A constructed wetland model for synthetic reactive dye wastewater treatment by narrow-leaved cattails (Typha angustifolia Linn.)
S. Nilratnisakorn, P. Thiravetyan and W. Nakbanpote

ABSTRACT

Textile wastewater is contaminated by reactive dye causing unattractive levels of wastewater color, high pH and high salt content when discharged into public water systems. Decolorization of textile wastewater by plant, phytoremediation, is an alternative, sustainable method which is suitable for long term operation. Narrow-leaved cattails are one species of wetland plant with efficiency for decolorizing and remediating textile wastewater. In addition, chemical oxygen demand (COD) can be lowered and dye residue can be removed. The plant also showed a good salt tolerance even after being exposed to a salt solution for 15 days. The narrow-leaved cattails were set up in a constructed wetland model with a vertical flow system operating from bottom to top for synthetic reactive dye wastewater (SRDW) removal. Narrow-leaved cattails could achieve the removal of SRDW at approximately 0.8 gSRDW m\(^{-2}\) day\(^{-1}\). Decolorization of SRDW by this plant was approximately 60%. The advantage of this method is that it is suitable for textile wastewater management and improvement of wetland. These plants could lower COD, remove dye, sodium and total dissolved solids (TDS) whereas other biological and chemical methods could not remove TDS and dye in the same time. These results suggested that the spongy cell structure of this plant has the ability to absorb large amounts of water and nutrients. Physico-chemical analysis revealed increasing amounts of sulfur, silicon, iron and calcium in the plant leafs and roots after exposure to wastewater. Proteins or amide groups in the plant might help in textile dye removal. Regarding decolorization, this plant accumulates dye in the intercellular space and still grows in this SRDW condition. Hence, it can be noted here that narrow-leaved cattails are efficient for textile dye wastewater treatment.

Key words | narrow-leaved cattails, phytoremediation, reactive dye, wastewater treatment, wetland

INTRODUCTION

Textile wastewater treatment by constructed wetland, phytoremediation, is environmentally friendly. This alternative treatment method is easy to operate, is cost effective and requires low maintenance (Willey 2007). In Thailand, the application of constructed wetland for use in the textile industry is of increasing importance since aquatic perennial plants are natural resources found around the textile industry. Until now, they were mainly applied in constructed wetlands in pre-treatment of wastewater prior to physical and/or chemical remediation methods before wastewater was released into the public water system. Textile effluent contains several substances released during processes such as bleaching, dyeing, and washing. Those substances are xenobiotic and difficult to degrade or eliminate by physico-chemical methods. The symbiosis in constructed wetland assumes a major role for xenobiotic
degradation (Kadlec & Knight 1995). Reactive azo dyes with highly soluble properties and the complexities of the effluent the causes of the environmental problem (Zollinger 2004). The colored wastewaters are unattractive to the public (USEPA 1996, 1999) since the conditional indicator of color indicates that the dye in wastewater has to be reduced to an acceptable level (Maguire & Burlington 1991). Reactive azo dyes are categorized as restricted chemical in European countries because the derivative compounds of this substance, such as aromatic amine and phenol, are mutagens and/or carcinogens in the food web via aquatic living organism and a risk to humans due to substances of very high concern. Thai government legislation has forced the textile industries to treat the effluent to meet environmental standard levels before releasing it into the public water system (Department of Industrial Works 2007).

Textile wastewater decolorization has been reported by several methods; nevertheless the physical and/or chemical methods could only enhance the efficiency of decolorization but required high investments of chemicals, energy and budget for maintenance (Beszedits 1980; Buckley 1992; Naumczyk et al. 1996). Constructed wetlands can fulfill several proposes such as organic, inorganic, heavy metal treatment, municipal wastewater treatment, and mining wastewater and highway runoff treatment with several submerge plant species (Cronk & Fennessy 2001; Doucette et al. 2005; Gessner et al. 2005; Nepovim et al. 2005). For reactive azo dye treatment, wetlands have been constructed using reed or Phragmites (Pervez et al. 1999; Davies et al. 2005), but for textile dye removal or textile wastewater treatment the use of cattails has never been reported. Nirlatnisakorn et al. (2007) studied the potential of narrow-leaved cattails for reactive dye removal; these plants showed a capacity for dye removal on the pot scale. The preliminary study investigated the dye toxicity under the condition of low and high concentration of dye. The results of the study showed that a dye toxicity of 25.33 mg l\(^{-1}\) could be removed, which is close to dye residue removal needed for textile effluent to be released in to the public water system. They were expressed in terms of the effects of the toxic dye on relative plant growth rate and the appearance of symptoms such as necrosis, chlorosis, chronic and acute wilting as well as the decrease of system pH. The results showed a maximum color removal and sodium removal of 60% and 40%, respectively, which indicated that this plant could treat wastewater. Scanned Electron Microscope (SEM) images of narrow-leaved cattail after treatment of synthetic reactive dye wastewater (SRDW) revealed that the root cortex was damaged and that crystalline sodium salts were deposited in the root cells which were caused by evaporation and transpiration while decreasing SRDW contamination. The salinity under caustic conditions also affected the growth of the plants. The salt accumulations in the roots or shedding of older leaves suggested that there were plant mechanisms which are known to avoid textile dye salt stress. In addition, elements such as silicon, calcium and iron in plants might help the plants to detoxify by forming complex molecules with the dye molecules. The preliminary results were interesting enough to scale up the pot scale and apply it in textile industry sites. Therefore, a model of a constructed wetland was calculated by using the results of the pot scale experiments to estimate the possibility of operation for constructed wetland by this plant on the large scale. Previous work has shown that narrow-leaved cattails revealed a potential for SRDW treatment and biodegradation of SRDW at 0.857 g\(_{\text{SRDW}}\) m\(^{-2}\) day\(^{-1}\) and 1.93 \times 10^{-4} g\(_{\text{SRDW}}\) m\(^{-2}\) g\(_{\text{syr}}\)\(\text{plant}\)\(^{-1}\) respectively. Hence, simulation results from models are needed to prove the biodegradation and treatment efficiency by setting up a pilot scale experiment. The aim of this research was to study a small pilot scale constructed wetland by using narrow-leaved cattails for treatment of SRDW (Figure 1).

The results of this study can be applied to the design of optimally constructed wetlands on a large scale for operation at sites of the textile industry. The efficiency of SRDW purification by narrow-leaved cattails were observed in terms of pH improvement, color removal (%), COD, TDS, sodium removal (%) and were discussed in this work.

**MATERIALS AND METHODS**

**Synthetic reactive dye wastewater (SRDW)**

The commercial diazo C.I. Reactive Dye 141-RR 141, Molecular weight = 1,774, Solubility = 50 g l\(^{-1}\)) (Figure 2) in this study was obtained from DyStar, Thai Co., Ltd. Thailand. Synthetic reactive dye wastewater was prepared
from 4 g l\(^{-1}\) of RR141, 90 g l\(^{-1}\) of sodium sulphate (Na\(_2\)SO\(_4\)) and 20 g l\(^{-1}\) sodium carbonate (Na\(_2\)CO\(_3\)) according the protocol for dyeing processes given by DyStar. In the dyeing process, sodium sulphate and sodium carbonate were added to increase the dye substance and improve the dyeing speed, respectively. At the end of the SRDW synthesis process, the SRDW contained 400 mg l\(^{-1}\) of RR141 with a pH 10–11. SRDW was scanned under a wavelength of maximum absorbance (\(\lambda_{\text{max}} = 544\) nm) by a UV-visible spectrometer, model UNICO-2100, USA.

**Plant culture condition**

Narrow-leaved cattails were collected from the brackish water King Mongkut's University of Technology Thonburi (KMUTT), Bangkhuntien Campus and cultured in a 12 × 20 inches plastic box to produce new shoots (Figure 3). Plants were selected and cultured with SRDW under caustic conditions as explained above. The concentrations of treatments were 20 mg l\(^{-1}\), and the initial pH was adjusted to 9. Plants at the same stage of growth (0.9–1 m. plant height, 4–5 leaves per plant, and 20–30 roots per plant) were selected for growth in a PVC box with an adjusted water level of 30 liters. The experiment was conducted in October 2005 at an average temperature of 30 ± 2°C, with 12 hr of light, 910 \(\mu\)mol m\(^{-2}\) s\(^{-1}\) of light intensity in a greenhouse. Duplicate experiments were performed with 10 plants per experiment and three replications of sample water.

**Operational condition**

The experimental was conducted in constructed wetlands (Figure 4) with a vertical subsurface flow from bottom to top in two pilot scales of constructed wetlands located at a greenhouse of KMUTT-Bangkhuntien campus which controlled the light intensity, moisture level and temperature of the control and the treatment set. The PVC boxes were 0.8 m in length, 0.6 m in width and 0.6 m in height, the working volume without gravel and sand was 0.288 m\(^3\). The constructed pilot scale wetland was first filled with washed gravel (particle size 0.01–0.05 m) up to 0.15 m in depth. It was then filled with washed sand (particle size 0.01–0.03 m) up to 0.15 m in depth. The average porosity of the constructed wetland at subsurface flow was approximately 0.4. To achieve a hydraulic retention time of 15 days, the flow rate was adjusted to 0.02 m\(^3\) day\(^{-1}\), organic loading

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*Figure 1 | A schematic overview of SRDW treatment by narrow-leaved cattails.*

*Figure 2 | Chemical structure of diazo C.I. Reactive Red 141-RR141.*
rate (OLR) = 2.777 gSRDW m$^{-2}$ day$^{-1}$. To achieve vertical flow, the inlet was placed on the bottom of the PVC box; the outlet for the SRDW was placed on the top of the model.

### Analytical methods

250 ml of SRDW was sampled from the inlet and the outlet of each experiment each day; to maintain water content, 250 ml of SRDW was added back to the system. Samplings were analyzed for chemical oxygen demand (COD), total dissolved solid (TDS) and sodium concentration according to the Standard Methods for Examination of Water and Wastewater (American Public Health Association 1998). The efficiency of constructed wetland was performed by measuring pH, absorbance of RR141 at $\lambda_{\text{max}} = 544$. The percentage of color removal was calculated by the following equation:

\[
\text{Color removal} \, (\%) = \left(1 - \frac{A_a}{A_b}\right) \times 100
\]

Where $A_b$ = Absorbance before treatment, $A_a$ = Absorbance after treatment.

The data collection of plant leaves and roots of the control and treatment sets included wet weight, dry weight, height, number of leaves, number of roots, number of shoots, and appearance symptoms.

### Chemicals analysis

Plants after treatment with SRDW were collected to study the functional group by Fourier Transmission Infrared (FTIR) Spectrophotometer, X-ray Diffraction (XRD), SEM/EDX, TEM/EDX and Inductively Coupled Plasma (ICP) Spectrophotometer (Nilratnisakorn et al. 2007).
RESULTS AND DISCUSSIONS

Constructed wetland removal efficiency

The results indicated that the pH level of the constructed wetland decreased from 9 to 7.8 because of the chemical fate of the color and various ions taken up by the plants and the plant itself has ability to modify pH-conditions in the rhizosphere (Brix et al. 2002). This led to a reduction in COD and the amount of TDS as shown in Figures 5 and 6. Color, COD and TDS removal were 58%, 59% and 86%, respectively. The correlative reduction of pH, color, COD and TDS expressed the treatment efficiency by these plants. This revealed that the semi-permeability of the plant system allowed the dye and other chemical compounds to pass through the plants’ vascular system (Doucette et al. 2005).

A plant’s internal selective process, filtration and absorption played a major role in SRDW removal (Lincoln & Eduardo 2002). The experiment was run for 2 crops within 30 days, and then narrow-leaved cattails accumulated dyes and salts in plant leaves and roots. It was found that narrow-leaved cattails were shedding old leaves and the dye-saturated roots were splitting from the main stem. The appearance of H2S, FS and eutrophication were not observed in the experiment, which implies that anaerobic microorganisms might not play a major role for biodegradation in this set up. This suggests that the symbiotic microorganisms in this system might be aerobic. However, this observation will need further study to be proven. The results of Soft X-ray Absorption to probe for sulfur in narrow-leaved cattails revealed that the main portion of sulfur in the plant after treatment with SRDW was R–SO32−. The reduced form of R–SO21− was observed in the plant roots after treatment with SRDW.

The effects of sand and gravel on dye absorption were observed by measuring dye adsorption of sand and gravel by adding 20 mg l−1 SRDW into substrates. At HRT 15, the dye color removal by sand was 2.82%, for gravel the color removal was 1.95%. Whereas the color removal in an experimental set of plants enriched with 20 mg l−1 SRDW without sand and gravel was 49%. In the experiment with plants, sand and gravel enriched with 20 mg l−1 SRDW the color removal rate was 58%. This implied that sand and gravel have only a minor effect on the dye removal in this constructed wetland system.

A race of narrow-leaved cattails grows in the mangrove area of Bangkhuntien where the salinity condition is 1–2% so it is likely that the plant could grow in the caustic conditions of SRDW. Therefore, when narrow-leaved cattails were grow in SRDW with a salinity of 4–6%, the plant might adapt and develop an avoidance defense mechanism. Salt accumulation in plant leaves and roots after treatment with SRDW was discovered under the electron microscope. The decrease of COD and TDS in SRDW suggested that the large molecules of the dye might be caught in barriers in the vascular system of the plants, but TDS of SRDW was mainly Na2SO4 and Na2CO3 which were added during the dyeing process. The small molecules of those salts could be dissolved, absorbed and then pass through the semi-permeable membrane of the plants. The results of TDS removal were higher than COD removal by these plants.

The discharge wastewater obtained during this experiment met the standard of polluted water as shown in Table 1. However, the COD parameter should be
considered which was a little higher than the standard, suggesting that we should add more plant material into the system to enhance the COD removal to the level of 120 mg l\(^{-1}\).

A previous study reported the efficiency of cattails for textile dye removal in pot scale. The removal capacity seems to follow the same trend in this pilot scale constructed wetland. The system pH decreased from 9 to 7.8 as found in the pot scale experiment, and color reduction was 60% (Nilratnisakorn et al. 2007). The result from a constructed wetland in a pilot scale and a constructed wetland model showed no difference in terms of SRDW removal. Unfortunately, TDS removal in the constructed wetland model was found to be higher than at pot scale (data not shown), this evidence could support that the greater number of plants in a constructed wetland might have an impact on this result since the pot scale experiment had only 3 plants per pot, while the pilot scale 10 plants per plot. Therefore, to improve the efficiency of SRDW treatment by narrow-leaved cattails the number of plants in the operation system should be increased. These would enhance the efficiency for SRDW treatment and lead to a decrease in the hydraulic retention time per cycle. Constructed wetlands using several plant species showed a trend which correlated with this study as presented in Table 2.

### Chemicals analysis of SRDW treatment by narrow-leaved cattails

Narrow-leaved cattails were exposed in SRDW under the hydraulic retention time of 15 days. SRDW contaminants were accumulated in the plant and the removal capacity was stabilized at 58%, even though at 18 days of HRT the removal capacity was 59%. Physico-chemical analyses were

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Influent before treatment</th>
<th>Effluent after treatment</th>
<th>Standard of polluted water(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical appearance</td>
<td>Dark pink</td>
<td>Light pink</td>
<td>Not objectionable</td>
</tr>
<tr>
<td>SRDW concentration in the solution (mg l(^{-1}))</td>
<td>20</td>
<td>10.24</td>
<td>N/A</td>
</tr>
<tr>
<td>pH</td>
<td>9.0</td>
<td>7.8</td>
<td>5.5–9.0</td>
</tr>
<tr>
<td>COD remaining in the solution (mg l(^{-1}))</td>
<td>1,123</td>
<td>453</td>
<td>(\leq 120)</td>
</tr>
<tr>
<td>TDS in the solution (mg l(^{-1}))</td>
<td>1,328</td>
<td>183</td>
<td>(\leq 3,000)</td>
</tr>
<tr>
<td>Efficiency for SRDW removal (g(_{\text{SRDW}}) m(^{-2}) day(^{-1}))</td>
<td>–</td>
<td>0.773</td>
<td>N/A</td>
</tr>
<tr>
<td>Biodegradation of SRDW (g(_{\text{SRDW}}) m(^{-2}) g(^{-1}) plant)</td>
<td>–</td>
<td>(1.5 \times 10^{-7})</td>
<td>N/A</td>
</tr>
</tbody>
</table>

\(^a\) Notification of the Ministry of Science, Technology and Environment, No. 3, B.E.2539 Department of Industrial Works (2007), Ministry of Science and Technology (1996). N/A = No available.

### Table 2 | Constructed wetlands with several plant species for treatment of textile dyes

<table>
<thead>
<tr>
<th>Dye</th>
<th>Constructed wetland plants</th>
<th>Initial dye concentration (mg l(^{-1}))</th>
<th>HRT (days)</th>
<th>System pH</th>
<th>Color removal (%)</th>
<th>COD removal (%)</th>
<th>TDS removal (%)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid Orange 7</td>
<td>Phragmites sp.</td>
<td>127</td>
<td>5</td>
<td>N/A</td>
<td>63.8</td>
<td>63.8</td>
<td>70</td>
<td>Davies et al. (2005)</td>
</tr>
<tr>
<td>Reactive Blue 171</td>
<td>Phragmites sp.</td>
<td>100</td>
<td>40</td>
<td>7.6–7.8</td>
<td>91</td>
<td>90</td>
<td>N/A</td>
<td>Pervez et al. (1999)</td>
</tr>
<tr>
<td>Sulphate dye</td>
<td>Cattails sp. and Cocoyam</td>
<td>N/A ((&lt;200))</td>
<td>1.45</td>
<td>7.83</td>
<td>72–77</td>
<td>68–73</td>
<td>N/A</td>
<td>Mbuligwe (2005)</td>
</tr>
<tr>
<td>Reactive Black 5, Vat yellow 46 and Disperse Yellow 211</td>
<td>Phragmites sp.</td>
<td>30</td>
<td>N/A</td>
<td>7.6–7.8</td>
<td>90</td>
<td>84</td>
<td>93</td>
<td>Bule &amp; Ojstrsek 2008</td>
</tr>
<tr>
<td>Reactive Red 141</td>
<td>Narrow-leaved cattail (Typha angustifolia Linn.)</td>
<td>20</td>
<td>15</td>
<td>7.8</td>
<td>58</td>
<td>59</td>
<td>86</td>
<td>This study</td>
</tr>
</tbody>
</table>

N/A = No available.
provided by sampling exposed plants to study the functional group via SEM/EDX, TEM/EDX, FTIR and XRD, respectively. Table 5 summarizes the results of physico-chemical analysis of SRDW contaminant removal by this plant. The results revealed that the amounts of sulfur (sulphonate group of dye), silicon, iron and calcium increased in the plant’s leaf and root after exposure to wastewater. Silicon and calcium elements were found in the complex forms of silicon, calcium–silicate and calcium oxalate in the plant. These complex elements were involved in detoxification of dye in the plant. In addition, protein or amide groups in the plant might have helped in the mechanism of textile dye removal. In terms of decolorization, this plant could accumulate dye in the intercellular space and can use the dye molecules for growth resulting in an increase in the relative growth rate (Nilratnisakorn et al. 2007).

However, the results suggested that SRDW might prohibit the growth of narrow-leaved cattails. The stressful condition from dye and salinity showed plant deficiencies such as necrosis, chlorosis, and wilting. The development of these symptoms can prevent further injury due to changes in biochemical processes. During 15 days of HRT, narrow-leaved cattail showed the capacity for sodium removal by absorption of sodium from the solute transported through the vascular system under caustic conditions. The plants grown in SRDW were observed to use less water due to the high levels of sodium salt in SRDW causing less evaporation and transpiration to take place. The evaporation and transpiration decreased under these conditions may cause oxygen deficiency and lead to a gas filled channel in the root degeneration of cells as evidenced under the Scanning Electron Microscope (SEM). The stress from the oxygen deficiency and sodium ion had shown influence on the calcium ion in the plants. After treatment of SRDW, plants can produce calcium oxalate and other complexes of calcium such as jasmundite which was deposited in the plants’ leafs or roots, which was confirmed by X-ray diffraction.

The results implied that a small amount of sodium could enhance the relative growth rate of the plant (data not shown). A limitation of sodium removal after the third week of treatment has been observed. The specific ion toxicity and osmotic pressure that affected the plant growth are possible explanations for this outcome. Plasma membrane permeability can detect and select ions that are less toxic to the cell, this process could reduce and change the specific ion toxicity effect on the plant (Park 1999). The amount of sodium decreased during the first two weeks, then the saline and water stress condition damaged the plant by precipitation of sodium in the plant leaf and root that can induce oxidative membrane damage. Hence, the signs of leaf tissue hydration were found and there was a decrease in relative growth rate similar to the result of Amarante et al. (2006).

Transmission electron microscopy connected with electron dispersive X-ray spectroscopy (TEM/EDX), and scanning electron microscopy connected with electron dispersive X-ray spectroscopy (SEM/EDX) were used to discover evidence of dye and salt damage to the membrane of the cell and the dye deposited in the intercellular space. The penetration of dye molecules was observed with the evidence of calcium, silicon, sulfur and iron accumulation in the cells of the apex leaf. The EDX results revealed an increase of silicon, sodium and calcium in the plant after expose to SRDW. The elements might precipitate with the dye in order to avoid damaging the plant, as confirmed by synthetic complex formation of calcium–silicon and/or calcium–iron. Since calcium–silicon and/or calcium–iron were found, it is possible to explain through this evidence that the dye also formed a complex with those elements.

FTIR spectra results could suggest that primary and secondary amide and siloxane (Si–O–Si) of plant plays an important role in SRDW treatment. The negatively charged dye compound (dye-) bound with O=C(–) and NH+ of amide I, II group and siloxane group or Si–O–Si bridges as in the study of Khraisheh et al. (2004). Amide II (NH-bending), C–OH or C–O–C binding of cellulose plants were replaced with the aromatic ring with azo bonds (2,112.5 cm−1) and sulfonate group (SO42−) at 1,117.6 cm−1.

The replacement of dye on the polysaccharide skeleton mode (C–O–C) of the plant might be due to the same mechanism that attaches the dye to cotton in the dyeing process, by attaching to the carboxylic group as occurred in the case of dye deposited in the old leaves of this plant.

Silicon group (Si–O–Si or SiO2) increases might help the morphological and chemical changes which resulted from the salt stress condition of SRDW. Silicon mainly in the cell wall helps maintain the integrity and function of plasma membrane, as does mitigated salinity toxic by the
Table 3 | The results of Physico-chemical analysis of SRDW treatment by narrow-leaved cattails

<table>
<thead>
<tr>
<th>Analytical techniques</th>
<th>Leaves</th>
<th>Roots</th>
<th>Leaves</th>
<th>Roots</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEM-EDX (JEOL, JSM-5800LV, Japan)</td>
<td>Healthy tissue</td>
<td>Healthy tissue</td>
<td>Salt accumulation</td>
<td>Salt accumulation</td>
<td>Salt accumulated in tissue, found cortex damage and wilting that was caused from salt barrier in the vascular system. The precipitation of sodium must be the cause of obstruction of solute transportation and lead to inhibition of photosynthesis</td>
</tr>
<tr>
<td>Element found</td>
<td>Na = 30</td>
<td>Na = 40</td>
<td>Na = 200</td>
<td>Na = 1,280</td>
<td></td>
</tr>
<tr>
<td>Si = 60</td>
<td>Si = 50</td>
<td>Si = 45</td>
<td>Si = 60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca = 15</td>
<td>S = 50</td>
<td>S = 60</td>
<td>S = 789</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TEM-EDX (JEOL, JEM-2010, Japan)</td>
<td>Intercellular space does not have dye deposit, smooth membrane</td>
<td>Intercellular space does not have dye deposit, smooth membrane</td>
<td>Dye deposits in intercellular space, rough membrane damage</td>
<td>Dye deposits in intercellular space</td>
<td>The increase in silicon, calcium and iron in this plant might enhance the efficiency of SRDW removal</td>
</tr>
<tr>
<td>Element found</td>
<td>Si = 2.47</td>
<td>Si = 78.49</td>
<td>Si = 48.22</td>
<td>Si = 158.83</td>
<td></td>
</tr>
<tr>
<td>S = 0.51</td>
<td>S = 25.81</td>
<td>S = 63.7</td>
<td>S = 34.98</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca = 17.98</td>
<td>Ca = 67.65</td>
<td>Ca = 62.79</td>
<td>Ca = 115.93</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe = 1,218.06</td>
<td>Fe = 374.12</td>
<td>Ca = 4,183.19</td>
<td>Fe = 829.86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FTIR (Perkin-Elmer spectrum one, Japan)</td>
<td>Found high sharp peak of amide NH-stretch, small peak of O−C−NH bending and Si−O−Si</td>
<td>Found small hill peak of amide NH-stretch, small peak of O−C−NH bending and Si−O−Si</td>
<td>Increasing of SO3 peak, Si−O−Si and amide of plant found peak shift and change by reducing</td>
<td>Increasing of SO3 peak, high sharp peak of Si−O−Si and amide of plant found peak shift and change by reducing</td>
<td>SO3 peak came from the RR141 dye structure, siloxane (Si−O−Si) and amide/protein of plant might be involved in the SRDW removal mechanism</td>
</tr>
<tr>
<td></td>
<td>Na2SOx, Burkeite (Na2SO4 + Na2CO3), Ca2SiO4 and Ca11(SiO4)O2S</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>XRD (JEOL, JDX-5330, Japan)</td>
<td>Found peak of carbon as D-glucose</td>
<td>Found peak of carbon as D-glucose</td>
<td>Found polyaniline, carbon backbone of dye structure, Na2SOx, Burkeite (Na2SO4 + Na2CO3) and Ca2SiO4</td>
<td>Found polyaniline, carbon backbone of dye structure, Na2SOx, Burkeite (Na2SO4 + Na2CO3), Ca2SiO4 and Ca11(SiO4)O2S</td>
<td>Confirmed that SRDW transported through vascular tissue. Calcium oxalate might be one of the substances which helped the plant avoided SRDW</td>
</tr>
</tbody>
</table>
decreasing of Na⁺ concentration in shoots, consequently an increased level of H⁺ in leaves from salt stress and silicon will maintain the optimal membrane fluidity of monocotyledon plant (Rodriguez et al. 2005).

The possible mechanism for textile wastewater treatment by this plant suggests that it has external and internal mechanisms to do so as the results from SEM-EDX, TEM-EDX, FTIR and XRD have shown. The dye absorption and the sodium salt precipitation at the outer membrane of the plant, as the external mechanism, found siloxane (Si–O–Si) group was involved. The results shown in FTIR and TEM-EDX implied that silicon, calcium and iron were involved in dye absorption by an internal mechanism. This indicated that silicon was induced by SRDW. SRDW treatment by this plant also needs NH from amide group as the result of FTIR showed that the amide group (NH) changed. The function of silicon, calcium and protein might be related to each other. At the beginning of stress from caustic conditions like SRDW, the stress will turn on the protein kinase and other proteins. The protein will increase from accumulation of free proline in the stem by function of calcium signal transduction. This will involve in the protons released in the cell and acting on hundreds of different proteins. During proline expression, plants will be avoiding osmotic stress that is caused by salt stress. Proline will help the plant to maintain its moisture and fluidity (Feng Ma & Yamaji 2006; Shao et al. 2007). The salinity toxic mitigation also the one of silicon function for decreasing sodium ion concentration in shoot of monocotyledon plant (Tuna et al. 2008). The complementary function of calcium and silicon was found in the formation of siloxane bond, this process also required calcium to achieve the maximum activity.

CONCLUSIONS

The constructed wetland with a vertical flow system operating from bottom to top in this study revealed the efficiency of narrow-leaved cattails for SRDW treatment. The results indicated that the constructed wetland could achieve the objective of improvement of effluent, especially color, COD and TDS removal, to levels that are within local legislation. Narrow-leaved cattails are the main source of dye removal in this constructed wetland system; however, the role played by symbiotic microorganisms need further study. The possible mechanism of textile wastewater treatment by this plant suggested that silicon, calcium and proteins of the plant might play a role by binding with dye molecules, which would help to prevent stressful conditions from developing in the plant by keep balance of osmolysis.

Further study is needed on which proteins are involved in the SRDW defense mechanism.

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