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Evaluation of Vertical Flow Constructed Wetland for Treatment of Domestic Wastewater

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Abstract

A lab scale model of vertical flow constructed wetland (VFCW) was operated at varying hydraulic loading rates(HLRs) to find out the optimum HLR for treatment of domestic wastewater. The results from laboratory analysis indicated that the maximum removal efficiency for BOD, COD, P and TSS is achieved at a HLR of 0.18$m^3/m^2/d$. The removal efficiencies of VFCW with and without intermittent aeration were evaluated and results indicated that there was improvement in BOD and P removal efficiencies and lesser effect on COD and TSS removal efficiencies. Substrate alteration in VFCW by using cupola slag along with conventional materials like sand and gravel was also evaluated. There was significant increase in removal efficiencies for BOD, COD, P, TSS and the VFCW treated effluent met the disposal standards. Thus, Cupola slag can be regarded as a suitable filter media that can be used along with conventional filter materials like sand and gravel for the treatment of domestic wastewater.

Keywords: Vertical flow constructed wetland; Cupola Slag; Artificial aeration; Hydraulic loading rates; domestic wastewater; Removal efficiency; Canna Indica

1.Introduction

Pollution of surface water is an important problem in the recent times. The main reason behind this is that the pollutants are discharged directly into the surface water bodies without treatment or with ineffective treatment. Rapid industrial development and urbanization has led to expansion of towns and cities. However, environmental facilities like sewers and other treatment facilities are absent due to lack of proper town planning. Thus, the wastewater in these areas is directly discharged into the natural water bodies with partial treatment or with no treatment causing pollution of the water bodies.

In order to arrest these problems, either these areas need to be connected to the central sewer network or decentralized system for treatment of wastewater must be provided. Sometimes, it is not possible to connect these areas to the central facility due to topography and terrain characteristics. Therefore, decentralized treatment facilities gain importance in such situations which treat the wastewater and then discharge it into the environment, thus reducing the chances of environmental pollution due to disposal of untreated wastewater. Constructed wetland is one such low cost decentralized treatment facility. Constructed wetlands use the natural functions of plants, soil and organisms to treat the wastewater.

1.1 Types of constructed wetlands

Constructed wetlands can be divided into two main categories:

1. Subsurface flow constructed wetlands and
2. Free water surface constructed wetlands.

The former type consists of a basin with substrate materials in which large amounts of biofilms are formed for biodegradation of waste as well as for plant growth. In the latter case, aquatic plants are held in floatation in the basin were they develop a thick mat of roots upon which biofilms form.

1.2 Types of subsurface flow constructed wetlands

The subsurface flow constructed wetland is further divided into three types:

1. Horizontal flow constructed wetlands,
2. Vertical flow constructed wetlands and
3. Hybrid systems.

The vertical flow constructed wetland had the advantage of smaller area demands and thus lower construction cost. Some of the pollutant removal mechanisms of VFCW are:

Microbial activity in the biofilm, filtration, adsorption and sedimentation in the substrate materials, uptake of nutrients by plants which are used for their growth, direct exposure to UV radiation, etc.

1.3 Components of VFCW

The main components of VFCW are vegetation and substrate materials. Vegetation in VFCW mainly consists of locally available plants that also exist in the natural wetlands in those areas. The plant species used in VFCW should be viable to local climatic conditions and should have resistance from a variety of pollutants in waste water and should also be resistant against pest and insect attacks. The substrate materials in VFCW mainly consists of filter media like sand and gravels. The substrate materials used in VFCW should have high permeability to allow proper downward passage of wastewater and thus avoiding any clogging problems. The substrate media should also support the growth of the vegetation as well as provide attachment surface for various microorganisms involved in pollutant removal mechanisms.

1.4 Objectives of the research work

In this study, a lab scale model of vertical flow constructed wetland were constructed using Canna Indica as the plant species in the wetland. Following were the objectives of the project work:

1. To study the efficiency of Vertical Flow Constructed Wetland (VFCW) planted with Canna Indica for the treatment of domestic wastewater using conventional layers such as river sand, crushed sand, fine gravel and coarse gravel.

2. To study the effect of change in hydraulic loading rate (HLR) on the removal efficiency of VFCW.

3. To study the effect of artificial aeration on the removal efficiency of VFCW.

4. To study the efficiency of VFCW planted with Canna Indica using alternate media such as foundry cupola slag along with conventional media.

5. To find out the removal efficiency of VFCW for the parameters such Biochemical Oxygen Demand(BOD), Chemical Oxygen Demand(COD), Phosphorus (P), Total Suspended Solids(TSS) for above mentioned cases.

2. Materials and methodology

The experimental setup consists of the following parts:
Overhead tank, inlet distribution system, VFCW bed.

2.1 Experimental Setup:

Fig 1. Experimental Setup

i) Overhead tank: Wastewater collected from the nallah was stored in the overhead tank. The overhead tank was made of PVC container having a capacity of 50 litres. The overhead tank was placed at a height of one meter from the top of VFCW basin

ii) Inlet distribution channel: It was provided with perforations on pipes to achieve uniform distribution throughout the cross sectional area. PVC pipes having diameter 0.75 inch was used along with flow adjusting valve.

iii) VFCW basin: The VFCW basin consisted of two crates placed one above the other. The cross sectional area of the VFCW basin was: 0.5m x 0.33m (length x breadth)

The height of the VFCW basin was: 0.6 m

The VFCW basin was filled in layers with the conventional substrate materials like gravel and sand. The layers of VFCW from top to bottom were as follows were as follows:

river sand (particle size:0.18-4.75mm),

crushed sand (particle size:0.6-4.75mm),

fine gravel (particle size:10-20mm),

coarse gravel (particle size:20-40mm)

The depth of each of these layers is about 0.15m. Thus, all the substrate materials were placed in such a way that porosity of the bed goes on increasing from top to bottom. At the bottom of the VFCW basin, an outlet arrangement made up of PVC pipes was placed to remove the treated water outside.

The plant was chosen on the basis of requirement of plants, their role, desired properties like local availability, deep root penetration and high tolerance to pollutants. The plant species used was Canna Indica. The wetland plant species, Canna Indica, was selected due to its high tolerance to pore clogging, its large biomass, and high removal of N and P. Canna Indica brought from a local nursery was planted in the pilot scale VFCW model.

2.2 Experimental Procedure:

The experiment was carried out for a period of six months and the pilot scale VFCW unit was initially fed with fresh water for a period of two months. Raw domestic wastewater was collected from a nallah near Unique park, Kolhapur and was analyzed for various parameters like BOD, COD, TSS, P to find out the characteristics of the nallah waste water.

The raw domestic wastewater collected from the nallah was filled into the overhead tank on a daily basis. The wastewater was given a primary treatment for removal of suspended solids by allowing it to settle for a period of 2 hours. The VFCW was operated at varying hydraulic loading rates(HLRs) of 0.12, 0.18 and 0.24 $m^3/m^2/d$.

After setting the optimum HLR, the efficiency of VFCW was found out for artificial aeration conditions. Two air pumps having a total output of $0.3m^3/h$ were used to supply artificial aeration to the VFCW bed. Air flow was delivered for a total of 8 hours per day intermittently.

Also the efficiency of VFCW was checked with alternate substrate materials like foundry cupola slag used along with conventional media. A part of coarse and fine gravel was replaced with cupola slag. Cupola slag is by-product of cast iron manufacturing unit. It is produced during the separation of the molten steel from impurities in cupola furnaces. The slag occurs as a molten liquid melt which solidifies upon cooling. About 5-7% of waste is generated in cupola furnaces while production of cast iron. Due to that large amount of waste is generated which is presently going to land filling only, polluting environment. At present industrialists are paying for disposal of this waste.

However, this slag, which is a waste otherwise can be taken advantage of in domestic wastewater treatment.

The VFCW bed consisted of the following layers:

river sand (particle size:0.18-4.75mm),

crushed sand (particle size:0.6-4.75mm),

cupola slag (particle size:0.6- 4.75mm),

fine gravel (particle size:10-20mm),

coarse gravel (particle size:20-40mm)

The thickness of each of these layers was about 0.15m each for river sand, crushed sand and cupola slag and 0.075m each for fine gravel and coarse gravel.

3. Results and Discussion

3.1 Observation of plant growth:

Fig 2. Initial size of Canna Indica planted in the VFCW model

Fig 3. Grown Canna Indica in the VFCW model

1)When Canna Indica was planted in the VFCW bed, they were about 6 to 8 in numbers. In the month of April, these plants multiplied in numbers tremendously to about 35 numbers. Thus, they multiplied to about 5 times their original number

2)Originally when Canna Indica was planted their height was about 20 to 25 cm. After six months, they grew very tall to about 150cm i.e. 1.5m

3)Leaf size had also undergone remarkable changes. The leaves grew in a very healthy manner. Originally, the leaf size was as follows: length- 15 to 20cm. and width 7 to 8cm. After six months the leaf size was as follows: length- 40 to 50cm and width 18 to 20cm.

4)The plants were flowering abundantly. About 20 to 25 flowers at a time grew on the plants in the VFCW bed. This improved the aesthetic appearance of VFCW as well. The flowers were of varying colours like red, yellow, orange and yellow mix.

Fig 4. Flowering of Canna Indica in the VFCW model

5)When the plants were fed with tap water initially for two months, they survived in the media they were planted in. However, they did not show any significant growth.

When the plants were fed with domestic wastewater, the plants not only survived, but also grew at a very fast rate and in a healthy manner. They multiplied very rapidly as well. Thus, domestic wastewater proved to be very beneficial for the plant growth.

6) The figure below shows comparison between untreated raw domestic wastewater before treatment and VFCW treated domestic wastewater. The raw untreated domestic wastewater looks very turbid and brownish in colour. However, after the water is treated using VFCW, the water looks transparent and clear.

Fig 5. Comparison between VFCW treated and raw domestic wastewater

3.2 Results of laboratory analysis:

To find out the optimum HLR, wastewater was fed to the VFCW model at varying HLRs. Laboratory analysis was carried out for inlet and outlet samples of the VFCW model.

Table 1. Average removal efficiencies for BOD and COD at varying HLRs

HLR ($m^3/m^2/d$)	BOD Inlet (mg/L)	BOD Outlet (mg/L)	R.E. (%)	COD Inlet (mg/L)	COD Outlet (mg/L)	R.E. (%)
0.12	164.12	41.76	74.69	378.87	73.62	80.70
0.18	196.11	36.89	80.97	446.5	60.37	86.32
0.24	199.75	45	77.29	390.87	68.5	82.28

Table 2. Average removal efficiencies for P and TSS at varying HLRs

HLR ($m^3/m^2/d$)	P Inlet (mg/L)	P Outlet (mg/L)	R.E. (%)	TSS Inlet s(mg/L)	TSS Outlet (mg/L)	R.E. (%)
0.12	10.53	5.24	50.58	262.5	75	71.47
0.18	11.93	5.04	58.03	262.5	65	75.56
0.24	12.68	5.65	54.58	272.5	72.5	73.54

The results from laboratory analysis indicated that the maximum removal efficiency for BOD, COD, P and TSS is achieved at a HLR of $0.18m^3/m^2/d$. Thus, HLR of $0.18m^3/m^2/d$ which was found to be optimum HLR was maintained for further experimentation.

Table 3. Average removal efficiencies for BOD and COD for intermittent aeration condition (HLR=0.18 $m^3/m^2/d$)

BOD Inlet (mg/L)	BOD Outlet (mg/L)	R.E.(%)	COD Inlet (mg/L)	COD Outlet (mg/L)	R.E. (%)
186.56	20.97	88.66	403.25	47.12	88.48

Table 4. Average removal efficiencies for P and TSS for intermittent aeration condition (HLR=0.18 $m^3/m^2/d$)

P Inlet (mg/L)	P Outlet (mg/L)	R.E.(%)	TSS Inlet (mg/L)	TSS Outlet (mg/L)	R.E. (%)
10.24	3.50	65.47	270	62.5	77.01

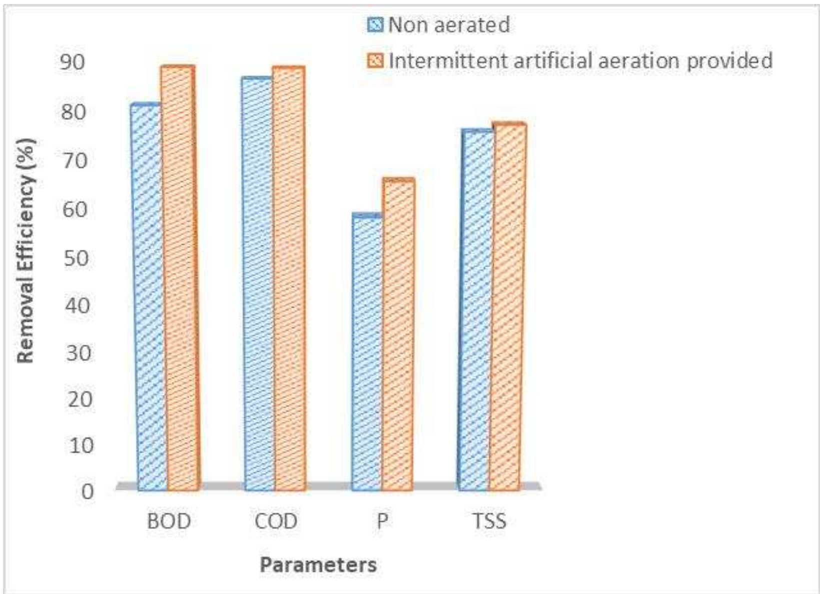

Chart 1.Comparison of removal efficiency for non-aerated and intermittently aerated VFCW at HLR of 0.18 $m^3/m^2/d$

Table 5. Average removal efficiencies for BOD and COD after substrate alteration (HLR=0.18 $m^3/m^2/d$)

BOD Inlet (mg/L)	BOD Outlet (mg/L)	R.E.(%)	COD Inlet (mg/L)	COD Outlet (mg/L)	R.E. (%)
184	13.82	92.54	419	30.47	92.81

Table 6. Average removal efficiencies for P and TSS after substrate alteration (HLR=0.18 m3/m2/d)

P Inlet (mg/L)	P Outlet (mg/L)	R.E.(%)	TSS Inlet (mg/L)	TSS Outlet (mg/L)	R.E. (%)
16.87	3.70	77.83	265	45	83.33

Substrate alteration of the VFCW bed using cupola furnace slag along with conventional substrate materials significantly increased the treatment efficiency of VFCW for domestic wastewater. About 92% removal efficiency for both BOD and COD could be achieved. Also the removal efficiency of phosphorus reached 77% and for TSS removal efficiency about 83% was achieved. Thus, Cupola slag which is a waste material produced from the foundries proved to be a very useful and efficient material in domestic wastewater treatment

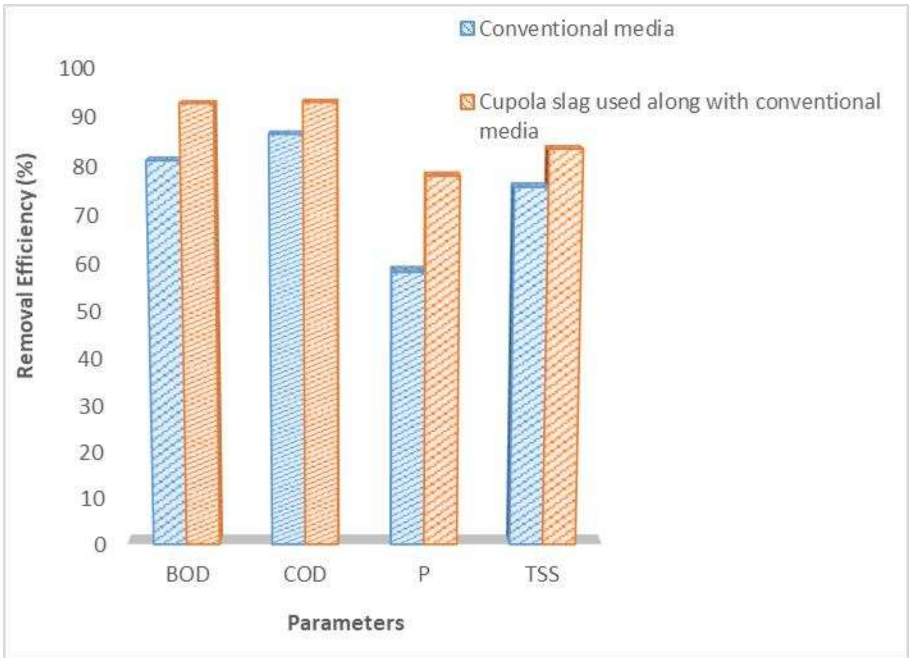

Chart 2. Comparison of removal efficiency for conventional substrate materials and substrate alteration using Cupola slag at HLR of 0.18 $m^3/m^2/d$

4. Conclusion

1. VFCW planted with Canna Indica and consisting of conventional filter media like sand and gravel can be used as a sustainable technology for the treatment of domestic wastewater.
2. The tropical plant species Canna Indica which is a native plant grew well in the VFCW bed fed with domestic sewage and proved to be very efficient in wastewater treatment. It also enhances the aesthetic appearance of wastewater treatment systems in tropical climates.
3. HLR is an important parameter that affects the treatment efficiency of VFCW for domestic wastewater.
   0.18 $m^3/m^2/d$ was found to be optimum HLR which gave the maximum pollutant removal efficiency.
4. Artificial aeration could increase the treatment efficiency for VFCW. About 8% increase in removal efficiency for BOD and P removal and 2% increase in removal efficiency for COD and TSS
5. Substrate alteration increased the treatment efficiency of wetland remarkably i.e. about
   12% increase in removal efficiency for BOD;
   7% increase in removal efficiency for COD;
   20% increase in removal efficiency for P;
   8% increase in removal efficiency for TSS
   All the parameters met the disposal standards laid down by the Central Government under the Environment(Protection) Act, 1986.
   Cupola slag proved to be an efficient filter material for the treatment of domestic wastewater. Thus, cupola slag used in combination with conventional filter materials proved to be very efficient in domestic wastewater treatment and improved the efficiency of VFCW.
6. Thus, VFCW can be considered as an efficient and cost effective treatment facility which can also be provided at decentralized level for each household for the treatment of domestic wastewater.

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