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Removal of Heavy Metal from Landfill Leachate Using Vertical Flow Construction Wetland

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Abstract: *Landfill leachate is a highly contaminated wastewater consisting of organic and inorganic matter and heavy metals. Heavy metals are present in high concentration in leachate. The direct release of heavy metals into the environment contaminates the soil and water bodies and causes health hazards. Most of the conventional methods used for leachate treatment do not give good results as per standard norms of Municipal Solid Waste Management (MSWM). Construction wetland (CW) is one of the alternative methods for landfill leachate treatment. This study is aimed at evaluating the efficiency of CW to treat landfill leachate using Cyperus altinofalius plant. This study presents the use of CW to reduce parameters such as Biological Oxidation Demand (BOD), Chemical Oxidation Demand (COD), Suspended Solids (SS) and heavy metals are examined. It is found that the vertical subsurface flow CW using Cyperus altinofalius plant has a removal efficiency of study parameters well within the norms viz - BOD (98.09%), COD (98.81%), SS (99.07%), Iron (90.58%), Copper (98.12%) and Zinc (99.45%). Also the growth of Cyperus altinofalius plant is very good during the flow of leachate in model reactor.*

Keywords*: Landfill, Leachate, Construction wetland, Heavy metals, Substrate, Cyperus altinofalius.*

I. Introduction

In the past few decades, population is increasing rapidly due to development of countries. This population growth has put tremendous pressure on the environment by generating large amount of waste. Solid waste thus generated is disposed off on landfill site to stabilize the waste. The leachate that is generated by the process of decomposition is a critical problem due to its toxic nature. It is highly contaminated wastewater consisting of organic matter and inorganic matter and heavy metals. The characteristics of leachate vary and depend upon the type of waste and age of the leachate. Young leachate has a high biological oxygen demand (BOD), chemical oxygen demand (COD), suspended solids (SS), pH, temperature, nitrogen, phosphorus and heavy metals.

The toxicity of heavy metals causes environmental pollution. The exposure of heavy metals into environment is of great concern as it has serious effect on food chain and human health. There are number of methods of landfilling leachate treatment such as chemical precipitation, membrane filtration, aerobic and anaerobic biological treatment, etc. [1]. But they do not reach the desired level of results due to complex composition of leachate. For this reason, it is very important to seek new methods for leachate treatment. Construction wetland (CW) is an alternative on-site method for treatment of landfill leachate. It is a natural system of wastewater treatment including vegetation, soil and microbial activates. Several studies demonstrated that CW is very effective in heavy metal removal from landfill leachate [2]. Heavy metals are removed by mechanisms such as plant uptake, soil binding, sedimentation, adsorption and precipitation. Plants absorb heavy metals from leachate sample and predominantly get accumulated in the roots and some portion is transported to other parts of the plant [3]. The accumulation and distribution of heavy metals in plants depend on the environmental factors such as plant species, dissolved oxygen, temperature and secretion of roots.

1.1 Mechanism of construction wetland

In CW, leachate is treated by three mechanisms viz. physical, biological and chemical methods (Fig. 1). (1) Physical processes involve filtration and sedimentation. After application of leachate to the CW, leachate flows slowly through substrate medium of wetland. This slow flow allows suspended solids, pathogens and part of organic substances to get filtered by plant roots and voids between gravel and sand to settle. (2) Biological processes such as plant uptake, decomposition, denitrification, transformation and storage of nutrients. Out of these processes plant uptake (absorption) is one of the important mechanisms. When plants absorb contaminants directly into their root structure, the process is known as Phytodegredation. When plants secrete substances and add to process of biological degradation it is called rhizodegradation. The process where contaminants enter the plant biomass and transpire through the plant leaves it is called phytovolatilization. Microorganisms in CW soil uptake and store nutrients for their growth. The bacteria in soil use the carbon from organic matter as an energy source and convert it into carbon dioxide in aerobic conditions and methane in anaerobic conditions. (3) Chemical processes include sorption, photo-oxidation, and volatilization. Sorption includes two processes, adsorption and precipitation.

Fig 1: Mechanisms of construction wetland.

The environmental benefit of landfill leachate treatment in CW includes (i) effective removal of pollutants from leachate (ii) decreased energy consumption by adopting natural processes (iii) providing a habitat for vegetation, fish and other wildlife. This method has low maintenance and capital cost and requires less land [3, 4].

The present work deals with design of model reactor for efficient removal of heavy metals from landfill leachate. Also growth of plants, amount of accumulation of heavy metals in plant tissues and retention of heavy metals in substrate is studied.

II. Methodology

2.1 Description of study area

In this study, the leachate used is collected from municipal solid waste landfill site located at Moshi, Pimpri - Chinchwad, Pune. Area of land-filling site is 566,556 m^2. Initial parameters such as BOD, COD, and SS, concentrations of Iron, Copper and Zinc of leachate sample are tested in the laboratory for the design of reactor model and treatment of leachate sample.

2.2 Design of Model Reactor

The CW reactor is designed and constructed using polyvinyl chloride (PVC) material having size 1.2 m X 0.6 m X 0.5 m (Fig. 1). The CW is filled with 10 cm soil layer at top, 5 - 25 mm size gravel as an intermediate layer and 35 - 50 mm size gravel at bottom. Table 1 below shows the details of model reactor designed for leachate treatment.

Table 1: Details of Model Reactor

Parameters	Unit	Value
Height reactor	M	0.50
Surface area	m 2	0.681
Flow rate of leachate sample	m 3/day	0.025
Weight of aggregate	Kg	89
Weight of sand	Kg	35
Weight of soil	Kg	45
Type of plant		Cyperus altinofalius
Age of plant	months	1 - 2
Number of plants		15
Thickness of soil	Cm	10
Sand	Cm	5
Gravel (5 -10 mm)	Cm	5
Gravel (20 – 25 mm)	Cm	10
Gravel (35 – 50 mm)	Cm	10

2.3 Selection of Plant

A perfect plant species for CW should have following characteristics: i) higher capacity of adsorption of heavy metals ii) rapid growth and large biomass iii) accumulation of several kinds of heavy metals. Plant selected in this study is Cyperus altinofalius (Umbrella palm). This plant is a species of aquatic flowering plant belonging to the family Cyperacceae. It is capable of storing large amount of metals in plant biomass and in its roots. It is an emergent plant and thus suitable for subsurface flow CW. It tolerates annual temperature of 20◦C to 30◦ C and pH of 6.0 to 8.5.

2.4 Working of Model Reactor

A vertical subsurface flow CW is designed and planted with 2 months old Cyperus altinofalius plant having 20 - 25 cm of height (Fig. 3). The influent leachate flows across the model reactor and the resulting effluent after treatment is collected in a collection tank. The flow of leachate in the model reactor is by gravity in batches. A 10 mm PVC feeding pipe and 20 mm valve is used to regulate the flow. The inlet feeding pipe is located at 10 cm above the substrate as show in Fig. 2. In the beginning the model reactor is filled with substrate shown in Fig. 2. The reactor is planted with Cyperus altinofalius with density of 15 stems. After plantation, the wetland reactor is saturated with tap water to establish the emergent plants in the reactor. The tap water is applied till new leaves grow. Cyperus altinofalius plant takes 4 days to establish in reactor. Leachate feeding is started after 5th day of plantation when the plants are ready for experiment with retention time of 2, 3, 4, 5, 6, 7, 8, 9, 10 and 11 days. Outlet samples are collected at regular intervals for analysis of study parameters such as BOD, COD, SS and heavy metals. The analysis is carried out according to standard methods of municipal solid waste management (MSWM). The experimental set up is continuously monitored throughout the treatment period.

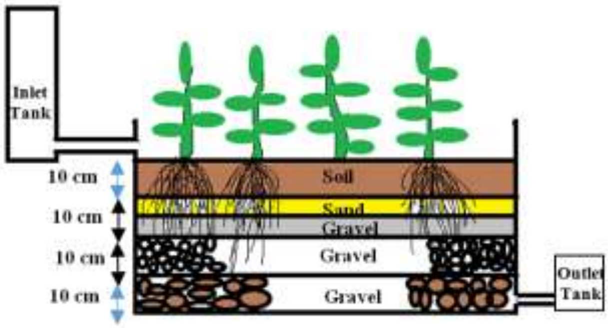

Fig.2 : Cross section of model reactor

Fig. 3: Experimental setup of model reactor

III. Results and discussion

Before operating the reactor model, study parameters such as BOD, COD, SS and heavy metals like iron, copper and zinc are tested. The test results of initial study parameters are given in Table 2. From Table 2 it is observed that leachate sample exhibit significant value of parameters such as iron (1.74mg/l), copper (0.35mg/l), zinc (0.20mg/l), COD (5667.84mg/l), BOD (2250mg/l) and SS (1730mg/l) respectively.

Table 2: Details of model reactor

Sr. No.	Study parameters	Units	Concentration

1	Iron (Fe)	mg/lit	1.74
2	Copper (Cu)	mg/lit	0.35
3	Zinc (Zn)	mg/lit	0.20
4	COD	mg/lit	5667.84
5	BOD	mg/lit	2250
6	SS	mg/lit	1730

4.1 Removal of BOD, COD and SS

In CW, organic matter is removed through sedimentation process. Vegetation supports the process of sedimentation by reducing velocity and turbulence of leachate. Organic matter is also removed by suspended and attached microorganisms by aerobic and anaerobic decomposition. Aerobic zone appears around the root zone. Fig. 4 shows the plot of removal efficiency against retention time of leachate in model reactor till 11th day. Initial BOD concentration of the leachate is 2250 mg/l which is above the threshold value. After the treatment in CW it is reduced up to 24 mg/lit (98%). From this, it is found that removal efficiency of BOD increases with retention time. Influent COD concentration of leachate is 5667.84 mg/l which is very high. After treatment it reduced up to 60 mg/lit (98%) (Fig 4). Rate of reduction of COD increases with retention time. SS influent concentration that flew into the reactor is 1730 mg/l. After treating for 11 days in CW it removed up to 10 mg/lit (99.07%) (Fig.4). Construction wetland removes SS by the process of sedimentation and filtration [6]. From Fig. 4 it is found that SS is removed more efficiently as compared to BOD and COD.

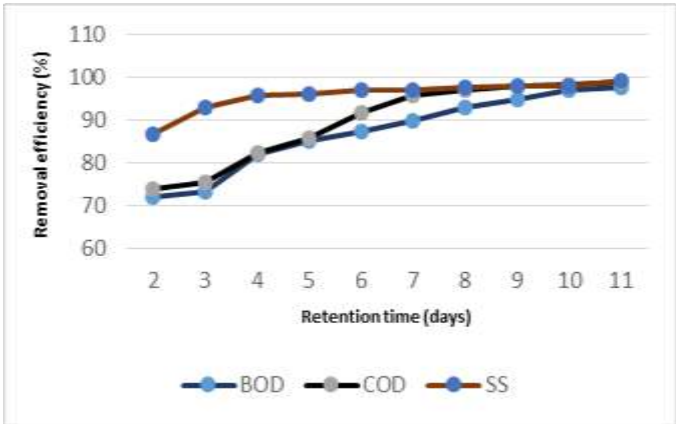

Fig. 4 : Comparison between BOD, COD and SS removal Efficiency

4.2 Removal of Heavy Metal

The initial analysis of leachate sample is conducted using standard method to determine the type of heavy metal and percentage of heavy metals present in leachate. After analysis it is found that Fe, Cu and Zn are present in higher concentration. The initial concentration of Fe is 1.74mg/l after treatment it is reduced to 0.33 mg/lit (90.58%) as shown in Fig. 5. Higher efficiency was recorded on 11th day of treatment period. The initial concentration of Cu was 0.35 mg/l after treatment it is removed to 0.004 mg/lit (98.12%) (Fig.5). Initial value of Zn recorded is 0.2mg/l which is reduce to 0.0015 mg/lit 99.45% after treatment in CW planted with Cyperus altinofalius. Removal efficiency of Zn is higher as compared to Fe and Cu. Among all the metals Fe is absorbed lowest by the plant.

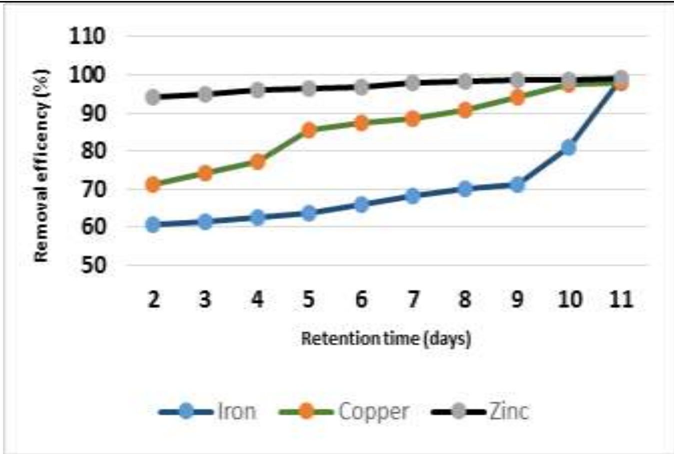

Fig. 5 : Comparison between Iron, Copper and Zinc removal Efficiency

4.3 Uptake of Heavy Metal by Plant tissue

The analysis of plant tissue is done to study the amount of heavy metals uptake by the plant tissue by dry ashing method. In this process, the plant is first cleaned by washing with distilled water. Then it's heated at 500ºC in muffle furnace. The ash residue is then cooled and tested for heavy metals. The result shows that, accumulation of heavy metals is higher on root than on stem and still less on leaves as shown in Table 3. The uptake of Fe, Cu and Zn on root is 0.01 mg/g, 0.02 mg/g and 0.4 mg/g respectively. The uptake Fe, Cu and Zn on stem is 0.01mg/g, 0.012 mg/g and 0.08 mg/g respectively. The uptake capacity of Fe, Cu and Zn by leaves is 0.003 mg/g, 0.005 mg/g and 0.012 mg/g respectively which is less as compared to roots and stems. Absorption of Zn by plant tissue is higher.

Table 3: Details of heavy metal uptake by plant tissue

Parameter	Weight of heavy metal (mg/g)		
	Root	Stem	Leave
Iron	0.01	0.01	0.003
Copper	0.02	0.012	0.005
Zinc	0.4	0.08	0.012

4.4 Retention of Heavy Metal in Substrate

The capacity of impurity removal of leachate depends upon the type of CWs, type of plants and substrate. Substrate of CW consists of gravel, sand and soil. The substrate provides suitable medium for plant growth and allows infiltration of leachate through it [7]. It provides surface area for microbial attachment and helps in removal of impurity by process of filtration, sedimentation, adsorption, chemical precipitation [8]. Microorganisms in CW soil uptake and store nutrients for their growth. The bacteria in soil use the carbon from organic matter as an energy source and convert it into carbon dioxide under aerobic conditions and methane in anaerobic conditions. Analysis of soil is done to determine the accumulation of heavy metals in the soil. The result shows that the higher amount of heavy metals is present in lower layer of substrate. This is because of rizofilteration.

4.5 Effect of Leachate on Plant growth

Observation is carried out on the plants to determine the effect of leachate on plant growth. Table 4 shows pattern of plant growth after plantation of Cyperus altinofalius in leachate. The stem height of Cyperus altinofalius is recorded weekly while the number of stems in reactor is recorded at the beginning and the end of experiment as given in Table 4. The number of plants before leachate application is 15. After retention time of 11th day number of stems increased to 73. Before application of leachate, the height of plants are 20 – 22 cm. At the end it is upto 26 – 30 cm. From this it is found that number of stems increased with the increase in contact time between plant and leachate. The clump around and near inlet zone is more due to amount of nutrient that is absorbed by plant is more as compared to far one.

Table 4: Plants growth

Plants	No. of stems		High of stems (cm)	
	Beginning	End	Beginning	End
Plant 1	1	4	20.5 cm	26.01 cm
Plant 2	1	3	22.3 cm	28,06 cm
Plant 3	1	5	21.9 cm	29.17 cm
Plant 4	1	5	19.09 cm	26.34 cm

IV. Conclusion

Based on the above results it can be concluded that vertical flow CW is a very effective method for landfill leachate treatment with removal efficiency of Iron (90.58 %), Copper (98.12%), Zinc (99.45%), BOD (98.09%), COD (98.81%) and SS (99.07%). Removal efficiency increases with increase in retention time. Removal of Zn is higher than Cu and Zn. During the flow of leachate in model reactor the growth of Cyperus altinofalius plant is very effective which is marked by the additional number of plants. Higher percentage of heavy metals are accumulated on plant root as compared to other part of plant. This is because of long fibrous root of Cyperus altinofalius which plays important role in contaminant removal. The ability of Cyperus altinofalius to withstand the high pollution load shows that his suitable for treatment of landfilling leachate and requires less maintenance. Thus CW can also be used for treatment of leachate in place of other conventional methods.

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