Purification of pulp and paper mill effluent through *Typha* and *Canna* using constructed wetlands technology

Neetu Rani, R. C. Maheshwari, Vivek Kumar and V. K. Vijay

**ABSTRACT**

The use of constructed wetlands (CW) to treat domestic as well as industrial wastewater is rapidly emerging as a viable alternative in India. Constructed wetland systems offer several potential advantages as a wastewater treatment process. These advantages include simple operation and maintenance and lower construction and operating costs. The study evaluated the effectiveness of the subsurface flow constructed wetland for pulp and paper mill wastewater treatment and also the effectiveness of plant species. A pilot scale study was conducted to examine the feasibility of a CW system for treatment of pulp and paper mill wastewater during summers as well as winters at different hydraulic retention time (HRT) such as 1.5 days, 3.5 days and 6.5 days. Wetland beds were prepared with easily available plants such as *Typha angustifolia* and *Canna indica*. Specific performance objectives were to decrease biochemical oxygen demand (BOD), chemical oxygen demand (COD), total solids (TS) and color. Comparison of mean inlet and outlet concentrations showed that the CW system could effectively reduce the output of TS (87.6 ± 1.1%), COD (86.6 ± 2.0%), BOD₅ (80.01 ± 0.1%), color (89.4 ± 0.6%) during summer and TS (72.15 ± 0.71%), COD (70.94 ± 2.3%), BOD₅ (72.07 ± 2.2%) and color (74.90 ± 0.47%) during winter at 3.5 days HRT.

**Key words** | BOD₅, *Canna*, COD, color, constructed wetland, *Typha*

**INTRODUCTION**

The rapid increase in population and increased demand for industrial establishments to meet human requirements have created problems such as over exploitation of available resources, leading to pollution of the land, air and water environments. For many years our industries have been polluting the environment indiscriminately as very few industrial units have adopted proper pollution abatement and treatment strategy. The pulp and paper industry is no exception to this (Viraraghavan & Pokhrel 2004). The heavy demand for paper aids the steady expansion of paper industries. In 1951 there were 17 paper mills in India, producing 0.13 million tons paper per annum, today the number has risen to 600, the equivalent to an installed capacity of over 7.5 million tons (CPCB Manual 2007).

Looking into the serious nature of pollution, untreated wastewater from pulp and paper industries discharged into water bodies causes considerable damage to water quality. Two hundred and fifty chemicals have been identified in effluents, which are produced at different stages of papermaking, thereby turning the pulp and paper industry wastewater into a Pandora’s box of waste chemicals (Sreekrishnan & Ali 2001; Thakur & Singh 2006).

Treatment of wastewater from pulp and paper industry is accomplished by few physical, chemical and biological processes but high performance efficiency can not be achieved during these processes. Therefore, the effluent treatment is also supported by natural components such as microorganisms, but this occurs with a complex array of energy intensive mechanical equipments. The use of plants in a natural system as a source of wastewater purification is of increasing interest worldwide. These natural
systems are aquatic or pond/lagoon systems, terrestrial or land application systems and wetland systems. Among all these systems wetlands system have become appropriate alternatives in both developed and developing countries due to the simplicity of design and low cost of installation, operation and maintenance (Peck & Daley 1994; Reed 1995).

It has been maintained that not only natural but also properly designed and constructed manmade wetland ecosystems are extremely efficient at utilizing and cleaning such nutrient-rich waters. Thus the ability of wetland to transform and store organic matter and nutrients has resulted in wetlands, often described as the ‘kidneys of the landscape’ (Vigneswaran & Sundaravadivel 2001).

Constructed wetlands (CWs), also known as treatment wetlands or artificial wetlands, are complex, integrated systems in which water, plants, animals and microorganisms, along with the sun, soil and air, interact to improve water quality. These systems are prototypes of natural wetlands designed to mimic the waste removal conditions of natural wetlands (Kadlec & Knight 1996). They are already widely used for the treatment of domestic wastewater, storm water runoff, acid mine drainage, landfill leachates and industrial wastewater in developing countries, though at a slow pace (Denny 1997).

CWs are easy to manage with respect to hydraulic and hydrological control and are least effected by extreme pollution load fluctuations (Khroda 1992). Constructed wetlands are also flexible and can be conveniently sited near problem locations and their performance can be easily monitored (Wolverton 1987).

### MATERIALS AND METHODS

#### Characterization of pulp and paper mill wastewater

The initial task of this research was to carry out an assessment of pulp and paper mill wastewater quality. Samples of wastewater from a primary clarifier outlet of an effluent treatment plant were taken daily for characterization. Results of the analysis are shown in Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Primary clarifier (value)</th>
</tr>
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<tbody>
<tr>
<td>pH</td>
<td>7.5–8.5</td>
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<tr>
<td>Total solids, mg/L</td>
<td>750–1,700</td>
</tr>
<tr>
<td>Chemical oxygen demand, mg/L</td>
<td>700–1,200</td>
</tr>
<tr>
<td>Biochemical oxygen demand, mg/L</td>
<td>180–400</td>
</tr>
<tr>
<td>Color</td>
<td>1,560–2,100</td>
</tr>
</tbody>
</table>

#### Experiment set-up

**Materials**

Materials used included plastic drums, plastic and iron feed pipe, 300 l capacity tanks, iron stands, polythene sheet etc. Coarse sand was used for the plants seedling in wetland pits.

**Design and construction of wetland beds**

Construction of wetland beds is generally carried out on the basis of BOD loading rate, effluent flow rate and residence time etc (Kadlec & Knight 1996; Price & Probert 1997). Subsurface flow, horizontal type wetland beds of dimensions, 1.5 m × 3.5 m × 0.3 m were constructed and lined with polythene sheet to avoid ground water seepage. Near the wastewater inflow and outflow of the beds a layer of gravel was added in order to facilitate the distribution of the effluent. Feeding of wastewater to the wetland beds was carried out through a perforated polyvinylchloride (PVC) rigid pipe with manual flow control using a flow valve.

Wetland beds were planted with two different plant species, *Typha angustifolia* and *Canna indica*, and filled with a substrate composed of coarse sand. The plants were harvested above the ground by hand in October of each year. The plan view of the wetland bed is shown in Figure 1 and the actual view of working wetland beds with a media filtration unit is shown in Figure 2.

#### Wetland bed operation and wastewater characterization

To begin the study the beds were filled with water for 2 weeks and then wastewater was supplied. The wastewater was procured daily from a typical paper industry and supplied continuously to the wetland beds. The system was...
operated continuously for two years under different HRTs; 1.5, 3.5 and 6.5 days (Kao et al. 2006). No monitoring for the wetland bed efficiency was carried out in the first two months, and then the bed was monitored for different HRTs. The loss of water due to evapo-transpiration was also calculated by measuring the water collection at outlet.

Samples from the inlet and outlet of bed were collected to analyze pH, BOD$_5$, COD, TS and color. Samples for COD analysis were collected in 100 mL plastic bottles and preserved on site by adding 1 mL of concentrated sulfuric acid and analyzed within 48 h upon arrival at the laboratory by the standard closed reflux, titrimetric method. BOD$_5$ samples were collected in 100 mL plastic bottles and immediately delivered to the laboratory where they were stored under refrigeration awaiting analysis, which was carried out within 24 hours after sampling using the Winkler method (APHA 1998). BOD analysis was carried out on unfiltered samples. 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 using a spectrophotometric method.

Physical measurements such as pH were performed *in situ* by direct measurements using a pH meter. Total solids were analyzed using the standard methods on total solids residues, drying at 103–105 °C for 1 h.

**RESULTS AND DISCUSSION**

**Field experiment**

A field study on the treatment potential of CWs was carried out on an overflow of primary clarifier wastewater. At the beginning the retention time was 6.5 days, this was then decreased gradually and study was carried out for 3.5 days and then 1.5 days. To collect adequate data for seasonal variation the study was carried out continuously for two years. For the summer season, the study was carried out in April, May, and June and for winter it took place in the months of December, January and February. The results of the rainy season, i.e. July–September, were not reported. In these months frequent rainfall was observed and treated effluent had very low concentrations of pollutants due to the dilution effect. The results of sample parameters studied at various retention times mentioned above for both type of effluents, during summer and winter, are reported in Tables 2 and 3.

**TS**

The removal efficiency of total solids was found to be 83.5 ± 0.6% (min.) at 1.5 days and 88.25 ± 0.55% (max.) at 6.5 days HRT during summer, and for winter were 67.82 ± 0.86% (min.) at 1.5 days and 73.37 ± 0.87% (max.) at 6.5 days. Table 3 also shows that the highest removal efficiency was 87.6 ± 1.1% during summer and 72.15 ± 0.71% during winter and can be achieved at 3.5 days HRT which is quite close to the percentage removal achieved at 6.5 days HRT.

**COD**

The COD removal was found to increase from 80.05 ± 0.05% (min.) to 87.3 ± 1.3% (max.) during summer
and 65.02 ± 3.52% (min.) to 71.97 ± 2.16% (max.) during winter from 1.5 days HRT to 6.5 days HRT, respectively (Tables 2 and 3).

### BOD$_5$

Tables 2 and 3 show that the percentage removal of BOD increased from 72.8 ± 0.8% (1.5 days) to 85 ± 1% (6.5 days) during the summer and 65.26 ± 0.92% (1.5 days) to 73.39 ± 0.94% (6.5 days) during winter.

### Color

The percentage reduction in the case of color increased from 84.95 ± 0.15% (min.) to 92.5 ± 0.5% (max.) during the summer and 69.0 ± 0.71% (min.) to 75.99 ± 0.35% (max.) during the winter, while increasing the retention time from 1.5 days to 6.5 days.

### Effect of HRT

The effect of HRT on the removal efficiency for field experiments is shown in Figures 3 and 4. The results obtained for the removal of TS, COD, BOD and color shows that there is an increase in the removal efficiency with an increase in HRT. The increase in removal efficiency is higher for a lower range of retention time, i.e. from 1.5 days to 3.5 days.
There is no significant rise in the removal efficiency after 3.5 days HRT. At very high retention times the significant improvement in removal efficiency could not be achieved, possibly due to the fact that at higher HRTs (that is low hydraulic loading) there was less nutrient supply per day to the microbial growth. On the other hand, low HRTs (higher hydraulic load) may lead to washouts of biofilms and/or a reduction in effective contact time of the organic wastewater components with the biofilms.

**Effect of seasonal variation**

Figure 5 shows that the TS, BOD, COD and color removal efficiency is relatively significant during summer rather than winter. During summer, higher evapo-transpiration rates reduce the outflow rates as compared to other seasons and second, wetlands function as land-intensive biological systems undergoing temperature-dependent biological activities and so perform better in summer (Song et al. 2005).

**DISCUSSION**

The study addressed the long term treatment behavior of subsurface flow CW. Results from the study demonstrated that the CW system could effectively reduce TS, COD, BOD₅ and color. Moreover, the total amount of TS, COD, BOD₅ and color removal occurring in the treatment beds is a function of input water quality, the residence time, water temperature, distribution of flow within the wetland bed, the capacity of plants to remove the parameters and the depth to which that removal occurs (Tettleton et al. 1993; Thut 1993; Song et al. 2005).

High TS in raw wastewater were not unexpected from a pulp and paper mill due to residues and fibrous materials and particulate matter from tree bark remains. The present removal of TS could be a result of filtration and microbial activities. The BOD₅ and COD removal efficiency of wetland was also high, probably because the treatment of wetlands functions as a land-intensive biological system. The two features of the CW considered are:

1. Wetlands are ecosystems that occur where water conditions are intermediate between uplands and deep-water aquatic systems (Knight et al. 1999). The mechanism of purification is complicated (House 1999), including physico-chemistry such as substrate adsorption, substrate filtration, pollutant sediment, ion exchange and biochemistry such as plant sorption and microbiological oxidation (Brix 1994).

2. Wetlands are autotrophic ecosystems. The nutrient sources are abundant (Batchelor & Loots 1997). During the operation, plants and microorganisms survive on the nutrients in the wastewater. In contrast, their metabolites provide the important N and P sources for microorganisms. These mechanisms play an important role in COD and BOD₅ removal (Ji et al. 2002). The oscillating performance of color removal is also the mechanism of microbial degradation (Hammer et al. 1993).

The seasonal influences presented in the wetland beds shows that reduction varies from 10 to 15% during summer as compared to winter. Such reductions in efficiencies were expected. First, the differences of parameters inlet concentrations and inflow loads among the season may be partly attributable to discharge differences. Second, during the summer, high evaporation rates reduce the outflow rates. Overall, it is observed that the constructed wetlands can be used to treat the pulp and paper mill wastewater to an acceptable level. It could be a viable alternative for reducing various pollution parameters, i.e. BOD, COD, TS and color, from wastewater.

**CONCLUSION**

The aim of this study was to investigate the application of selected plant species in CWs receiving pulp and paper
mill wastewater at different hydraulic retention times, as well as to study seasonal variations. It is concluded that the CW can be used to degrade the quality of pulp and paper mill wastewater to an acceptable level.

1. Subsurface flow CW appears to be a viable alternative for reducing the TS, BOD, COD and color from pulp and paper mill wastewater treatment, and it is able to tolerate little fluctuations, including interruptions in the feed.

2. The plants species *Typha angustifolia* and *Canna indica* were found to be well adapted to pulp and paper mill wastewater in terms of survival and propagation.

3. HRT of 3.5 days was the ideal operating hydraulic condition observed for the CW system, accompanied with appropriate quality loading patterns.

4. Removal efficiency for all pollutants was improved with higher temperatures. Therefore, the results obtained showed the maximum removal efficiencies during the summer as compared to winter.

5. Flow rate can be increased in summer to maintain 3.5 days HRT so as to allow for effluent treatment.

**REFERENCES**


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