MULTI LAYERED SOIL COLUMN ANALYSIS FOR WASTEWATER

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Abstract - *Large portions of domestic wastewater in several communities are discharged into the environment without effluent treatment. In several areas, wastewater system strategies are needed which are environmentally, socially and economically sustainable. A full-scale, land-based approach developed from the most recent efforts in this emerging field is described. A brief description of the mechanisms in the treatment process within the multi-layered soil column system, as well as the design and operation are provided. The experiment shall be conducted using various layers of soil placed in different arrangements and the most effective arrangement shall be chosen.*

Key Words: *domestic wastewater, treatment process, multi-layered soil column system*

1. INTRODUCTION

Water safety has received a greater attention in the past decades. In small and remote communities, a large portion of domestic wastewater is being discharged into the environment without any effective treatment or no treatment. Although the characteristics of wastewater may vary from one community to the other in both quality and quantity, wastewater is able to be generalized as having high content of particulate matter, dissolved organic matter, nutrients and microbes. The receiving water bodies may be heavily polluted, resulting in serious environmental and ecological problems. This issue is mainly seen in villages and remote regions in various countries. Centralized wastewater treatment plants have been established to remove pollutants from the wastewater with high loading rates and high efficiency. However it requires a well-designed sewage network to collect the wastewater from every household. The construction, operation and maintenance of these wastewater treatment facilities are quite costly.

In less densely populated areas, it becomes necessary to develop technologies and techniques to treat the wastewater using decentralized treatment facilities as centralized facilities would require a lot of work and cost. This would prove to be economically inefficient.

Many traditional and modern technologies have been used for the decentralized treatment of wastewater such as septic tanks. Although septic tanks are safe and easy to adopt, it is also noted that septic tanks are not designed, built and operated correctly in many situations. The failing septic tanks are one of the most common causes for ground water contamination.

An alternative technique that holds interesting potential for decentralized wastewater treatment is multi layered soil column system. The application of multi soil layering system method to direct treatment of polluted river water was discussed in terms of its performance and adaptability to improve the public water environment (*Masunaga et al., 2003*). The removal of pollutants in this system involves various physical, chemical and biological processes. The multi layered soil column system is cheap because it can be developed from local resources, such as soil, sawdust, iron and charcoal and other alternative materials.

Until now the multi soil layering system has been used only to treat the general wastewater. This paper gives an insight about the performance of the multi layered soil column system when used to treat greywater.

2. EXPERIMENTAL SETUP

The mode of operation of multi soil layered column system is based on the percolation infiltration using the ground as a purification system. The adsorption, infiltration and biodegradation are the major processes occurring in the filter (*Lamzouri et al., 2016*).

The lab scale model is made up of acrylic tube of dimensions 1m length, 75mm outer diameter and thickness 3mm. The soil mixture layer of thickness 20cm was placed between other permeable-filter layers. A gap of 10cm was introduced separating the tube after the top three layers to facilitate aeration.

3. MATERIALS AND METHODOLOGY

Selection of materials plays an important role. The materials selected must be such that they are easily available, effective in contaminant removal, and moreover economical. The materials selected for the multi soil layered column system meets all these requirements.

The materials used in the multi soil layered column system were grouped as Soil Mixture Block and Permeable-Filter layers. The materials used in the system are natural materials which are locally available. The materials used are:

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Soil Mixture Block (SMB):

The materials used for preparing the soil mixture block are as follows:

a. **Soil:** Soil is a mixture of organic matter, minerals, gasses, liquids and organisms that together support life. Soil is used to influence the microbial activity in the treatment of wastewater. Soil passing through 4.75mm sieve was used in the soil mixture block.
b. **Powdered charcoal:** Is a form of carbon which has small pores thereby increasing the surface area which is effective in adsorption and chemical reactions.
c. **Sawdust:** Sawdust is an organic matter that provides the carbon source for microorganisms. Sawdust passing through 4.75mm sieve and retaining on 0.18mm sieve was used in the setup.
d. **Iron scraps:** Addition of iron scraps into the soil mixture block facilitates the phosphorous adsorption. The iron scrap passing through 4.75 mm sieve was used in the mixture block.

Permeable-Filter Layers:

It includes materials which act as a permeable media for the wastewater to be past. The materials selected must be locally and easily available. Various permeable materials such as pebbles, cobbles, gravels, zeolite, expanded clay aggregates, etc… can be used. Zeolite was substituted with comparatively cheaper and ecofriendly materials such as gravels, expanded clay aggregates, oyster shells *(Ho and Wang, 2015)*. But, from experimental analysis it was found that using oyster shells were ineffective as they began secreting solution of salt into the water. Natural zeolite is not easily available in India; therefore other materials such as gravels and sand were used here. Totally, four layers of permeable-filter layers were used in this setup.

4. GREYWATER TREATMENT MECHANISM OF MULTI LAYERED SOIL COLUMN SYSTEM

As greywater passes through the multi layered soil column system, organic matter examined using biochemical oxygen demand (BOD), chemical oxygen demand (COD), and organic nitrogen (Org-N) tests) adhere to the surface of the soil aggregates or Permeable Layers (PL) through physical or chemical mechanisms. The microorganism growing on these surfaces starts decomposing the organic matter, converting a portion of the Org-N in the greywater into ammonium (NH_4^+-N). Regarding phosphate adhesion, the divalent ions from the iron materials in the Soil Mixture block dissolve under anaerobic conditions and are transferred to the surface of the Soil Mixture Block (SMB) and onto the Permeable Layer. In an aerobic environment, the divalent ions oxidise into trivalent ions, and react with the phosphate ion in the wastewater, forming sediments. A high quantity of NH_4^+-N that enters the system is adsorbed by the Soil mixture block and Permeable Layer aggregates. Nitrification subsequently occurs in the aerobic environment, oxidizing the NH_4^+-N into nitrites (NO_2-N) and nitrates (NO_3-N) and releasing hydrogen ions that reduce the pH of the system. The NO_2-N and NO_3-N are then transported into the Soil Mixture Block, in which denitrification occurs because of the anaerobic environment. The NO_2-N and NO_3-N are reduced to nitrogen (N_2), nitrous oxide (N_2O), and nitric oxide (NO). The reaction process consumes hydrogen ions, thus re-elevating the pH of the system. When this treatment mechanism is used, the pH value becomes an indicator for the ventilation conditions within the system. Appropriately adjusting the ventilation of the system facilitates decomposing NH_4^+-N and NO_3-N, and eliminating BOD, COD, suspended solids (SS), and soluble reactive phosphorous (SRP). However, excessive ventilation suppresses denitrification, consequently reducing the removal efficiency of total nitrogen (TN) and total phosphorous (TP), and hindering the transfer of ferric hydroxide from the Soil Mixture Block Layer to the Permeable Layer.

5. DESIGN OF SOIL COLUMN APPARATUS

The soil column apparatus is made using two acrylic tubes, one of 40cm length and the other of 60cm length. The 60cm long tube is placed above the 40cm tube. Polythene sheets are place below each of the tubes to hold the tubes in place. The inner diameter of the tubes is 75mm each and thickness of 3mm. Acrylic tubes were used so as to provide a clear view of the contents inside the set-up and also they have been proven to be non-reactive to the reactions that will occur in the soil column. The acrylic tubes are supported over steel cylinders to hold in position that are connected to a steel rod of 165cm. A gap of 15cm has been left between the two tubes so that it aids in the aeration process. The inner diameter of the steel cylinders is 85mm each. A square plate of 0.5m has been used as base plate to support the entire stand along the soil column. A gap of 50cm has been left underneath for collecting the filtered water sample.

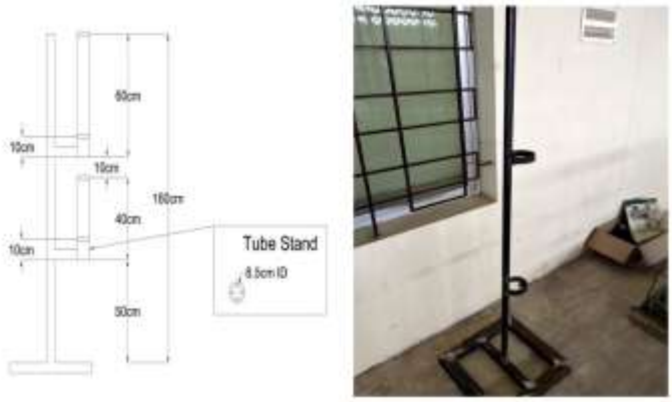

Fig -1: Soil Column Apparatus

6. LAYERING OF SOIL COLUMN SYSTEM

The important consideration to be taken while layering the materials in the soil column is that, the layers must be placed in such a way that the materials are placed from top to bottom in decreasing grain size. The layers must be arranged so that the risk of clogging is reduced. The efficiency of contaminant removal mainly depends on the arrangement of layers. By selecting the right arrangement of layers, the overall efficiency of the system is improved.

The multi layered soil column system consists of five layers. The first three layers are placed in the tube positioned in the top level. The next two layers are placed in the tube positioned in the bottom level. The following are the layers arranged in the soil column system:

First Layer

The first layer consists of pebbles. The first layer is filled through a depth of 20cm. This layer acts as both permeable and filter layer. This layer performs in a manner similar to screening except that this is done inside the tube. This layer filters out the coarse solid particles such as plastics, large vegetable wastes etc.

Second Layer

The second layer consists of fine gravel. The second layer is also filled through a depth of 20cm. This layer also acts as permeable cum filter layer. The fine gravel passing through 20mm sieve and retained in the 4.75mm sieve were used.

Third Layer

The third layer consists of coarse sand. The third layer is also filled through a depth of 20cm. This layer also acts as permeable-filter layer. The coarse sand passing through 4.75mm sieve and retained at 2.36mm sieve were used.

Fourth Layer

The fourth layer consists of Soil Mixture Block (SMB) layer. The thickness of this layer is 20cm. The SMB consists of soil, charcoal, sawdust and iron dust that are homogeneously mixed in the ratio of 7:1:1:1 based on their volume. This ratio has been chosen based on previous methods where the performance efficiency was good compared to other ratios. Charcoal passing through 9.5mm and retained at 4.75mm was used. The mixture of these were wrapped inside a polythene cloth and placed inside the tube so that the contents do not get mixed with the other layers. Chemical and bio-adsorption takes place in this layer. This is the most important layer in the soil column system.

Fifth Layer

The fifth layer consists of medium sand. The fifth layer is also filled through a depth of 20cm. This layer also acts as permeable cum filter layer. The medium sand passing through 2mm sieve and retained in the 0.425mm sieve were used.

Fig -2: Multi layered Soil Column

7. OPERATION OF MULTI LAYERED SOIL COLUMN SYSTEM

The greywater samples collected were initially tested to find out their various parameters such as colour, pH, odour, total dissolved solids, total solids, total suspended solids, chemical oxygen demand, biological oxygen demand, and total phosphorous, ammoniacal nitrogen before introducing them into the multi layered soil column. After setting up the soil column, water was introduced into the column to clean the layers and remove them of any dust particles and other unwanted particles that might hinder the operation of the soil column for 2 days. The system was then made to dry up for 2 days. The greywater sample was then introduced into the system using a tube and bucket arrangement. The flow rate at the inlet and outlet of the multi layered soil column system were measured using a stopwatch. The flow rate was measured at regular intervals of one hour. The treated greywater was collected using a bucket placed below the system. The outlet sample was then again tested for the same parameters that were conducted before the application into the system. The multi layered soil column system was operated with alternative wetting and drying cycles. The wetting cycle was performed for 3 days (Monday, Tuesday and Wednesday). The drying cycle was performed for 4 days (Saturday and Sunday). The outlet samples were tested at the end of each cycle. This was done to observe the behaviour of the system such as clogging. The experiment was performed for 4 cycles and the results were compared.

8. RESULTS AND DISCUSSION

8.1 RESULTS

The various parameters of the soil and the greywater sample used in the multi layered soil column were tested both before and after the application into the system. The obtained results were compared as shown below:

Specific gravity

	Pebbles	Fine Gravel	Coarse Sand	Medium Sand
W1 (Kg)	0.667	0.667	0.667	0.667
W2 (Kg)	0.867	0.868	0.867	0.867
W3 (Kg)	1.646	1.635	1.623	1.622
W4 (Kg)	1.497	1.497	1.497	1.497
Specific Gravity (No unit)	3.921	3.190	2.702	2.66

Flow rate

		Cycle 1	Cycle 2	Cycle 3	Cycle 4
Inlet (mL/min)	1st hour	410	417	405	407
	2nd hour	406	413	401	403
	3rd hour	397	404	392	394
Outlet (mL/min)	1st hour	164	154	169	167
	2nd hour	168	158	173	171
	3rd hour	220	210	225	223

Colour, odour and pH

Sample: Greywater
Colour: Greyish yellow
Odour: Pungent smell
pH: 7.4

Other physical and chemical parameters

		Cycle 1	Cycle 2	Cycle 3	Cycle 4
Total Dissolved Solids	Before treatment (mg/L)	568	573	571	577
	After treatment (mg/L)	98.3	116.9	74.2	90.6
	Removal efficiency (%)	82.7%	79.6%	87%	84.3%
Total Suspended Solids	Before treatment (mg/L)	254	258	253	251
	After treatment (mg/L)	54.1	64.8	43	47.7
	Removal efficiency (%)	78.7%	74.9%	83%	81%
Total Solids	Before treatment (mg/L)	822	831	824	828
	After treatment (mg/L)	152.4	181.7	117.2	138.3
	Removal efficiency (%)	81.5%	78.13%	85.8%	83.3%
Chemical Oxygen Demand	Before treatment (mg/L)	267.5	268	268.6	268.8
	After treatment (mg/L)	46	48.8	43.8	44.9
	Removal efficiency (%)	82.6%	81.8%	83.7%	83.3%
Biochemical Oxygen Demand	Before treatment (mg/L)	123.5	123.8	124.2	124.7
	After treatment (mg/L)	20.1	21	19	19.8
	Removal efficiency (%)	83.7%	83.1%	84.7%	84.1%
Total Phosphate	Before treatment (mg/L)	1.3	1.32	1.34	1.347
	After treatment (mg/L)	0.230	0.238	0.227	0.233
	Removal efficiency (%)	82.3%	81.9%	83%	82.7%
Chloride Content	Before treatment (mg/L)	53	53.3	53.6	53.8
	After treatment	20	20.5	19.8	20

	(mg/L)				
	Removal efficiency (%)	62.1%	61.6%	63%	62.7%
Ammoniacal Nitrogen	Before treatment (mg/L)	11	11.5	11.9	12
	After treatment (mg/L)	1.64	1.77	1.66	1.73
	Removal efficiency (%)	85.1%	84.6%	86%	85.6%

8.2 DISCUSSIONS

In the present study experimental set up was installed for Multi layered soil column system and series of indoor tests were conducted. The system proved to be efficient in remediating the pollution of greywater wastewater. The Total solids removal efficiency was 78.13% to 85.8%. The COD removal efficiency was 81.8 to 83.7%. The BOD removal efficiency was 83.1 to 84.7%. The TP removal efficiency was 81.9 to 83%. The change in hydraulic loading rate inside the experimental setup discovered that the performance of the Multi Layered Soil Column System decreased with increasing loading rate. Clogging was not observed throughout the operating period of the system. The flow rate of 405 mL/min with aeration condition was efficient for treating greywater by multi layered soil column system. Once the capacity of purification of soil is over, the soil can be further used in agricultural land as fertile soil. The treated water may be reused for various purposes or can also be introduced into the ground for artificial recharge.

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