Feasibility of Typha and Canna for pulp and paper mill wastewater treatment through small wetlands
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ABSTRACT

The bucket reactors based wetland system were adopted for the treatment of pulp and paper mill wastewater using two macrophytes namely Typha angustifolia and Canna indica. The study was carried out for the treatment of wastewater collected from primary clarifier overflow (E1) and wastewater after the partial aerobic treatment of primary clarifier overflow (E2). Effectiveness of the two macrophytes was studied and compared for the removal of COD, BOD₅, TS, and Colour at two hydraulic retention times (HRT).

The comparison of inlet and outlet concentrations showed high removals of Color, TS, BOD₅ and COD during summer season. The best removals were obtained at 3.5 days HRT. Also the treatment efficiency of both plants was compared where Typha showed significant removal efficiency than Canna. However, the aerobic treatment provided showed the significant improvements in the removal efficiency of Canna. The aerobic treatment provided to the wastewater also showed significant increase in removal of BOD₅ in case of both macrophytes during summer as well as winters. According to these results, it can be concluded that wetland system utilised in this research could be a suitable solution for industrial wastewater treatment.

Key words: Color, BOD₅, Canna, Typha, pulp and paper mill wastewater

1. Introduction

Pulp and paper industry may contain small quantities of a variety of substances but the most significant components by volume are the organic compounds that result in oxygen depletion (BOD) due to microbial decomposition, COD etc. Conventional biological treatment systems including aerated lagoons, aggregated lagoons, aggregated precipitations and activated sludges, provide favourable environmental conditions and adequate retention times mainly for bacterial populations to decompose organic substances in the wastewater. However, these methods provide poor control of water color. Lignins and their derivatives are abundant in pulp mill wastewater and along with tannins, are principally responsible for the blackish brown color. Only certain fungi and a few bacterial groups are capable of attacking this very complex polymer. Conventional methods are likely to have few fungal species and thus low corresponding biomass. Consequently, potential for color removal is negligible.
Industrial wastewater treatment by artificial wetlands has gained popularity in the last four decades as an alternative to conventional treatments such as activated-sludge systems. Four main components make up the CW—water, media, microbes and vegetation. Water is transferred through the filtering media, and contaminants are removed mainly by physical mechanisms, such as filtration or sedimentation, and biochemical interactions, such as microbial degradation. Plants are an important component of wetland systems (J. Kalff, 2002). However, the mechanisms by which macrophytes affect water treatment in CWs are still being debated (M. Scholz, 2006). Plant efficiency in promoting CW performance depends on several factors: CW type (e.g., vertical, horizontal, surface, or subsurface flow, with or without recirculation), quality and quantity of the wastewater loads (M.Y. Sklarz et al, 2009), plant species and their combinations (Brisson and Chazaren, 2009), climate, medium type, and plant management, such as harvesting regime. In the present study the system using Typha and Canna has been developed for treatment of color from pulp and paper mill wastewater along with BOD, COD and total solids. A treatment system was designed to optimize environmental conditions and retention time as well as to enhance fungal decomposition of complex organics. Since fungal population require an attachment substrate, a vegetated sand or gravel media was likely to simulate natural soil conditions and provide the aerobic environment and hydraulic conductivity needed to enhance fungal growth.

2. Material and methods

2.1. Pulp and paper mill wastewater characteristics

Pulp and paper mill effluent which was used in this study was collected from the overflow of the primary clarifier of wastewater treatment plant. The results are shown in Table 1. After collection the effluent was provided partial aerobic treatment also. The treatment potential of Typha and Canna was carried out on these two types of effluents namely (i) E1-primary clarifier overflow and (ii) E2-Effluent after partial aerobic treatment of Primary Clarifier overflow.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Primary Clarifier Overflow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Solids, mg l⁻¹</td>
<td>1170-1225</td>
</tr>
<tr>
<td>Chemical Oxygen Demand, mg l⁻¹</td>
<td>925-950</td>
</tr>
<tr>
<td>BOD₅, mg l⁻¹</td>
<td>260-290</td>
</tr>
<tr>
<td>Color</td>
<td>1800-1830</td>
</tr>
</tbody>
</table>

2.2 Bucket design

The principal procedure was bucket reactor based experiments adopted from Zhu and Sikora, 1995 for removal of color, BOD₅, COD and total solids. The buckets were having average surface area of 0.905 m² with a full height of 0.41 m. Full capacity of bucket was 35 liters and the total working volume was observed as 24 liters. The surface water level stood at the outlet level, an internal height of 0.33m from the bottom of the bucket. The actual view of working bucket with a media filtration unit is shown in Figure 1.
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Two hydraulic retention times of 3.5 and 6.5 days (HRT-3.5 and HRT-6.5) were selected on the basis of reported typical constructed wetland retention time (Vymazal et al, 1998 and Kao et al, 2006). Each macrophyte was planted in two buckets for each set of hydraulic retention time.

Table 2: Bucket experiment layout

<table>
<thead>
<tr>
<th>Concentrations</th>
<th>Macrophytes</th>
<th>HRT-3.5</th>
<th>HRT-6.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>Typha</td>
<td>B1</td>
<td>B2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B5</td>
<td>B6</td>
</tr>
<tr>
<td></td>
<td>Canna</td>
<td>B3</td>
<td>B4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B7</td>
<td>B8</td>
</tr>
<tr>
<td>E2</td>
<td>Typha</td>
<td>B9</td>
<td>B10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B13</td>
<td>B14</td>
</tr>
<tr>
<td></td>
<td>Canna</td>
<td>B11</td>
<td>B12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B15</td>
<td>B16</td>
</tr>
</tbody>
</table>

2.3. Cultivated-plant species

*Typha augustifolia* that showed the highest removal efficiency with wastewater in SFCW (Thut and Hammer et al, 1993; Sohsalam et al, 2007) and *Canna indica* which is a commonly found macrophyte, were selected to use in this study. For plantation in buckets young shoots were separated from the main rhizome leaving only a supportive rhizome and root portion to help the shoots start growing. Two shoots were planted directly into the buckets, with approximately 900gm of compost soil to provide them with some initial nutrients (Zhu and Sikora, 1995).

2.4. Bucket operation

The buckets were operated as semi continuous batch reactors. Initially buckets were filled with water for four weeks after planting and then wastewater was supplied. Consequent addition of wastewater after start-up time of each experiment was done every day over the respective hydraulic retention times. The volume of the wastewater fed into the bucket was, therefore, based on the total working volume was measured at the outlet level distributed over the hydraulic retention times. This was done in one day batch of 24 litres/day for hydraulic retention times of 3.5 days and 6.5 days respectively. Before any feed was done, correction...
for evapo-transpiration was done by topping up the water level to the overflow mark and the volumes of wastewater required measured.

2.5. Monitoring of macrophyte treatment efficiency

The bucket influent and effluent samples were collected and analyzed to determine the removal rates of total solids, COD, BOD$_5$ and color. Monitoring was carried out for 60 days. Total solids were analyzed using the standard methods on total solids residues, drying at 103-105°C for 1 hr. Samples for COD analysis were collected in 100mL plastic bottles and preserved on site by 1mL of concentrated sulphuric acid and analyzed within 48 hours by closed reflux titrimetric method. BOD$_5$ was also carried out within 24 hours using Wrinkler method. Color samples were preserved in 100 mL plastic bottles by adjusting the pH to between 1.5 and 2.0 with analytical grade HNO$_3$ and then analyzed by spectrophotometric method (APHA, 1989).

3. Results and discussion

3.1. Performance of treatment system

The characteristics of the wastewater used in this study are given in table 1. The quality of effluent was examined after providing the treatment through Typha and Canna at both retention times. To collect the adequate data study was carried out during summer and winter. For the summer season, the study was carried out in April, May, June and for winters it was done in the months of December, January and February. The findings are presented in table 3, 4, 5 and 6.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Inlet Concentration</th>
<th>HRT (3.5 days)</th>
<th>HRT (6.5 days)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>During summer</td>
<td>During Winter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>During summer</td>
<td>During Winter</td>
</tr>
<tr>
<td>Color</td>
<td>1820±10</td>
<td>91</td>
<td>86</td>
</tr>
<tr>
<td>TS (mg L$^{-1}$)</td>
<td>1195±22</td>
<td>85</td>
<td>85</td>
</tr>
<tr>
<td>BOD$_5$ (mg L$^{-1}$)</td>
<td>275±15</td>
<td>60</td>
<td>53</td>
</tr>
<tr>
<td>COD (mg L$^{-1}$)</td>
<td>940±15</td>
<td>84</td>
<td>76</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Inlet Concentration</th>
<th>HRT (3.5 days)</th>
<th>HRT (6.5 days)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>During summer</td>
<td>During Winter</td>
</tr>
<tr>
<td></td>
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<td>83</td>
<td>79</td>
</tr>
<tr>
<td>TS (mg L$^{-1}$)</td>
<td>1195±22</td>
<td>78</td>
<td>77</td>
</tr>
<tr>
<td>BOD$_5$ (mg L$^{-1}$)</td>
<td>275±15</td>
<td>49</td>
<td>43</td>
</tr>
<tr>
<td>COD (mg L$^{-1}$)</td>
<td>940±15</td>
<td>74</td>
<td>68</td>
</tr>
</tbody>
</table>
Table 5: Color, TS, BOD\textsubscript{5} and COD removals (in %) during the bucket operation using Typha at different HRT for E2 type of effluent

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Inlet Concentration</th>
<th>HRT (3.5 days)</th>
<th>HRT (6.5 days)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>During summer</td>
<td>During Winter</td>
</tr>
<tr>
<td>Color</td>
<td>1690±10</td>
<td>92</td>
<td>89</td>
</tr>
<tr>
<td>TS (mg L\textsuperscript{-1})</td>
<td>830±20</td>
<td>87</td>
<td>84</td>
</tr>
<tr>
<td>BOD\textsubscript{5} (mg L\textsuperscript{-1})</td>
<td>140±10</td>
<td>63</td>
<td>60</td>
</tr>
<tr>
<td>COD (mg L\textsuperscript{-1})</td>
<td>580±15</td>
<td>82</td>
<td>75</td>
</tr>
</tbody>
</table>

Table 6: Color, TS, BOD\textsubscript{5} and COD removals (in %) during the bucket operation using Canna at different HRT for E2 type of effluent

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Inlet Concentration</th>
<th>HRT (3.5 days)</th>
<th>HRT (6.5 days)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>During summer</td>
<td>During Winter</td>
</tr>
<tr>
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<td>60</td>
</tr>
<tr>
<td>COD (mg L\textsuperscript{-1})</td>
<td>580±15</td>
<td>78</td>
<td>73</td>
</tr>
</tbody>
</table>

3.2. Effect of HRT and seasonal variations

The results obtained from the bucket experiments (Figure 2, 3, 4 & 5) shows that there is slight increase in the removal efficiency with increase in HRT from 3.5 days to 6.5 days HRT. At high retention time the significant removal could not be achieved, possibly due to the fact that at higher HRTs there was less nutrient supply per day to the microbial growth (Ngirigacha, 2000). Also the results show that removal efficiency of BOD\textsubscript{5}, COD and Color significantly improved during summers instead of winters. Somewhere in case of TS no significance differences between percentages of removal were obtained during the study. This could be in agreement with the fact that the removal of this parameter was mainly due to the physical processes (sedimentation and filtration) rather than biological process (Solano et al., 2004)

![Figure 2: Graphical representation of Color, TS, BOD\textsubscript{5} and COD removal at different HRT's using Typha for E1 type of effluent](image-url)
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Figure 3: Graphical representation of Color, TS, BOD₅ and COD removal at different HRT’s using Canna for E1 type of effluent

Figure 4: Graphical representation of Color, TS, BOD₅ and COD removal at different HRT’s using Typha for E2 type of effluent

Figure 5: Graphical representation of Color, TS, BOD₅ and COD removal at different HRT’s using Canna for E2 type of effluent
3.3. Efficacy of Typha and Canna

Data obtained from the bucket experiments to compare the treatment efficacy of Typha and Canna is shows that *Typha angustifolia* has good potential for removing color, COD, and Total solids except in case of BOD$_5$. Both Typha and Canna has shown almost uniform potential for BOD$_5$ removal in case of E2 type of effluent during summer and winter. This uniformity has also observed in case of color removal for E2 concentrations during summer. Overall it has been observed that *Typha angustifolia* is having high treatment potential then *Canna indica*.

3.4. Effect of aerobic treatment

The removal efficiency for TS, Color and COD after aerobic treatment at both HRT’s in both the seasons increases in case of Canna, while in case of Typha there is no significant change in removal efficiency after aerobic treatment. But both macrophytes show significant rise in BOD$_5$ removal efficiency at both HRT’s during summer as well as in winters. It can be seen from the efficacy studies of Typha and Canna (Table 3,4,5 & 6) that Typha plays dominant role in the treatment; hence there is no impact of aerobic treatment on the performance of wetland except for BOD$_5$ removal. Increase in BOD$_5$ removal efficiency may be attributed to the fact that biofilms degrade the pre degraded organic matter (aerobically treated wastewater) at faster rate (Brix, 1987; Solano et al., 2004).

4. Conclusions

The bucket reactor system proved to be quite effective in reducing BOD$_5$, COD, Color and TS from the pulp and paper mill wastewater. This emphasis the relative importance of physiochemical and microbial process within the gravel matrix. A significant association was found between the removal of contaminants and HRT, the significant percentage removal was found in 3.5 days HRT. The removal efficiency was higher during summers and lesser during winters, although the removal percentages have never been below 40%. Typha showed high treatment efficiency than Canna except in case of aerobically treated effluent, no significant difference was observed between Typha and Canna performance with regards to the BOD$_5$ and Color removal. The aerobic treatment provided to the effluent prior to bucket experiments showed that COD, Color and TS removal efficiency improved in case of Canna while no significant change was observed in case of Typha. But both macrophytes showed significant change in case of BOD$_5$ removal after aerobic treatment. Biomass productions derived from this study could be utilized as fuel in domestic boilers for heating some of the public buildings of small villages.

Acknowledgement

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5. References

1. APHA (1989), Standard methods for the examination of water and wastewater, American Public Health Association, Washington, DC.


