry, it absorbs and reflects sunlight in water, thus can cause impeding the photosynthesis [35]. The MB dye was tested at five different target concentrations of 10, 20, 30, 40 and 750 mg/L to simulate the most concentrations available in the wastewater for different contact times. To evaluate the effect of contact time on the performance of CWs units packed with FS or WFS, the MB concentrations were measured in the effluent leaving VSSF after 1, 2, and 3 d. For vegetated and non-vegetated units, the results proved that these units have high efficacy in the removal of colour (i.e., dye concentration) from treated water with efficiency not less than 98%. The measurements certified that the vertical units are able to achieve this percentage for operation time equal to 1 d regardless the type of bed material and presence of plants. Results demonstrated that the efficacy of CW unit in the treatment of dye concentration will improve with slight values due to increase of contact time, decrease of influent dye concentration and presence of vegetation. This means that the removal process depends mainly on the packed bed material and biofilms on the solid particles which support the dye degradation as in the COD measurements; however, the used plants have approximately the same effects on the removal process.

Another indicator that adopted to evaluate the treatment feasibility of simulated textile wastewater contaminated with MB dye is the difference in the degree of colour between effluent and influent wastewater. Fig. 6 lists a set of photos for appearance of effluent treated by CW units filled with FS and WFS beds after detention time of 3 d in comparison with influent for dye C_o of 250 mg/L. It seems that the colour of the wastewater entering to all units is blue and this colour can remove with various percentages depended on the type of CW unit as clear from the appearance of produced wastewater. The conclusion from this figure signified that the efficacy of CW packed with WFS is identical to one contained of FS. The results of this investigation, which were measured for the removal of dye, are consistent with those of a number of previous studies, such as [23,38].

6.5. Characterization analyses

The X-ray diffraction analysis (XRD, Philips-Magix Pro MPD, Netherlands) was applied to identify the crystalline structure of FS and WFS used as substrates in the CWs units. Results proved that the diffraction reflections at intensities of 21.372°, 27.247°, 42.972°, 60.422°, 68.247° and 76.122° can be recognized for FS; while reflections for WFS can be observed at 21.025°, 26.927°, 36.1°, 40.475°, 42.925°, 40.496°, 50.325°, 60.301°, 68.175° and 78.008°. The analysis of measurements revealed that the FS and WFS are primarily consisted of silica which responsible of reflections appearance as identified by comparison with "Joint Committee on Powder Diffraction Standards (JCPDSs)".

The results of energy dispersive X-ray (EDX; EdaxDX-4) analysis showed that the main content of the sample (FS and WFS) is SiO_2 (elements Si and O). Also, very low percentage of trace elements like Al, K, Mg, and Fe can be appeared clearly with different percentages in the composition of FS and WFS (Fig. 7). The morphological characteristics of FS and WFS are illustrated in Fig. 8. It is clear that the FS has relatively an irregular shape surface with some cavities and small cracks. Image of WFS proves that this sand has the shape of a coherent and heterogeneous surface with lightly roughness; however, its surface structure looks very compact and disorganized. Moreover, these structures may be important for high internal surface area and to support the removal of organic matter from polluted water.

7. Conclusions

This study demonstrated that after 3 d of detention, both planted and unplanted vertical subsurface flow constructed wetland units packed with FS and WFS were able to remove COD, NH_4, and NO_3 from wastewater contaminated with MB at concentrations ranging from 10 to 750 mg/L. Because it is used in the oxidation of organic compounds, the treated water has a significant reduction in DO. According to observations, units that were planted with *P. australis* and *Canna indica* perform better during the treatment process; however, the utilized plants have roughly the same effect on the characteristics of the effluent. Both vegetated and non-vegetated units can remove color from treated wastewater with an efficiency of at least 98% at the chosen dye concentration. Additionally, COD was removed from effluents after 3 d, with removal efficiencies ranging from 46.8% to 80.5%. Monitoring of pH, COD, DO, temperature, nutrient, and dye concentration for treated wastewater proved that the performance of WFS is more efficient than FS in the treatment process; thus, WFS waste can utilize as alternative to FS. All treatment unit effluents are suitable for irrigation, according to guidelines from various agencies.

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