

Wastewater Recovery Using Soil Aquifer Treatment

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Abstract

This study investigated that the soil aquifer treatment (SAT) approach allows the effluent to percolate through the soil hence removing contaminants in the wastewater. The soil can be utilized as a reactive agent for improving the quality of the surface water. At different locations, soils were collected to determine the type of soil. Similarly wastewater was collected from Nesapakkam Sewage Treatment Plant and Anna University Sewage Treatment Plant to characterize the quality before SAT. Then three columns of 1m height and 6mm diameter of acrylic material were fabricated and used for the research project to study the SAT efficacy. Effluent from the column was analyzed after SAT. Wastewater qualities were monitored and the most major parameters such as pH, Turbidity, TDS, Nitrate, Nitrite, BOD₅ and COD in assessing the degree of quality improvement were selected for monitoring through the study. The three types of soil such as sandy loam, silty loam and clay soils with three cycles such as one day wetting and one day drying, two days wetting and two days drying and three days wetting and three days drying were carried out to evaluate which soil under which cycle removes maximum physical, chemical and biological contaminants. In addition, soil was tested before and after SAT to determine the adsorption of ions by the three types of soils. The organic compounds were reduced to maximum level only by the clay soil. Therefore clay soil was suitable for reducing the organic compounds in the wastewater.

Keywords: BOD₅, COD, Nitrate, Nitrite, pH, Turbidity, TDS

Introduction

Many countries and regions of the world are facing water scarcity and deterioration of groundwater quality caused by climate change and a continuous population growth especially in coastal areas. The utilization of alternative water sources such as

seawater and brackish water desalination as well as water reclamation and reuse are mitigation options applied up to now (Bixio et al., 2006; Fritzmann et al., 2007) [2,3]. Wastewater if not properly disposed off, can create problems of hygiene and health. Several conventional and innovative technologies are available for treatment and disposal of municipal wastewater. Conventional primary and secondary treatment techniques have mostly aimed at removal of treated effluent either into public sewers for irrigation, into marine coastal area and or inland water bodies, without much consideration for conservation and renovation (Nagarajappa et al., 2007) [5]. It is therefore, desirable that alternative technology for wastewater disposal that result in conservation of natural water sources in their pristine condition and renovation of wastewater for reuse are devised. Innovative methods in wastewater treatment for reuse have been developed. One of the techniques is the renovation of wastewater with rapid infiltration system known as soil aquifer treatment (SAT). Several studies have proved that wastewater can be efficiently renovated by SAT (Bouwer, 1985; Wilson et al., 1995; Vishwanathan et al., 1999) [1,6,7]. In a pilot study on SAT, there was found 90 % reduction in organic pollutants (COD, BOD and SS) and effective removal of bacteria and viruses (Gupta et al., 1997) [4]. Thus this study was carried out to recognize and describe the soils with reference to their physical properties and to assess the deeds of soils with wastewater and depth of soil as a filter bed. A representation of soil aquifer treatment is provided in Figure 1.

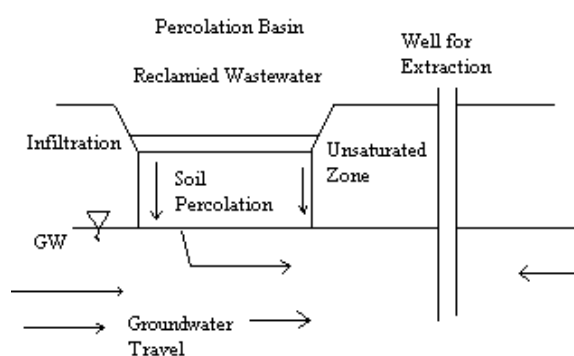


Figure 1: Representation of Soil Aquifer Treatment

Materials and Methods

The experimental set up was carried out in Centre for Water Resources, Anna University Chennai.

Batch Study

Before going for the column study, the batch studies were needed. Experimental studies are needed to investigate the vadose zone capability in transforming the secondary treated wastewater and to analyze the soil aquifer treatment parameters that are responsible for reducing the constituents of the wastewater. The steps for the batch study were as follows.

Before Soil Filling Up

The height of the bucket was 23.5 cm. Many holes were made in the bottom of the buckets. Then the fine mesh was placed in such a way that it covers all the holes. The mesh was mainly to collect the water samples without soil particles. Gravels and pebbles were filled on the top of the mesh up to 2.5 cm. Gravels and pebbles were placed on the mesh to avoid the clogging of the mesh by the soil.

After Soil Filling Up

The soil was sieved through 2mm before placing over the gravels and pebbles. Then the sieved soil was placed upon the gravels and pebbles up to a depth of 13.5 cm.

After Pouring the Wastewater Reclaim

Ponding depth was maintained for a depth of 5 cm and 2.5 cm was provided as free board. The wastewater from Anna University Sewage Treatment Plant (for batch study) was poured up to a depth of 5 cm. The experiment was conducted in a full saturated soil column. After pouring of the wastewater over the soil, it travels through the soil which was collected through at the bottom of the bucket which was called as effluent. The collected sample was found to be without soil particles and analyzed for its characteristics to compare with influent characteristics.

Soil Column

Three soil columns (one dimensional model) were fabricated to study the improvement of secondary treated wastewater using different soil types. The columns were made of Acrylic material whose inner diameter is 6 cm, the length of the columns were one metre. The lower part of the columns (approximately 10 cm) was filled with pebbles. Then the soil was placed upon the soil up to 50 cm. The columns were provided with outlets for sample collections at the bottom were shown in Figure 2. The three columns were filled with sandy loam, silty loam and clay soil. Soils were not compacted inside the columns. Secondary treated wastewater from Nesapakkam Sewage Treatment Plant was allowed to infiltrate into the columns. The columns were equipped with sampling ports to obtain liquid and soil samples at various depths. The experiment was carried out for three months and the effluent was collected at the outlet of the column.

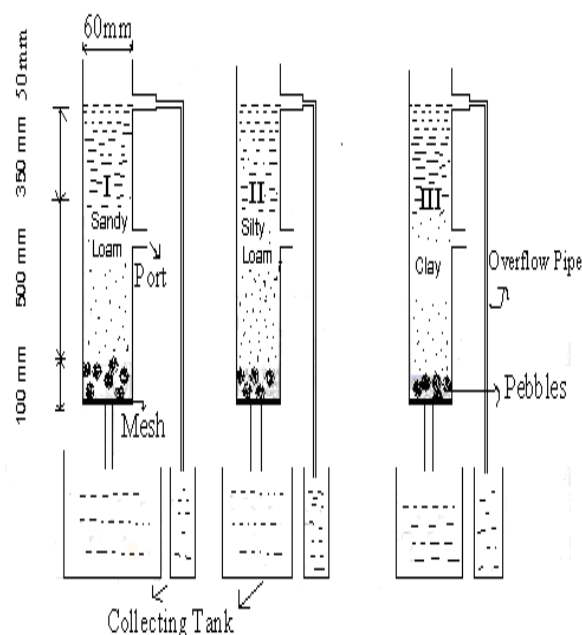


Figure 2: Soil Column Design

Column Operation

Column operations were started initially with one day wetting followed by one day drying. During drying, the soil from the columns were taken out which was spread on the ground surface in such a way to make the soil to get exposed to the atmosphere. Therefore the soil gets enriched with oxygen and micro organisms from the nature. During wetting, the exposed soil was placed into the columns and allowed the wastewater to pass through it.

Results and Discussion

Hydrogen Ion Concentration (pH)

Initially pH of secondary treated wastewater (influent) was 7.77. Initially the column operation was started with one day wetting followed by one day drying. The average pH of influent was less than the outflow. This indicates a general increase in the pH values when compare with the influent. The increase in pH may be attributed to production of CO_2 during biodegradation of organics. This indicates that the pH was reduced by the silty loam under three days wetting and three days drying cycle.

Turbidity

Turbidity was due to the presence of suspended solids. Initially turbidity level in the secondary treated wastewater (before SAT) was 6.64 NTU. The sandy loam soil has shown better turbidity removal efficiency under one day wetting and one day drying cycle.

Total Dissolved Solids (TDS)

Initially TDS level in secondary treated wastewater (before SAT) was 1470 mg/l. At the initial stage, the soil particles may significantly capture the dissolved solids of the effluent. The silty loam soil has shown better TDS removal efficiency under two days wetting and two days drying cycle.

Nitrate (NO_3) and Nitrite Values (NO_2)

Natural groundwater contains 5 mg/l of nitrate and nitrite. Desirable permissible limit of nitrate in drinking water is 45 mg/l and maximum permissible limit is 100 mg/l. But the secondary treated wastewater contains an average 0.2 mg/l which was very less compared to parent groundwater. Hence nitrate and nitrite removal was not needed. Therefore the wastewater was passed through the different soil under three different cycles. In a one day wetting and one day drying cycle, nitrate was increased initially and then started decreasing. But in a two days wetting and two days drying cycle, nitrate was steadily reducing. In a three days wetting and three days drying cycle, initially nitrate was increased but it was reduced after three days drying. But in all the three cycles, clay had more efficiency in reducing nitrate. Increase in nitrate content may be contributed to the presence of nitrate in soil which may be washed out in the initial days. Initially nitrite value of secondary treated wastewater (before SAT) was 0.497 mg/l (approximately 0.5 mg/l). It was also increase initially in a sandy loam and silty loam soil. But increment was comparatively very less.

Biochemical Oxygen Demand (BOD_5)

Initially BOD_5 level in secondary treated wastewater was 28 mg/l. Generally, the BOD_5 level showed a steady decrease with time after passing through the soil. All the values were below the inlet value. The high values obtained during the initial period of the experiment may be influenced by the time needed for the microbial population to adapt to the organic compounds in the effluent. The clay soil has better BOD_5 removal efficiency than the sandy loam soil and silty loam under one day wetting and one day drying cycle within six days when compared to two days wetting and two days drying. This was due to that the travel of wastewater in the clay soil was very slow when compared to sandy loam and silty loam. So the slow movement has lead to more reduction in the clay soil and reduced the biological oxygen demand.

Chemical Oxygen Demand (COD)

As in BOD_5 , the removal efficiency of the soil columns is attributed to two major processes: biodegradation by anaerobic bacteria and adsorption by the soil particles. During the test, both BOD_5 and COD concentration levels followed a declining pattern. The COD values of the outflow were generally below those for the inflow water. Initially COD was 53.5 mg/l. The clay soil has shown better COD removal efficiency than the other two soils under one day wetting and one day drying cycle.

Maximum Reduction of Parameters after SAT

Table 1 shows which type of soil has maximum reduction under which cycle. The removal (or reduction) of organic compounds such as nitrate, nitrite, BOD_5 and COD

was the main concentration of the study. W/D represents the wetting and drying cycle. It was understood that clay soil has shown maximum reduction in organic compounds such as nitrate, nitrite, BOD₅ and COD. Hence, clay soil was found to be suitable soil for reducing the organic compounds. But the other parameters such as pH, turbidity and TDS may be reduced to better through pretreatment, in which the sandy loam and silty loam may be mixed and then the wastewater may be allowed to pass through the clay soil.

Table 1: Maximum Reductions of Parameters after SAT

Parameters	Before SAT	Wetting and Drying cycle (W/D)			Remarks
		1 W/1D	2W/2D	3W/3D	
pH	7.77	8.2	7.6	7.1	Maximum reduction in silty loam under 3W/3D
Turbidity (NTU)	6.64	2.51	2.4	2.0	Maximum reduction in sandy loam under 3W/3D
TDS (mg/l)	1470	1010	810	960	Maximum reduction in silty loam under 2W/2D
Nitrate (mg/l)	0.168	0.27	0.006	0.051	Maximum reduction in clay soil under 2W/2D
Nitrite (mg/l)	0.497	0.485	0.483	0.484	Maximum reduction was found to be in clay soil under 2W/2D
BOD (mg/l)	28	7 (with in 6 days)	7 (with in 9 days)	-	Maximum reduction in clay soil under 1 W/1D
COD (mg/l)	53.5	45.09	45.10	45.12	Maximum reduction in clay soil under 1 W/1D

Comparative Study of Quality after Sat for Clay

As the clay soil was found to be suitable soil for reducing the organic compounds, therefore only clay soil was again experimented for ten days (parallel study) to compare the quality after SAT for one day, two days and three days. The same columns were used for the comparative study of quality. Quality analysis for one day, two days and three days only for clay soil were shown in Table 2. Clay soil has shown good reduction in organic compounds. The quality was also increased after drying period as the soil gets enriched with oxygen and also enriched with microbes. Therefore purification was taking place after the drying period. The parameters were permissible according to Indian Standards for recharging groundwater.

Table 2: Comparative Study of Quality after SAT for Clay Soil

Before SAT							
Date	pH = 7.62	TDS = 967 (mg/l)	NO ₃ ⁻ = 0.273 (mg/l)	NO ₂ ⁻ = 0.4864 (mg/l)	NH ₃ -N = 5.6 (mg/l)	BOD ₅ = 29 (mg/l)	COD = 64 (mg/l)
One day wetting/ one day drying (After SAT)							
6 th June	7.9	885	3.846	0.5216	5.6	9	54.7
10 th June	-	-	-	-	-	-	-
12 th June	8.3	871	3.319	0.4911	2.24	11	45.8
14 th June	8.5	866	2.552	0.4907	1.12	10	45.7
16 th June	7.5	855	2.295	0.4903	1.12		45.3
Two days wetting / two days drying (After SAT)							
9 th June	7.9	993	1.250	0.4816	2.24	15	48.2
13 th June	7.8	823	1.238	0.4842	2.24	19	44.0
17 th June	7.8	830	1.195	0.4840	1.12	16	44.0
Three days wetting / three days drying (After SAT)							
10 th June	8.2	817	1.904	0.4849	2.24	19	45.6
16 th June	7.8	806	1.647	0.4875	1.12	15	44.3

Comparative Study of Quantity after Sat for Clay

From the Table 3, it was observed that after the drying period, the clay soil was absorbing more quantity of wastewater. Continuous wetting has lead to blockage of soil pores. Deposition of organic and inorganic solids at the surface, developing into a clogging mat and leading to outer blockage of soil pores (Surface filtration). Deposition at the grain surface in the pores, leading to inner blockage of soil pores (Volume filtration).

Table 3: Comparative Study of Quantity after SAT for Clay Soil

Date	One day wetting/ one day drying			Two days wetting/ Two days drying			Three days wetting/ Three days drying		
	V _i (ml)	V _o (ml)	D _r (cm)	V _i (ml)	V _o (ml)	D _r (cm)	V _i (ml)	V _o (ml)	D _r (cm)
8 th June	1535	957	5	1630	921	5	1690	1019	1
9 th June	Dry			980	584	6	1228	1120	3
10 th June	945	10	5	Dry			800	775	5
11 th June	Dry			Dry			Dry		
12 th June	1000	980	3	1605	765	8	Dry		
13 th June	Dry			705	508	12	Dry		
14 th June	1006	975	2	Dry			1400	1040	2
15 th June	Dry			Dry			1220	995	4
16 th June	900	806	2	1420	1024	13	1210	806	6
17 th June	Dry			506	499	11	Dry		

Clogging Issues

One of the main limitations of using SAT systems is their clogging propensity while effluent percolates through the soil. There are three possible types of clogging resulting from the injection of reclaimed wastewater: chemical, biological and physical clogging. One separate column study was conducted to analyze the clogging in the soil. The column was flooded (ponding depth was maintained) continuously for ten days. Initially more quantity was collected at the outlet of the column. Continuous wetting has lead to blockage of soil pores which was observed from the quantity collected at the outlet of the column, since the quantity was started to decrease. It was indicated by the white layers that can be seen from the outside of the column surface. Very less suspended algae growth has also observed at the top surface of the clay soil. Figure 3 shows the white layers in the clogging soil column. Chemical clogging occurred when wastewater containing dissolved salts interacts with the soil blocking the pores and therefore decreasing the permeability. Physical clogging happened when suspended solids clog the soil pores. Biological clogging was caused by the growth of microorganisms (anaerobic bacteria) in reclaimed wastewater which can lead to formation of a clogging layer either on the soil surface or in soils by decreasing the quality of the recharge water as well affecting both hydraulic conductivity and chemical quality of the recharge water.



Figure 3: White Layers in the Clogging Soil Column

Conclusions

Maximum reduction in organic compounds such as nitrate, nitrite, BOD and COD were occurred in one day wetting followed by one day drying cycle. The initial BOD₅ in an influent was 28 mg/l has reduced to 7 mg/l in six days under one day wetting and one day drying cycle when it was passed through clay soil. Hence clay has maximum removal capacity than the other two soils. Initial value of COD was 53.5 mg/l. It was reduced to 45 mg/l under one day wetting and one day drying cycle when it was passed through clay soil. Continuous wetting has lead to blockage of soil pores. Deposition of organic and inorganic solids at the surface, developing into a clogging mat and leading to outer blockage of soil pores (Surface filtration). Deposition at the grain surface in the pores, leading to inner blockage of soil pores (Volume filtration). The organic compounds were reduced to maximum level only by the clay soil. Therefore clay soil was suitable for reducing the organic compounds. More quantity of sample (after SAT) was collected during one day wetting followed by one day drying. The quality was also increased after drying period as the soil gets enriched with oxygen and also enriched with microbes. Purification was taking place after the drying period. The parameters were permissible according to Indian Standards for recharging groundwater. The quality of the samples (after SAT) was good in one day wetting and one day drying. But the work was cumbersome in one day wetting and one day drying cycle when compared to other cycles.

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