Development of floating treatment wetlands with plant-bacteria partnership to clean textile bleaching effluent

DOI: 10.35530/IT.070.06.1679

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ABSTRACT – REZUMAT

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Treatment of textile wastewater prior to its discharge into the environment is a highly concerned issue of the industry. The current established methods in textile industry for effluent treatment are typically high in cost, require range of chemicals along with the generation of concentrated hazardous sludge. It is therefore inevitable to look for economical and eco-friendly ways to treat textile wastewater. Hence, the present study was endeavored to develop green, chemical free and sustainable bacteria inoculated plant based technique for remedying textile bleaching effluents. A lab scale floating treatment wetlands (FTWs) system was developed and implemented for remediation of H_2O_2 based textile bleaching wastewater. This system was designed by vegetating two free floating aquatic plants Eichhorniacrassipes and Pistia stratiotes. The performance of this system was enhanced by inoculating two pollutant degrading and plant growth promoting bacteria, Bacillus cereus and Bacillus subtilis. The efficacy of this bacterial augmented FTWs system was assessed by monitoring physicochemical parameters of treated wastewater. A substantial decrease in pH, EC, TDS, TSS, BOD and COD was noted. This stamped the effectiveness of this sustainable technique to treat textile effluents.

Keywords: *waste water treatment, textile bleaching effluent, floating treatment wetlands, plant-bacteria synergy, plant growth promoting bacteria*

Sistem plutitor bazat pe sinergia plante-bacterii pentru tratarea efluenților rezultați din tratamentul de albire al materialelor textile

Tratarea apelor uzate textile înainte de evacuarea acestora în mediu este o problemă extrem de importantă pentru industrie. Metodele actuale existente în industria textilă pentru tratarea efluenților au de obicei costuri ridicate și necesită o serie de substanțe chimice, generând nămoluri active poluante. Prin urmare, este necesară identificarea unor modalități economice și ecologice pentru tratarea apelor uzate rezultate din finisajul textil. Studiul de față are ca obiectiv dezvoltarea unei metode ecologice și sustenabile, bazate pe sinergia plante-bacterii, pentru tratarea efluenților rezultați din procesul tehnologic de albire al materialelor textile. La nivel de laborator, a fost dezvoltat și implementat un sistem plutitor de tratarea efluenților (FTW) rezultați din procesul tehnologic de albire a materialelor textile pe bază de H_2O_2. Acest sistem a fost proiectat prin cultivarea a două plante acvatice plutitoare, respectiv Eichhorniacrassipes și Pistiastratiotes. Performanța acestui sistem a fost îmbunătățită prin inocularea a două bacterii, care degradează poluanții și care favorizează creșterea plantelor, respectiv Bacillus cereus și Bacillus subtilis. Eficacitatea acestui sistem FTW augumentat cu bacterii a fost evaluată prin monitorizarea parametrilor fizico-chimici ai apelor uzate tratate. S-a observat o scădere substanțială a pH-ului, EC, TDS, TSS, BOD și COD. Acest lucru a permis evaluarea eficienței acestei metode sustenabile de tratarea efluenților rezultați din finisajul textil.

Cuvinte-cheie*: tratarea apelor uzate, efluenți finisaj textil, tehnologie plutitoare, sinergie plante-bacterii, bacterii pentru creșterea plantelor*

INTRODUCTION

Textile industry plays significant role to boost up the economy of developing and developed countries [1], nevertheless, effluents generated by textile wet processing sector is responsible for massive destruction of aquatic ecology [2]. Moreover, the presence of organic and inorganic ingredients in receiving water bodies leads to reduce the sunlight penetration in them which directly disrupt the photosynthetic activity and concentration of dissolved oxygen [3]. The environmental and aquatic pollution caused by textile wet processing (TWP) industry is because of the release of its effluents directly to nearby drains without treatment or partial treatment especially in developing countries. These effluents have high values of pH, suspended and dissolved solids, biological oxygen demand (BOD), chemical oxygen demand (COD), and other pollutants [4–5]. A typical textile wet processing comprises a series of processes like pre-treatment, dyeing and finishing [6]. Bleaching is the most significant pre-treatment process carried out prior to dyeing for removing colouring impurities and to increase the fabric whiteness. Bleaching has to be performed on all fabrics whether sold as white or coloured. Among other bleaching agents like sodium hypochlorite, hydrogen peroxide has dominant share in industrial bleaching process [7]. It has been found that 38% of water in textile wet processing industry is used during bleaching process [8]. So a huge magnitude of wastewater is released from the bleaching process. Approximately 70 billion tons of wastewater is generated every year by textile industry [9]. Treatment of textile wastewater prior to its discharge into naturally occurring water bodies is highly desirable.

Many physicochemical and biological techniques like filtration, adsorption, coagulation, flocculation, oxidation and electrochemical methods are being exercised to treat textile wastewater. However, these methods have limitations with respect to operational and maintenance cost, requirement of skilled man power and generation of hazardous sludge that creates huge problem of its safe disposal [4]. In comparison to these capital and labour intensive physicochemical ways, bioremediation is an eco-friendly, less expensive and handy approach to clean textile wastewater from both organic and inorganic pollutants. It is based on plants, microbes and their partnership for wastewater treatment. In this technique bacteria boosts up the plant growth due to catabolism. In return plants provide nutrients, metabolites and habitats to microbes in their (endo)rhizoshpere. This plant-bacteria synergistic interaction results in enhanced degradation of hydrocarbons containing pollutants [10]. In this partnership plants contribute towards phyto-extraction, phytovolatilization, phytouptake, phytodegradation, rhizofiltration, phytostabilization (figure 1) while microbes take part in plant growth promotion activities and metabolization of organic pollutants and mineralization of inorganic pollutants. The application of this plant-microbe interactive mechanism has been suggested as an efficient mean to treat many kinds of wastewater and considered to have in situ applicability [11].

Floating treatment wetlands (FTWs) technique, being economical and low energy consuming, provide a green solution to clean polluted water. This method has been successfully applied to treat municipal, sewage, storm, domestic, industrial and poultry processing wastewater [12–17] while efficacy of constructed wetlands have been explored for general textile water [18]. However, to the best of our knowledge, floating treatment wetlands, vegetating with free floating aquatic plants, has not been assessed until now for cleaning textile bleaching enriched wastewater. Hence the current study has been conducted to remediate H_2O_2 enriched bleaching water of textile industry applying plant-microbe augmented FTWs technique.

MATERIAL AND METHODS

Collection of plants and development of their nursery

Plant selection for this technique is of utmost importance. The plants having dense root system are preferable for phytoremediation. In addition, native plants are more favorable to use as they are better tolerant to existing climate conditions. Therefore, two local plants which are found in abundance in the surroundings of Lahore and Faisalabad (the textile industry hub in Pakistan) "*Eichhorniacrassipes* (Water hyacinth)and *Pistia stratiotes* (Water lettuce)", were selected for the present research study. Adult plants were collected from local water bodies and stored in water tubs of circular shape having 76 cm diameter and 30 cm depth under ambient conditions for the development of their nursery (figure 2). In order to survive in textile wastewater they were immuned by feeding them with the textile wastewater for one week with increasing ratio of tap water and textile

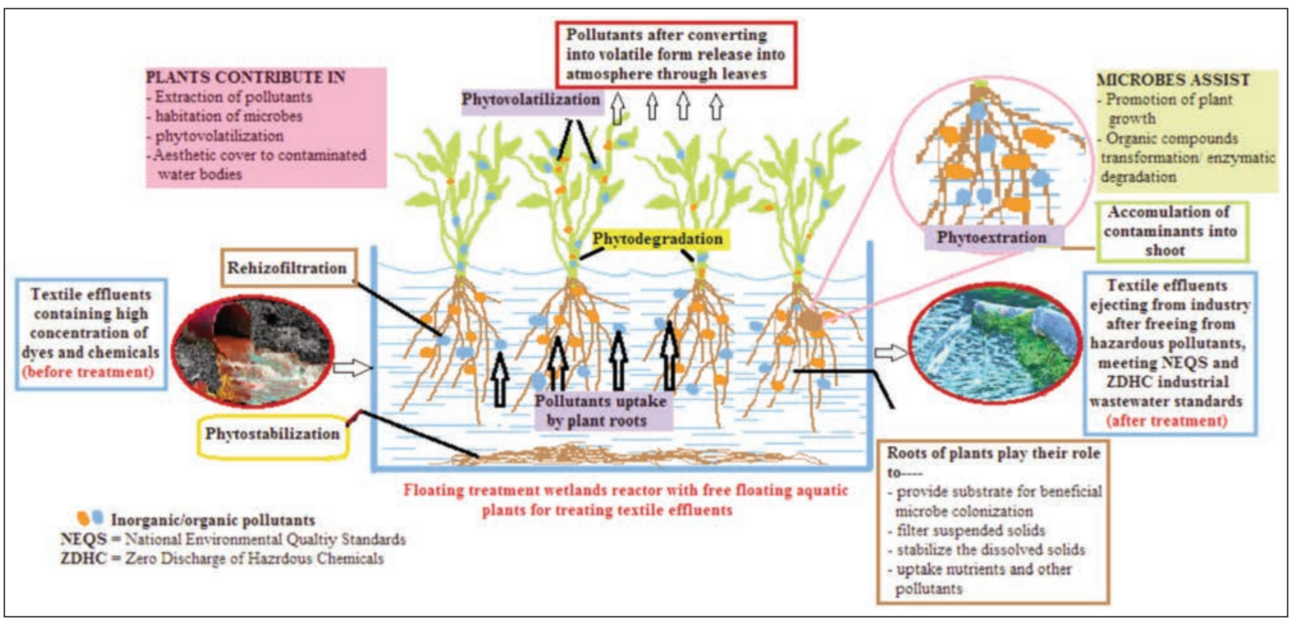

Fig. 1. Schematic view of FTW based phytoremediation mechanism proposed for the remediation of textile bleaching effluents

Fig. 2. Plants collection, their storage in tubs and development of their nursery

wastewater i.e. 0:100, 20:80, 40:60, 60:40, 80:20 and 100:0 respectively. After getting immunity the plants flourished well in pure textile wastewater and increased their population to double within 10 days.

Collection of wastewater degrading bacterial strains

Previously isolated and characterised [19] pollutant degrading bacterial strains, *"Bacillus cereus"* and *"Bacillus subtilis"*, were selected and developed using general purpose agar media (glucose peptone agar media) applying dilution plate technique. Inoculation of media plates was made with soil solution and these plates were then incubated at 28±2°C for 72 hours. From each soil sample the colony farming units (CFU/g soil) were calculated. The isolates of bacteria were examined for their polycyclic aromatic hydrocarbon biodegrading prospective using Bushnell-Haas broth in 24-well microtiter plates [20]. The efficacy of these bacterial isolates for plant growth promoting was also verified by testing their ACC-deaminase activity through method described by Jacobson [21]. Performance evaluation of these bacterial strains in respect to their textile effluent degradation and plant growth promotion activities has also been acknowledged in many other studies [22–23].

Hydrogen per oxide (H_2O_2) enriched bleaching solution preparation

The bleaching solution of 0.2% concentration was prepared according to the recipe; Hydrogen per oxide (H_2O_2) [50% concentrated solution] and Sodium carbonate (Na_2CO_3) 0.6 g/L.

Designing and development of FTWs

FTWs system was designed in transparent polyethylene containers (39 cm × 28 cm × 20 cm) of 10 liter capacity. Lab scale treatment reactors were developed for this research in order to evaluate the performance of the selected plants and bacterial strains for remediation of H_2O_2 enriched bleaching water. Nine treatment reactors for each color were developed. Their details are given below:

C = control (only bleaching solution)
T1 = solution + P1 (plant 1; *Eichhoriniacrassipes*)
T2 = solution + P1 + B1 (bacteria 1; *Bacillus cereus*)
T3 =solution + P1 + B2 (bacteria 2; *Bacillus subtilis*)
T4 = solution + P2 (plant 2; *Pistiastratiotes*)
T5 = solution + P2 + B1
T6 = solution + P2 + B2
T7 = solution + B1
T8 = solution + B2

The reactors according to the above cited details were developed by vegetating 5 plants of each type having nearly equal mass in transparent polyethylene containers. Before vegetation the plants roots were thoroughly washed. After this the selected bacterial strains were inoculated in these containers according to the designed specifications of the reactors. For the development of plant-bacteria interaction, the plants were dipped in 500 ml broth of each bacterium for 40 minutes. Then these plants were transferred to each treatment reactor (figure 3).

Testing of textile effluents

500 ml sample was taken from each reactor after four retention time intervals (TM1 0 hours, TM2 24 hours, TM3 48 hours and TM4 72 hours) in transparent plastic bottles after washing them thoroughly with distilled water and analysis were performed for examining

Fig. 3. Washing of plant's roots before vegetation and development of treatment reactors

the effects of selected treatments and retention times on physicochemical parameters i.e. pH, EC (electric conductivity), TDS (total dissolved solids), TSS (total suspended solids), BOD_5 (biological oxygen demand) after five days, COD (chemical oxygen demand) for hydrogen per oxide enriched bleaching wastewater, table 1, according to standard procedures [24].

Table 1

APHA STANDARD METHODS USED TO EXAMINE THE WASTEWATER QUALITY PARAMETERS	
Parameter	**APHA method**
pH	Method 4500-H+B
Electric conductivity (EC)	Method 2510
Chemical oxygen demand (COD)	Method 5220 D
Biological oxygen demand (BOD)	Method 5210 D
Total dissolved solids (TDS)	Method 2540 C
Total suspended solids (TSS)	Method 2540 D

Statistical analysis

The statistical tests were conducted using the SAS program version STAT 9.1 of SAS Institute [25]. All the selected water quality parameters were analyzed employing General Linear Model (GLM) whereas multiple comparisons were made using the least significant difference (LSD) test for differences between means. A significance level of $p < 0.05$ was used for all statistical tests. Furthermore, regression analysis was also carried out in order to analyze the effect of time on quality parameters of textile wastewater.

RESULTS AND DISCUSSION

pH value of wastewater as affected by various treatments and hydraulic retention times

LSD (least significant difference) test along with comparison of individual treatment means of pH value for variant retention times are presented in table 2. The results reflect significantly ($\alpha = 0.05$) highest value of pH along column wise for control treatment C (9.64) and lowest for treatment T2 (9.30). Similarly along row wise the greatest value of pH was noted for retention time TM1 (9.87) while lowest value was observed for retention time TM4 (9.22). These findings clearly indicate a good reductionof 8.8% in pH value (figure 4, *a*) of the solution for reactor T2 (*Bacillus cereus* + *Eichhorniacrassipes)* at retention time TM4 (*72 hours)* when compared with that of control reactor (C). These results exhibit considerable effect of *Eichhorniacrassipes* and *Bacillus cereus* in synergy to reduce pH of the bleaching solution.

The analysis of variance (ANOVA) for regression with respect to time (table 3) for bleaching solution disclosed a significant impact ($\alpha = 0.05$) on the reduction of pH of the solution. The regression model so developed narrated an inverse affect of time on the pH values at the rate of 0.009. There came high degree of certainty ($r^2 = 0.67$) that ensured the best representation of the data observed by the predicted equation (1).

$$pH = 9.74 - 0.009 \times TM \qquad (1)$$

It is derived from all the above findings that interactive action of *Eichhorniacrassipes* and *Bacillus cereus*is responsible for greater reduction in pH of bleaching solution and bringing it towards neutral side matching with the standards set by for industrial wastewater. This reduction in pH from alkaline side towards neutral is due to the production of carbonic acid in solution as a result of degradation of organic pollutants in the effluents. Similar conclusions were also predicted in previous studies [26–27] for non-bleach processes. Additionally the bacterial addition in this system enhanced the performance of this mechanism by promoting the growth of the plants resulting in their ability to take up contaminants. Moreover, rise in the degradation of organic pollutants

Table 2

EFFECT OF VARIOUS TREATMENTS (T) AND TIME (TM) ON PH VALUE OF BLEACHING SOLUTION

Treatment	pH				Mean	LSD (0.05)
	TM1	TM2	TM3	TM4		
C	9.89^{a}_{a}	9.59_{b}^{a}	9.55_{bc}^{a}	9.51_{c}^{a}	9.64_{a}	0.0580
T1	9.88_{a}^{a}	9.37_{b}^{c}	9.28_{c}^{c}	9.23_{c}^{c}	9.44_{c}	0.0580
T2	9.86_{a}^{a}	9.25_{b}^{d}	9.08_{c}^{f}	9.02_{c}^{f}	9.30_{f}	0.0632
T3	9.87_{a}^{a}	9.31_{b}^{cd}	9.20_{c}^{de}	9.16_{c}^{de}	9.39_{de}	0.0595
T4	9.87_{a}^{a}	9.47_{b}^{b}	9.39_{bc}^{b}	9.33_{c}^{b}	9.52_{b}	0.0873
T5	9.85_{a}^{a}	9.30_{b}^{cd}	9.18_{c}^{e}	9.13_{c}^{e}	9.37_{e}	0.0685
T6	9.86_{a}^{a}	9.36_{b}^{c}	9.24_{c}^{cde}	9.18_{c}^{cde}	9.41_{cd}	0.0692
T7	9.86_{a}^{a}	9.33_{b}^{c}	9.26_{bc}^{cd}	9.20_{c}^{cd}	9.41_{cd}	0.0873
T8	9.88_{a}^{a}	9.35_{b}^{c}	9.27_{bc}^{c}	9.22_{c}^{cd}	9.43_{c}	0.0873
Mean	9.87^{a}	9.37^{b}	9.27^{c}	9.22^{d}	9.43	0.0207
LSD (0.05)	0.0586	0.0756	0.0611	0.0657	0.0311	

Superscripts (a, b, c, d, e, f) showed comparison among means vertically in columns and subscripts showed comparison among means horizontally along rows. Any two values not sharing a letter in common differ significantly at $p < 0.05$.

Table 3

ANOVA FOR REGRESSION ANALYSIS FOR TIME FOR BLEACHING SOLUTION													
Source	**DF**	**Dep. Var. pH**		**Dep. Var. EC**		**Dep. Var. TDS**		**Dep. Var. TSS**		**Dep. Var. BOD**		**Dep. Var. COD**	
		MS	**P>F**	**MS**	**P>F**	**MS**	**P>F**	**MS**	**P>F**	**MS**	**P>F**	**MS**	**P>F**
Model	1	5.6427	0.0001	45.3618	0.0001	10069607	0.0001	26882	0.0001	6283.27	0.0001	6636.02	0.0001
Error	106	0.0260		0.4063		115907		253.5377		24.4660		45.1909	
Corr Total	107												

by these bacteria is due to their metabolic properties that results in release of organic acids which reduced the pH of the solution.

Effect of various treatments and hydraulic retention time on EC value of bleaching solution

The results presented in table 4 regarding the comparison of individual mean values of EC was analyzed statistically by applying LSD test. It indicates significantly (α = 0.05) greatest value of EC (4.99 dS/m) along column wise for control treatment (C). While the lowest value of EC (3.80 dS/m) along row wise was noted for T2 treatment. Similarly for various retention times the greatest value of EC (5.42 dS/m) along row wise was observed for TM1 while lowest value of EC (3.51 dS/m) was noted for TM4.

The ANOVA for regression (table 3) related to time disclosed a significant (α = 0.05) effect of retention time on the EC value of the solution. The developed regression model indicated an inverse effect of time on EC value at the rate of 0.024. The degree of certainty was found higher (r^2 = 0.51) clearly indicating the best representation of data by the predicted equation (2)

$$EC = 4.88 - 0.024 \times TM \qquad (2)$$

All these findings clearly exhibit the dominant effect of *Eichhorniacrassipes* and *Bacillus cereus* synergy to reduce EC value of the solution as compared to that of other treatment combinations. Maximum reduction in EC value of 40.63 % was observed for this combination (T2) (figure 4, *b*). This decrease in EC value of bleaching solution under the plant-bacteria partnership is attributed towards the decrease of soluble salts that might be taken up by the plant through its root and shoot system. Similar decrease in EC was also reported previously for non-textile application [28]. Basically plants provide habitat to bacteria and in return bacteria add up the plant growth due to their catabolic activities which improves the nutrient up take ability of plants through their root and shoots. This plant-microbe combination enhanced the reduction of EC value of wastewater.

Effect of various treatments and hydraulic retention time on TDS value of bleaching solution

The statistical analysis of data regarding TDS value of the bleaching solution, table 5, clearly indicates the significant (α = 0.05) effect of selected treatments on TDS. The comparison of individual treatment reflects highest value of TDS along column wise for control treatment C (2737 mg/L) while the lowest value for treatment T2 (1958 mg/L). In the same line the greatest TDS value was noted for TM1 (2809 mg/L) while lowest value was recorded for TM4 (1911 mg/L) along row wise.

The analysis of data applying regression analysis (table 3) described significant (α = 0.05) effect of time

Table 4

EFFECT OF VARIOUS TREATMENTS (T) AND TIME (TM) ON EC VALUE OF BLEACHING SOLUTION						
Treatment	**EC**				**Mean**	**LSD (0.05)**
	TM1	**TM2**	**TM3**	**TM4**		
C	5.44_a^a	4.89_b^a	4.83_c^a	4.80_c^a	4.99_a	0.0541
T1	5.43_a^a	3.49_b^{bc}	3.43_{bc}^{bc}	3.41_c^{bc}	3.94_{bc}	0.0692
T2	5.40_a^a	3.33_b^f	3.27_c^f	3.23_c^f	3.80_f	0.0580
T3	5.42_a^a	3.39_b^{ef}	3.34_{bc}^{de}	3.31_c^{de}	3.87_e	0.0541
T4	5.44_a^a	3.51_b^b	3.46_{bc}^b	3.43_c^b	3.96_b	0.0610
T5	5.41_a^a	3.40_b^{de}	3.31_c^{ef}	3.29_c^e	3.85_e	0.0645
T6	5.43_a^a	3.43_b^{de}	3.39_{bc}^{cd}	3.36_c^{cd}	3.90_d	0.0541
T7	5.41_a^a	3.46_b^{bcd}	3.40_c^c	3.37_c^c	3.91_d	0.0541
T8	5.42_a^a	3.48_b^{bc}	3.41_{bc}^{bc}	3.39_c^{bc}	3.93_{cd}	0.0810
Mean	5.42^a	3.60^b	3.54^c	3.51^d	4.02	0.0178
LSD (0.05)	0.0428	0.0654	0.056	0.0583	0.0267	

Table 5

EFFECT OF VARIOUS TREATMENTS (T) AND TIME (TM) ON TDS VALUE OF BLEACHING SOLUTION						
Treatment	**TDS**				**Mean**	**LSD (0.05)**
	TM1	**TM2**	**TM3**	**TM4**		
C	2810_a^a	2747_b^a	2701_c^a	2689_d^a	2737_a	5.4081
T1	2809_a^a	1920_b^c	1909_c^{bc}	1906_c^b	2136_c	6.9180
T2	2808_a^a	1700_b^f	1669_c^g	1656_c^f	1958_g	14.7960
T3	2808_a^a	1860_b^d	1815_c^e	1797_c^d	2070_e	19.7250
T4	2810_a^a	1968_b^b	1911_c^b	1903_c^b	2148_b	19.2930
T5	2808_a^a	1760_b^e	1695_c^f	1683_c^e	1987_f	15.1800
T6	2809_a^a	1867_b^d	1823_c^e	1800_c^d	2075_e	25.2080
T7	2809_a^a	1913_b^c	1889_c^d	1883_c^c	2124_d	19.6350
T8	2809_a^a	1919_b^c	1893_c^{cd}	1886_c^c	2127_d	24.8190
Mean	2809^a	1962^b	1923^c	1911^d	2151	5.1945
LSD (0.05)	16.153	17.67	17.522	14.099	7.7918	

on TDS value of the solution. The developed regression model in this respect indicated an inverse relation between time and TDS value at the rate of 11.38. The high degree of certainty (r^2 = 0.45) ensures the best representation of the data observed by the predicted equation (3).

$$TDS = 2560.83 – 11.38 \times TM \quad (3)$$

It is obvious from the results that *Eichhorniacrassipes* and *bacillus cereus* combination under treatment T2 made significant reduction (41.07%) in TDS value of bleaching solution after 72 hours retention time (figure 4, *c*). This substantial decrease in TDS is attributed to plant-bacteria partnership due which plant's roots provide more spaces for bacteria attachment. These spaces also motivate the adsorption and accommodation in plant tissues for both organic and inorganic matters while the bacteria presence enhance the efficacy of these processes due to its ability to degrade contaminants by transforming and mineralization.

Effect of various treatments and hydraulic retention time on TSS value of bleaching solution

Table 6 depicts significantly (α = 0.05) greatest value of TSS (139 mg/L) along column wise at control treatment C and lowest (98 mg/L) at treatment T2. The overall mean value of TSS along row wise was noted greatest at retention time TM1 (140 mg/L) and lowest at retention time TM4 (96 mg/L).

The ANOVA, table 3, highlighted significant (α = 0.05) impact of time on TSS value of the solution. The developed regression model in this respect showed inverse effect of time on TSS at the rate of 0.59 while the high degree of certainty (r^2 = 0.50) made the best representation of data by the predicted equation (4).

$$TSS = 131.61 – 0.59 \times TM \quad (4)$$

It is clear from all these facts that under the treatment T2 (*Eichhorniacrassipes and Bacillus cereus)* high reduction in TSS value (45.39%) of bleaching solution was observed (figure 4, *d*). This high level reduction

Table 6

EFFECT OF VARIOUS TREATMENTS (T) AND TIME (TM) ON TSS VALUE OF BLEACHING SOLUTION						
Treatment	**TSS**				**Mean**	**LSD (0.05)**
	TM1	**TM2**	**TM3**	**TM4**		
C	141_a^a	140_a^a	138_a^a	137_a^a	139_a	6.92
T1	140_a^a	110_b^b	102_c^b	99_c^{bc}	113_{bc}	5.80
T2	139_a^a	94_b^d	81_c^c	77_c^e	98_e	6.92
T3	140_a^a	97_b^c	86_c^e	81_c^{de}	101_d	7.65
T4	140_a^a	113_b^b	105_c^b	104_c^b	116_b	5.41
T5	139_a^a	97_b^c	87_c^c	83_c^{de}	102_d	6.92
T6	140_a^a	99_b^c	88_c^c	85_c^d	103_d	8.73
T7	140_a^a	108_b^b	100_c^b	97_c^c	111_c	6.10
T8	140_a^a	109_b^b	101_c^b	99_c^{bc}	112_c	5.80
Mean	140^a	107^b	99^c	96^d	110	1.95
LSD (0.05)	5.86	5.63	7.03	6.05	2.92	

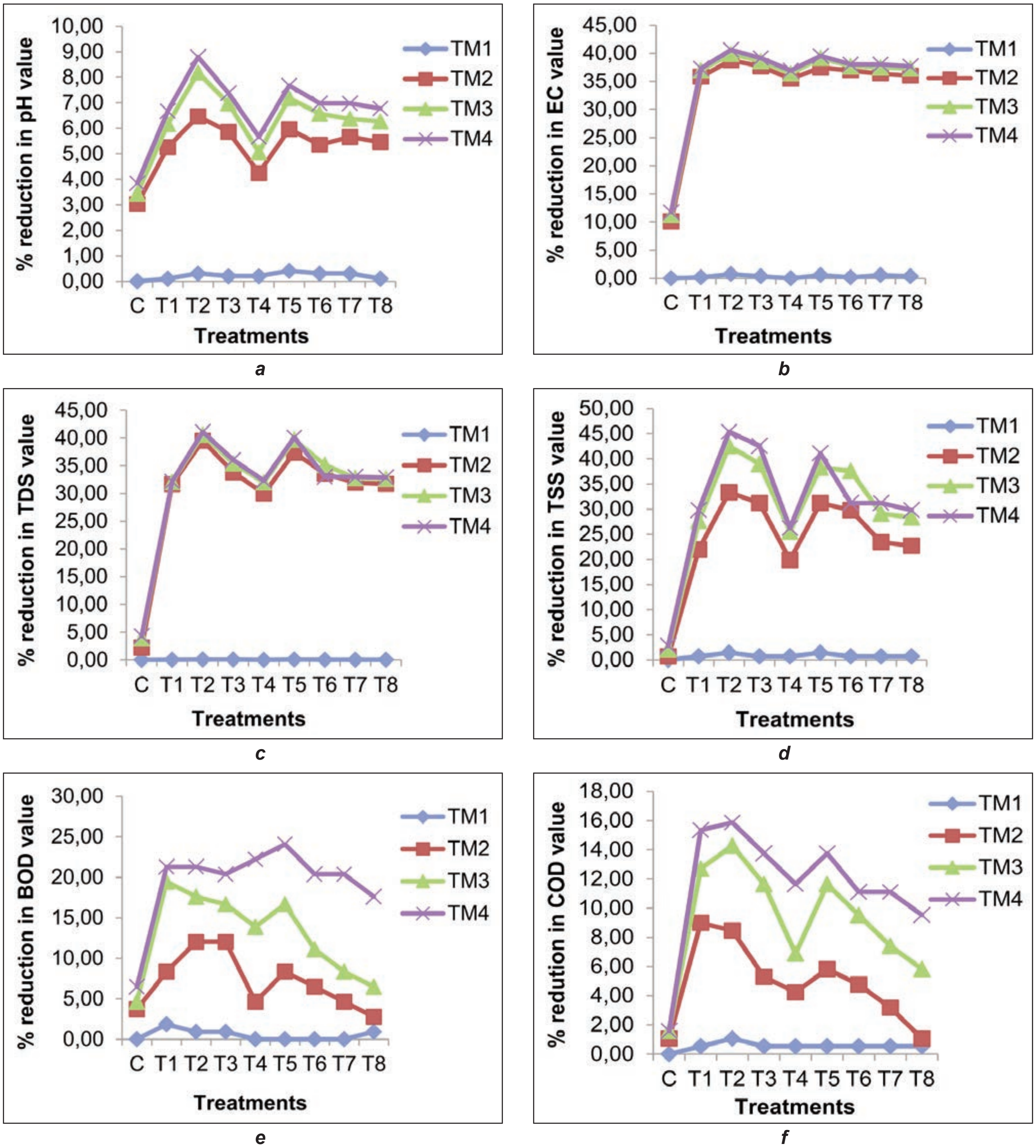

Fig. 4. Percentage ofreduction in physicochemical properties of bleaching solution for various treatments (T) and retention times (TM)

in TSS is accredited towards the dense root system of plants that makes availability of more places for filtering, settlement and trapping of suspended particles. Moreover, the presence of plant growth promoting and pollutant degrading bacteria enhanced this factor by boosting up plant's biomass.

Effect of various treatments and hydraulic retention time on BOD value of bleaching solution

The analysis of data demonstrated significant impact ($\alpha = 0.05$) of selected treatments on the BOD value of bleaching solution (table 7). Highest value BOD along column was recorded for control treatment C (104 mg/L) while lowest value was noted for treatment T2 (93 mg/L). Following the same trend along row, the highest value of BOD was reflected at time TM1 (107 mg/L) while lowest one was resulted for TM4 (87 mg/L).

The regression analysis of data exposed off an inverse impact of time on BOD value of the solution at the rate of 0.28 as shown in ANOVA, table 3. The high degree of certainty ($r^2 = 0.71$) stamped the best presentation of the data observed by the predicted equation (5)

$$BOD = 107.46 - 0.28 \times TM \quad (5)$$

Table 7

EFFECT OF VARIOUS TREATMENTS (T) AND TIME (TM) ON BOD VALUE OF BLEACHING SOLUTION						
Treatment	**BOD**				**Mean**	**LSD (0.05)**
	TM1	**TM2**	**TM3**	**TM4**		
C	108_a^a	104_b^{ab}	103_b^a	101_b^a	104_a	3.65
T1	106_a^a	99_b^{bc}	87_c^e	85_c^{bc}	94_e	4.71
T2	107_a^a	95_b^c	89_c^{de}	82_c^{bc}	93_e	4.98
T3	107_a^a	95_b^c	90_{bc}^{de}	86_c^{bc}	95_e	5.41
T4	108_a^a	103_a^{ab}	93_b^{cd}	85_c^{bc}	97_{cd}	5.41
T5	108_a^a	99_b^{bc}	90_c^{de}	83_d^c	95_{de}	6.92
T6	108_a^a	101_b^{ab}	96_b^{bc}	84_c^c	97_{cd}	5.80
T7	108_a^a	103_{ab}^{ab}	99_b^{ab}	86_c^{bc}	99_{bc}	6.92
T8	107_a^a	105_a^a	101_a^a	89_b^b	101_b	6.92
Mean	107^a	100^b	94^c	87^d	97	1.65
LSD (0.05)	5.15	5.24	4.75	5.72	2.48	

All these results unrevealed the best performance of *Eichhorniacrassipes* and *Bacillus cereus* combination with maximum reduction in the value of BOD (21.29%) of bleaching solution (figure 4, *e*). The high performance of this partnership regarding the reduction of BOD value could be due to the desirable rate of oxygen transfer through the roots of plants and high accumulation of microbes in rhizo/endo sphere of plants that resulted in degradation of organic pollutants.

Effect of various treatments and hydraulic retention time on COD value of bleaching solution

The results in table 8 pointed out significant ($\alpha = 0.05$) effects of all selected treatments on the COD value of the bleaching solution. The highest COD value along column (187 mg/L) was noted for control treatment C, while the lowest value (170 mg/L) was found for treatment T2. Similarly along row the highest value of COD was noted for TM1 (187 mg/L) and lowest one was observed for TM4 (167 mg/L).

The effect of time on COD value was analyzed by applying regression analysis. The results represented in ANOVA, table 3, and the developed regression model described significant ($\alpha = 0.05$) inverse effects of time on COD value of the solution at the rate of 0.29. The best representation of data ensured by high degree of certainty ($r^2 = 0.58$), observed by the predicted equation (6)

$$COD = 187.10 - 0.29 \times TM \quad (6)$$

These results disclosed the supremacy of *Bacillus cereus* augmented *Eichhorniacrassipes* based FTW system to have maximum reduction (15.87%) in COD (figure 4, *f*) when compared with control treatment reactor. COD is an important pollutant indicating parameters and it reflects the amount of oxidizable contaminants present in wastewater. The reduction in COD is attached with the decomposition of these oxidizable pollutants due to the addition of oxygen by

Table 8

EFFECT OF VARIOUS TREATMENTS (T) AND TIME (TM) ON COD VALUE OF BLEACHING SOLUTION						
Treatment	**COD**				**Mean**	**LSD (0.05)**
	TM1	**TM2**	**TM3**	**TM4**		
C	189_a^a	187_a^a	186_a^a	186_a^a	187_a	4.80
T1	188_a^a	172_b^d	165_c^{ef}	160_c^{de}	170_e	5.41
T2	187_a^a	173_b^{cd}	162_c^f	159_c^e	170_e	6.59
T3	188_a^a	179_b^{bc}	167_c^{de}	163_c^{cde}	174_d	6.92
T4	188_a^a	181_b^{ab}	176_b^b	167_c^{bcd}	178_c	6.92
T5	188_a^a	178_b^{bcd}	167_c^{de}	163_c^{bc}	174_d	5.16
T6	188_a^a	180_b^b	171_c^{cd}	165_c^{bcde}	176_{cd}	6.92
T7	188_a^a	183_{ab}^{ab}	175_{bc}^{bc}	168_c^{bc}	179_c	10.18
T8	188_a^a	187_a^a	178_b^b	171_c^b	182_b	6.32
Mean	187^a	180^b	172^c	167^d	177	1.94
LSD (0.05)	5.21	6.91	4.78	7.30	2.92	

plants because of their photosynthetic activity as previously accredited [29]. Moreover inoculation of bacteria in the system boosted up this oxidation process by adding up plant growth that resulted in increase of photosynthetic activity and increasing of oxygen rate in the solution as reported earlier [27].

Comparison of results of treated solution with NEQS and ZDHC standards

A comparison of physicochemical quality parameters of treated H_2O_2enriched textile bleaching wastewater by applying plant-bacteria synergized FTWs technique was made with industrial and municipal wastewater quality standards set by NEQS (National Environmental Quality Standards of Pakistan) and ZDHC (Zero Discharge of Hazardous Chemicals). All the parameters were found within the set limit, table 9, demonstrating the considerable efficacy of this technology to clean textile effluents.

Table 9

COMPARISON OF RESULTS WITH NEQS AND ZDHC INDUSTRIAL AND MUNICIPAL WASTEWATER STANDARDS

Textile effluent properties	For T2 and TM4	Units	NEQS	ZDHC
	Bleaching solution			
pH	9.02 ± 0.023	-	6–10	6–9
EC	3.23 ± 0.017	dS/m	-	-
TDS	1656 ± 3.468	mg/L	3500	-
TSS	77 ± 2.312	mg/L	150	30–150
BOD	82 ± 1.156	mg/L	80	30–150
COD	159 ± 2.890	mg/L	150	40–400

The values in ± are the standard errors.

CONCLUSIONS

The present study successfully investigates the efficacy of floating aquatic plants and their growth promoting and pollutant degrading bacteria in combined form by applying FTWs phytoremediation technique to degrade H_2O_2 enriched bleaching solution of textile industry. This technique marked itself a plausible approach to remediate textile bleaching effluents by making comprehensive reduction in major physicochemical parameters of effluent. After 72 hours retention time the combination of *Eichhorniacraccipes* and *Bacillus cereus* made extensive reduction in pH (8.80%), EC (40.63%), TDS (41.07%), TSS (45.39%), BOD (21.29%) and COD (15.87%) values of bleaching solution and consequently, bring them within the limits set by NEQS and ZDHC industrial wastewater standards. This embossed the efficacy of FTWs amplified with pollutant degrading and plant growth promoting bacteria to degrade textile bleaching effluents. Moreover, use of floating aquatic plants made FTWs technique more economical by the involvement of less infrastructure. It demonstrated the suitability of this technique to be applied directly on existing wastewater ponds, lakes, and drains or even in the running wastewater treatment plants in textile industry. Hence this technique can be a chemical free, less expensive, aesthetically pleasant and sustainable substitute to the existing expensive and complex wastewater techniques for textile effluents.

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