Performance of Combined Vertical and Horizontal Flow Sub-Surface Constructed Wetlands

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Abstract - The present study demonstrates wetland projects to treat industrial wastewater for reuse implemented for different hydraulic & organic loadings. The combination of vertical and horizontal flow wetland treatment system with fill and draw controls provides a design for effective contact of wastewater with the root system to achieve higher treatment efficiencies by creating necessary environments for nitrification-denitrification removal of organic materials, and phosphorus adsorption reactions. Systems have been implemented for large scale applications in automobile, sand reclamation, municipal leachate and other industries for process and domestic wastewater treatment & reuse. The results show that there is a marked removal efficiency using Typha species & several other indigenous plants. The percentage reductions in various physicochemical parameters such as Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), Nitrate (N), Phosphate (P), and Fecal Coliforms (FC) are 85%, 90%, 70%, 60% and 95% respectively. The study further reveals the effect of variable hydraulic loading rates on treatment efficiencies. The system has been successfully adopted for the past 3 years reducing electrical, mechanical operations and maintenance requirements for wastewater treatment by almost 70% benefiting industries to a great extent and exploring opportunities for application in other industrial sectors for implementation of such technologies which were not in practice earlier.

Keywords: Denitrification; nitrification, phosphorus; physicochemical; Typha spp.; wetland treatment system.

I. INTRODUCTION

On-site wastewater treatment design has evolved into a sophisticated technology with numerous advances, but its adverse impacts on ground and surface waters as non-point sources of nitrogen, phosphorus and pathogenic bacteria and virus continue (House et al., 1999). Industrial wastewater, sewage or municipal treatment plant typically consists of mechanical systems that can have high construction, energy, and labor costs. More advanced mechanical treatment systems require higher operator grades. One of the major concerns for communities & industries that operate such systems is the annual energy and labor cost. These costs form a significant portion of the total budgets for industries & small communities (Sauer and Kimber, 2001). Treatment systems that may require more land but have lower energy and labor costs are more attractive economically to small communities.

Of many alternatives for wastewater treatment, wetland technology is an attractive option as a land-based wastewater treatment systems, it consists of shallow ponds, beds, or trenches that contain floating or emergent-rooted wetland vegetation. Treatment in wetlands is accomplished by a complex combination of physical, chemical and biological mechanisms and relies on vegetation, water depth, substrates and microbial populations according to (Pullin,
1989; Bastian and Hammer, 1993; Kadlec and Knight, 1996; U.S. EPA, 1999). Wetland technology differs from natural wetlands as in the former; operators have greater control over natural processes in the constructed wetland treatment system because flows are more stable, whereas natural wetlands are subject to the variability of precipitation.

The use of treatment wetlands is well established in Europe, where the technology originated with laboratory work in Germany 30 years ago (Aslam et al., 2004). Subsurface flow systems are the norm because they provide more intensive treatment in a smaller space than marsh type wetlands, an important design constraint in countries where open space is limited. Denmark alone has 150 systems, most in small villages handling domestic wastewater (Cole, 1998). However, the application of wetlands for industrial process wastewater has been limited especially in India. Wetland treatment system, like any other biological wastewater treatment process, will exhibit variability in the level of contaminant removal (Crites and Techohanoglous, 1998). For example, Bastian and Hammer (1993) compiled pollutant removal results for a number of North American constructed wetland systems and reported a wide range of efficiencies for organic (50-90%), suspended solids (40-94%), nitrogen (30-98%) and phosphorus (20-90%) contaminant removal. Research efforts in the U.S. were developing in the 1970’s and 1980’s. This paper presents the study carried out on a pilot subsurface system meant for a single household with features leading to better performance.

II. METHOD AND MATERIALS

Vertical cells in combination with horizontal flow type wetland were designed and constructed. The cell was about 15m long, 5m wide and 1.7m deep for automobile industry whereas that for sand reclamation was about 10m long, 3m wide and 1.7m deep. Industrial wastewater was used for the experiment after removal of grits and floating matter augmented with primary treatment facility including neutralization & chemical reaction for removal of suspended solids using acid, ferrous alum, and polyelectrolyte. Figure 1 depicts a schematic of the pilot constructed wetland. The secondary process of the conventional biological system was replaced by wetland and species such as Typha, Cyperus, Canna, Scirpus species were selected for plantation of the cell in the present study since a great deal of research has been already done on the utilization of these species in wastewater treatment through wetlands (Juwarkar et al., 1995). Plants were sourced locally from natural wetlands in and around Mumbai and Pune, and were acclimatized in the laboratory for a period of 3 months by subjecting them to cytokinin & auxin and then subsequently to increasing strength of wastewater before planting them in the cell.

The cells were stabilized initially with fresh water. The cells were operated with different hydraulic loading rate and hydraulic retention time to evaluate the effect of these on treatment efficiency. The cells were loaded with 150 m3/day for automobile process wastewater and 10 m3/m2/day sand reclamation (graphite/binder - metal based) process wastewater having a detention time of 0.5 days and 2.5 days respectively, depending upon the type & characteristics of wastewater from the industries. The cells are being continuously run for a period of three years now. The samples of inlet and outlet were monitored every fortnightly for parameters viz., TSS, BOD, TKN (Total Kjeldahl Nitrogen), P, and COD. All parameters were analyzed as per as Standard Methods (APHA-AWWA-WPCF, 1989).

III. RESULTS AND DISCUSSION

The results of analysis of the influent and effluent characteristics as well as the efficiency of the wetland process for treatment of wastewater for different hydraulic loadings is represented in Table 1 and Table 2.
Most of the suspended solids are removed through chemical reaction and sedimentation in primary treatment whereas polishing treatment is achieved in the wetland cell where vegetation acts as another source of contaminant removal. Thus the overall TSS, BOD & COD removal is found to be about 95.7% for 0.5 d HRT & 99.3% for 2.5 d HRT respectively, and are represented in Figures 2 and 3.

Table 1: Inlet and Outlet Characteristics at 150 m3/d Hydraulic Loading Rate

| Treatment         | TSS (mg L⁻¹) | BOD (mg L⁻¹) | TKN (mg L⁻¹) | P (mg L⁻¹) | COD (mg L⁻¹) |
|-------------------|--------------|--------------|--------------|------------|--------------|
| Influent          | 700          | 1000         | 35           | 4.2        | 1600         |
| Primary Treatment | 180          | 640          | 22           | 2.9        | 780          |
| Wetland Treatment | 30           | 41           | 13           | 1.7        | 80           |

Values are average of 60 samples

Table 2: Inlet and Outlet Characteristics at 10 m3/d Hydraulic Loading Rate

| Treatment         | TSS (mg L⁻¹) | BOD (mg L⁻¹) | TKN (mg L⁻¹) | P (mg L⁻¹) | COD (mg L⁻¹) |
|-------------------|--------------|--------------|--------------|------------|--------------|
| Influent          | 2400         | 450          | 42           | 3.8        | 7800         |
| Primary Treatment | 430          | 220          | 23           | 2.1        | 670          |
| Wetland Treatment | 34           | 28           | 11           | 1.4        | 74           |

Values are average of 32 samples

Most of the suspended solids are removed through chemical reaction and sedimentation in primary treatment whereas polishing treatment is achieved in the wetland cell where vegetation acts as another source of contaminant removal. Thus the overall TSS, BOD & COD removal is found to be about 95.7% for 0.5 d HRT & 99.3% for 2.5 d HRT respectively, and are represented in Figures 2 and 3.

Removal of organics in the form of BOD was to the extent of 95.9% and 93.8 and with retention of 0.5 and 2.5 days respectively. The BOD removal rates achieved are in line with that reported by Brix (1987). The soluble organic material is aerobically degraded by bacterial biofilm that is attached to the plants. In the treatment cell, plants supply oxygen to the treatment floor through their roots, thereby promoting aerobic digestion of organic material. Some anaerobic degradation of organic material also occurs in the bottom sediments. Biofilms are formed by bacteria and microorganisms, which attach themselves to the plant roots and the media filled in the treatment zone to form a biological filter from the water surface to the treatment floor. As wastewater passes through the thick growth of plants, it is exposed to this living biofilm, which provides a treatment process similar to that found in conventional treatment plants.

Treatment zone promotes the process of nitrification/denitrification which removes nitrogen from wastewater. In simple terms, bacteria in the wastewater (Nitrosomonas) oxidize ammonia to nitrite in an aerobic reaction. The nitrite is then oxidized aerobically by another bacteria (Nitrobacter) forming nitrate. Denitrification occurs as nitrate is reduced to gaseous forms under anaerobic conditions in the litter layer of the treatment substrate. The
denitrifying bacteria (*Pseudomonas* spp.) and other bacteria catalyze this reaction. Plants also play an important role in nitrogen removal by providing biofilm attachment points and by supplying oxygen for nitrification in the root structures.

The total N removal was found to be 37.1 and 45.2% in primary treatment whereas 62.9 and 73.8% after final wetland treatment for a retention period of 0.5 and 2.5 days respectively. Nitrogen removal was higher in the planted cell as also found by many researchers (Gersberge et al., 1986; Wathugala et al., 1987; McIntyre and Riha, 1991).

Phosphorous removal in wetlands is based mainly on the phosphorus cycle and can involve a number of processes such as adsorption, filtration, sedimentation, complexation/precipitation and assimilation/uptake. In case of the present study, phosphorus removal was found to be 31 and 59.5% in primary treatment, which is somewhat similar to that reported by Drizo et al. (1996) whereas it was found to be 44.7 and 63.2% after final wetland treatment for 0.5 and 2.5 days retention respectively. Phosphorous removal efficiency did not show a significant difference between primary & secondary compared to that of BOD and N.

COD removal has been observed to be in the range of 95% & 99.3% for 0.5 d HRT and 2.5d HRT respectively which is a promising feature of the wetland, especially when compared to the State Pollution Control Board standards of India, thus helping industries to comply with the norms.

As mentioned earlier, the HRT depends on upon the type and characteristics of effluents and the extent of treatment required. Though there is a huge difference in the loading rates and HRT of both the effluent treatment systems, the treatment efficiencies for criteria parameters such as TSS, BOD & COD are almost in the same range both for primary and wetland treatment. This is the most important factor of design to be considered for designing wetland treatment system. However, as far as removal of nutrients is concerned, HRT might play a more significant role as observed from the efficiency figures.

The stabilization time required for the planted and unplanted cells was also evaluated during the course of the study. The percentage removal of TSS, TKN, BOD and P has been plotted against time in weeks and are represented in Figures 4 through 7 for automobile wastewater and Figures 8 through 11 for sand reclamation wastewater.

As evident from figures, the stabilization period for an automobile to process wastewater was about 6 to 9 weeks, whereas that for sand reclamation process wastewater is about 4-6 weeks. However, it has been found that the stabilization period for individual parameter varies within the cell as well as between the two cells with and without plantation as shown in the following figures.
IV. CONCLUSION

The wetland technology of treating wastewater can be better utilized in a country like India where native species are easily available for the plantation and their efficacies are known. The process is very effective in removing most of the pollutants. The high-cost effectiveness of the system and ease of operation are the major points for large-scale implementation. Wastewater thus treated can be utilized for irrigation since the balanced nutrient removal rate gives it an opportunity to be used as a safe and efficient option for application as alternative fertilizer thus decreasing the demand of artificial manures and resulting in long-term economic benefits.

In the climate of Mumbai & Pune which is mainly dry & humid and the temperature normally ranges between 22-34oC, the efficiencies achieved are very good. The major drawback of this process is that the system cannot be started as soon as the bed is prepared because the plants require a sufficient acclimatization period of a minimum of 6 weeks. However, considering the overall benefits of the system and the cost effectiveness, especially related to the ease of operation & maintenance, this process proves the scope of extensive acceptability by the industrial sector.

Although this paper describes the combined vertical and horizontal flow sub-surface wetland technology in a restricted region, different methods for this technology and plants used can be evaluated according to respective geographical regions and native plant species.

ACKNOWLEDGEMENTS

We are grateful to Dr. S. Devotta, Director National Environment Engineering Research Institute (NEERI) for giving us an opportunity to carry out the work at the institute.

Declaration: All authors have disclosed no conflicts of interest.

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