Design of a Plant for the Treatment, Management and Reuse of Water Collected in Septic Tanks. Case Study: Harare Company

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Abstract

A company in Harare disposes 20 000L of septic tank wastewater daily at a Municipal Water Council. This is expensive for the company and environmentally unfriendly. This paper aims at designing a plant that treats wastewater by cleaning septic tank wastewater for reuse in the gardens, toilets and brick making project. The treatment plant is easy to operate, maintain and runs daily. To decide on the best treatment processes, various laboratory tests were done for BOD, COD, total phosphorous, turbidity, total fecal coliforms and pH. After results' analysis, an activated sludge process was chosen to be the key biological treatment process. The whole plant consists of a bar screen, primary and secondary settling tanks, an aeration tank, chlorine pump and storage tanks. 8 samples were tested. The treatment processes chosen were effective. This initiative will save the company money since setting up of the treatment plant is cheaper than disposing the wastewater at the Town Council.

Keywords

Coliforms, Sludge, Aeration, Treatment

1. Introduction

A company located in Harare specialises in the production of tiles. It uses septic tanks as part of its toilet systems. Due to high water tables, the septic tanks get filled with water very fast. Figure 1 is showing a septic tank at the company that is almost overflowing with water.

Figure 1. A septic tank at the Company.

The septic tanks are made of bricks and concrete which are inadequate to shield the tanks from the underground water. The company has six septic tanks in total with each tank having a capacity of 5000L. The toilet system used is different from the usual toilet systems available in Zimbabwe as can be seen in figure 1.2. This system needs a constant supply of water and hence due to this extreme water usage the septic tanks also get filled quickly.

Figure 2. A Chinese toilet system at Sunny Yi Feng Company

Honeysuckers are used to drain the equivalent amount of four septic tanks daily (20000L). According to Environmental Management Agency regulations, no person shall dispose general waste or hazardous waste at any other place except in a licensed general landfill. Three loads of wastewater are transported to the Town council for treatment on a daily. The company pays Zim$12 000 per load. 10L of fuel is needed for each trip. From the numbers, this way of managing the wastewater is very expensive for the company.

2. Problem Statement

The company is incurring a huge expense in disposing black wastewater due to the septic tanks filling up quickly. Underground water is not prohibited from entering the septic tanks since they are made of brick and concrete only which is not water proof. The tanks are required to be drained daily. The wastewater is disposed at the town council. The costs per trip is expensive for the company.

3. Justification

Having a treatment plant at the company will cut most of the expenses incurred in disposing the wastewater. If the wastewater is treated up to the appropriate standards, it can then be used for gardening and farming at the company which are failing due to water shortages. The recycled water can also be used for the toilet system which requires a lot of water for the toilets to be usable. Brick moulding is also done at the company which will benefit from the recycled water. The recycling system will act as a way of saving water relieving the underground from being the only source of water. Due to climate changes, water sources are getting scarce every day and underground water is drying up hence the need to come up with ways to recycle the water that is already available (Mukheibir, 2010). Having a treatment plant at the company will also reduce the amount of waste that the Town council has to deal with hence bettering at its job. Lastly recycling wastewater is in compliance with the zero liquid discharge which is intended to be beneficial to the environment.

4. Aim

The aim of the paper is to design a treatment system that will manage black water for reuse at the company.

5. Objectives

- To design a blackwater treatment plant that can run continuously ensuring the six 5000L septic tanks remain three quarters full.
- To design a black water treatment plant that can successfully run for 24 hours a day without failing.
- To design a blackwater treatment plant that is easy to operate and maintain.

6. Literature Review

6.1. Characteristics of wastewater

Wastewater is characterised by mainly three characteristics: physical, biological and chemical characteristics. Physical characteristics include: Solids (volatile, fixed, suspended, volatile suspended, fixed suspended, dissolved, settleable), Temperature, Colour, Odour, Salinity, Dissolved oxygen and Turbidity. Chemical characteristics include: Inorganic and organic matter, pH, Oxidation reduction (OR) potential, Nutrients (Nitrogen, phosphorous, chlorides, sulphites), Gases and Biological oxygen demand (BOD). Chemical oxygen demand (COD). To degree the feasibility of waste for organic treatment, the ratio of BOD to COD is used. If the ratio is 0.5 and greater, then the sewage is straight forward to deal with however if it’s under 0.3 then the wastewater is probably containing a few poisonous elements (The Constructor Civil Engineering Home, 2020). Biological characteristics are: Bacteria, Viruses, Algae, Fungi, Protozoa and Faecal coliforms.

6.2. Wastewater treatment

- *Physical methods* - These are methods in which physical processes are predominant for example screening, mixing, flocculation, sedimentation, flotation, filtration (Tesh, 2021).
- *Chemical methods* - chemical products are added to cause chemical reactions for the removal or conversion of pollutants for example precipitation, adsorption, disinfection (CIVILDIGITAL, 2019).
- *Biological methods* - Biological activity by microorganisms causes the removal of the contaminants for example carbonaceous organic matter removal, nitrification, denitrification (Combest, 2015).

In treating wastewater, according to (Sperling, 2007), the following points must be considered,

- Environmental impacts of the wastewater on the receiving bodies.
- Treatment objectives.
- Treatment levels and treatment efficiencies.

The wastewater effluent should be in compliance with the receiving body standards (High Tide Technologies, 2020). Wastewater can be treated up to the levels indicated in table 1.

Table 1. Wastewater treatment levels (Thajudeen, 2017)

Level	Description
Preliminary	This level is used to remove coarse suspended solids and sand using physical pollutant removal mechanisms
Primary	Settleable solids and some organic matters are removed in this process by physical pollutant removal mechanisms
Secondary	Remaining organic matter and some nutrients like phosphorous and nitrogen are removed in this level mainly by biological mechanisms.
Tertiary	In this level, all the pollutants that were not sufficiently removed in the secondary level are removed usually pathogens and toxic and non-biodegradable compounds.

7. Methods

Eight wastewater samples were collected from 2 different septic tanks at the company. A single tank was chosen to represent the two septic tanks that holds wastewater from the toilets used by the management team at the company. Another septic tank was also used to represent the four septic tank that receives water from the toilets used by the rest of the employees. From each septic tank, four samples were taken at different times and different points. So, from the management septic tank, 2 samples were taken at the same time at different points. One of the samples was taken from the water entering into the septic tank while the other one was taken at the far end of the septic tank. For the second septic tank, the wastewater entering into the tank could not be accessed. As a result, the 2 points were the middle of the tank as well as the far end of the septic tank. The first set of samples were taken at 9am while the other one at 1300hrs giving a time difference of 4 hours. Turbidity and pH were measured on site using a turbidity meter and pH meter respectively while the rest of the tests were done in the laboratory. The tests and results are given in the following sections.

8. Results and Discussion

8.1. Observations

The wastewater at septic tank exit and entrance was black and grey respectively. The wastewater at the septic tank exit had an unbearable odour. This is because wastewater at the exit had matured while that at the entrance was still fresh. The septic tanks held due to careless disposal of litter into the septic tanks.

8.2. Turbidity and pH Test Results

Tables 2 and 3 show the results for turbidity and pH.

Table 2. Turbidity and pH of the wastewater from the management tank

Time	Entrance of the septic tank		End of the septic tank	
	pH	Turbidity (NTU's)	pH	Turbidity (NTU's)
9:00am	8.6	176.4	7.9	125.4
1:00pm	7.8	155.3	7.5	51.27

Table 3. Turbidity and pH of wastewater from employees' tank.

Time	Entrance of the septic tank		End of the septic tank	
	pH	Turbidity (NTU's)	pH	Turbidity (NTU's)
9:00am	8.5	270.2	8.0	46.92
1:00pm	8.0	260.1	7.6	37.10

The turbidity at the septic tank end was lower than at the entrance of the septic tanks due to the continuous flow of water into the tank at its entrance disturbing the settling of the wastewater resulting in increased turbidity. At the end of the septic tank, some of the solids have settled hence low turbidity. It can also be observed that the readings at different times are different due to quality of sewage fluctuations with time. The turbidity was less in the afternoon than in the morning because of increased use of water in the morning for bathing leading to a higher disturbance of the wastewater in the septic tank. A majority of the solids is suspended. The data from tables above indicates that this is a very poor quality of water. The pH was high due to the various chemicals in detergents, washing powders and soaps used by for bathing and washing clothes. The pH decreased with time for the same septic tank because the bathrooms are busy during the morning as employees take a shower preparing for work. In the afternoon there are less detergents and soaps used.

8.3.COD Test Results

Table 4 shows the titration results. The samples are named according to the tank, position and time at which the sample was taken. M and R represent management and employees' tanks respectively. The letter is then followed by 2 numbers. The first number represents the position: 1 means the sample was taken at the entrance of the tank while 2 means at the end of the septic tank. The second number represents the time: 1 means the sample was taken at 9:00 am while 2 means at 1300hrs.

Table 4. Titration results.

Sample	Initial reading (ml)	Final reading (ml)	Difference (ml)	COD (mg\L)
Blank	0.6	4.5	3.9	
M1.1	4.5	8.2	3.7	1000
M1.2	8.2	11.8	3.6	1500
M2.1	11.8	15.4	3.6	1500

M2.2	15.4	19.1	3.7	1000
R1.1	19.1	22.7	3.6	1500
R1.2	22.7	26.3	3.6	1500
R2.1	26.3	30.0	3.7	1000
R2.2	30.0	33.7	3.7	1000

$$COD\ (mgL^{-1}) = \frac{(B-S)\times N\times 8000}{V}\times D, where$$

B is blank titre, S is sample titre, N is normality of ferrous ammonium sulphate = 0.025, V is volume of sample taken = 2mls and D is dilution factor of sample taken = 50

$$COD\ for\ sample\ R2.2 = \frac{(3.9-3.7)\times 0.025\times 8000}{2}\times 50$$
$$= 1000\ mgL^{-1}$$

Normal domestic sewage has influent COD that ranges from 600-900mg/L (Butler Manufacturing Services, 2018). The values for COD in the sample wastewater are above the normal range. This is expected for a tile manufacturing company. Many chemicals can be easily washed into the septic tanks. One of the tanks is right beside the sedimentation tanks of the water used to clean the tiles. Employees also tend to contribute to this when they wash off the chemicals from their bodies after work and also during washing clothes. The chemicals kill bacteria cells. The bacterial cells decompose and release dissolved organic carbon. Soluble organic compounds greatly take part in escalated COD concentrations.

8.4.BOD Test Results

$$BOD\ (mgL^{-1}) = \frac{D1-D2}{p}, where$$

D1 is dissolved oxygen of diluted sample soon after preparation.

D1 is dissolved oxygen of diluted sample after 5 days of incubation at 20ºc.

P is decimal volume fraction of sample used = $\frac{1}{500} = 0.002$.

Table 5. Amount of oxygen used by each sample.

Sample	Initial dissolved oxygen (mg/L)	Final dissolved oxygen (mg/L)	Difference (mg/L)	BOD (mg/L)	BOD/COD
M1.1	7.29	6.29	1.00	500	0.500
M1.2	6.73	5.25	1.48	740	0.493
M2.1	6.88	5.87	1.01	752	0.501
M2.2	6.85	5.45	1.4	517	0.517
R1.1	6.85	5.82	1.03	700	0.466
R1.2	6.94	5.44	1.50	750	0.500
R2.1	6.90	5.88	1.02	508	0.508
R2.2	6.91	5.41	1.50	503	0.503
Average BOD				621.25	

Ordinary domestic sewage has a BOD that generally ranges between 250-400 mg/L. The BOD obtained from the septic tanks under consideration is high. High BOD indicates poor water quality and hence more oxygen is required. The samples were taken in March and it was very hot at the time. cold water holds more oxygen than warm/ hot water. The high temperatures contributed to the high BOD levels. If the BOD/COD is higher than 0.5, the wastewater can be easily biologically treated. Since all the values except one for BOD/COD are greater than 0.5, biological methods maybe applied to treat the water.

8.5.Total Phosphorous Test Results

Below are the absorbance values determined from the standard solutions used to create a calibration graph.

Table 6. Concentrations and absorbance of the standard solutions and the samples

Standard solution (SS) concentration (mg/L)	Absorbance of SS	Sample	Absorbance of sample	Total phosphorous (mg/L)
0.02	0.070	M1.1	0.131	0.042
0.04	0.104	M1.2	0.277	0.073
0.06	0.146	M2.1	0.246	0.067
0.08	0.280	M2.2	0.416	0.100
0.10	0.408	R1.1	0.541	0.130
0.12	0.532	R1.2	0.655	0.150
		R2.1	0.415	0.100
		R2.2	0.323	0.083

Typical levels of total phosphorous in municipal water are 5-20 mg/L. The values above are below this range. The total phosphorous recommended in flowing waters is 0.1mg/L. There are only two samples that exceeds this value. Since they are slightly above 0.1mg/L, the phosphorous can be removed from the wastewater by biological means.

8.6.Faecal Coliforms

$$\text{faecal coliforms per 100ml} = \frac{\text{number of faecal coliform colonies counted}}{\text{number of ml of sample filtered}} \times 100$$

2 ml were filtered for each sample.

The table below gives the total faecal coliforms per 100ml of each sample.

The high numbers of faecal coliforms prove that disease causing microorganisms are present in the water. This is as a result of human excreta from the toilets. The results are shown in table 7.

Table 7. Number of faecal coliforms in each sample

Sample	faecal coliform colonies counted	Faecal coliforms per 100ml
M1.1	1 176	58 800
M1.2	4 200	210 000
M2.1	2 688	134 400
M2.2	1 512	75 600

R1.1	2 184	109 200
R1.2	2 016	100 800
R2.1	2 520	126 000
R2.2	1 680	84 000

9. Design of the Treatment Plant.

The wastewater tank is designed to collect 20 000 L. The full design included designs of the bar screen, the trench, the Chain Drive and the Rake.

9.1. Design of a plate that cleans the rake.

Figure 3 shows the complete bar screen in a trench of water.

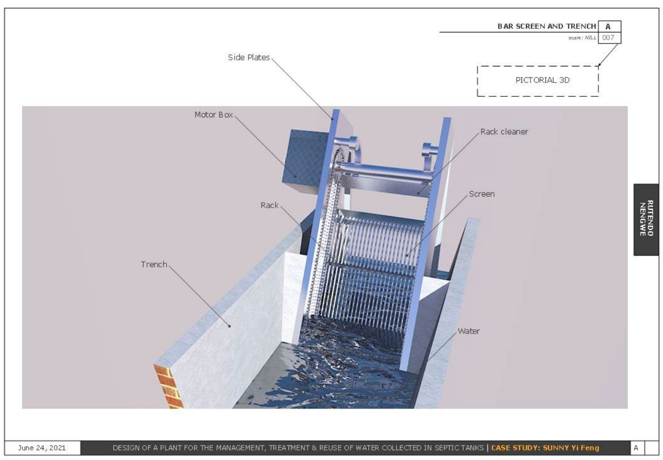

Figure 3. Complete bar screen with all its parts assembled together

The pipe that transfers the effluent from the trench to the primary settling tank will be 150 mm in diameter.

9.2. Design of settling tanks

The figures below show the primary and settling tanks. The primary tank is capped at the bottom while the secondary settling tank is connected to an outlet pipe at the bottom to return the sludge to the aeration tank.

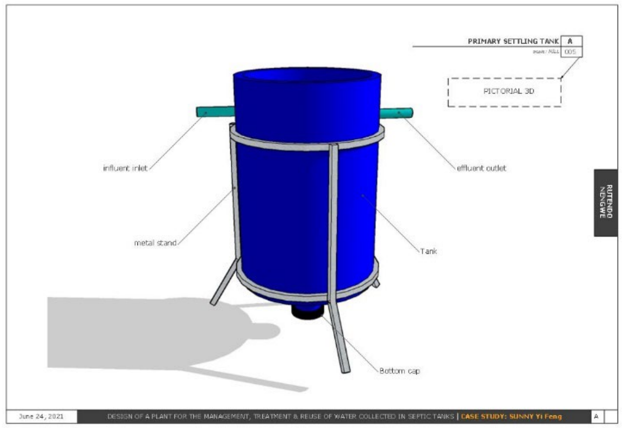

Figure 5. Primary settling tank with its supporting stand.

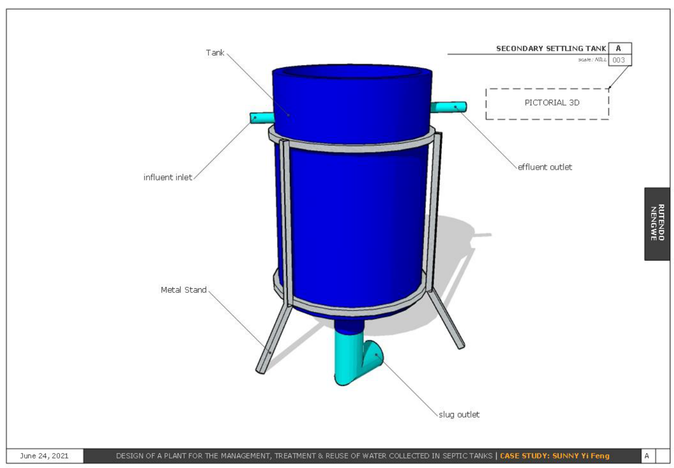

Figure 6. Secondary settling tank with its supporting stand.

The stands supporting the tanks will be made from cast iron. Cast iron is chosen because of its good strength.

9.3.Design of an aeration tank.

Figure 7 is showing the aeration tank.

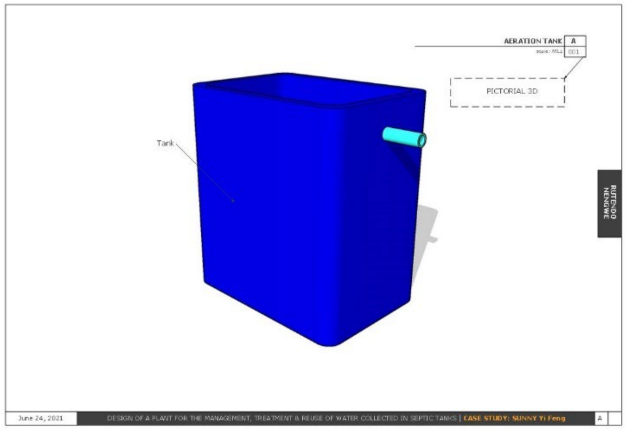

Figure 7. Aeration tank

10. Disinfection

chlorine will be used for disinfection. Regular 5.25 unscented bleach will be used. For every 1000L of the wastewater 1 L of the bleach should be used. Since the flow rate is 1L/s, 0.001L/s should be added. One drop of a liquid is 0.00005L so 20 drops of the bleach should be added per second. A chlorine dosing pump will be used to achieve this.

11. Storage.

After adding chlorine, the water should stand at least an hour before usage. The water will be stored in a $20m^3$ tank. The water can then be used for gardening coming from the tank. Since water is incompressible, the flow rate will be constant unless changed by flow valves. The diameter of the pipes can remain constant and only vary the velocity. In all the calculations done in the previous sections, it is the flow rate that is of great importance and not the velocity of the water in the pipes. And as such the diameter of all the pipes will be kept with a diameter of 150 mm. The pipes will be made of PVC.

12. Sludge treatment.

The sludge will be heated at 40ºc for 60 minutes using the heat generated in the factory during tile manufacturing. After heating, the sludge is taken drying beds where it will be completely dried by the atmosphere. The drying beds will be made of gravel. The sludge is placed on top of the gravel and is left in the open air to dry.

13. Cost Benefit Analysis

Below is an analysis to see if the introduction of the wastewater treatment plant is more economic than disposing the wastewater at the local municipal water council. It was noted in chapter 1 that the company spends $36 000 RTGS per day to dispose the wastewater and 30L of diesel. Using a bank rate of $1 USD: $82.9456 RTGS as of 16 June 2021, $36 000 RTGS is equivalent to $434 USD. The cost of 1 L of petrol as of 16 June 2021 was $1.20 bringing the total amount of fuel needed per day to $36 USD. The total that the company spends on disposing the wastewater in a day is $470 USD. The amount spent in a year then amounts to $171 550 USD. The prices were taken from Steel center, Electrosales hardware, Bhola hardware in Harare and Aliexpress.com. Below is a table with the price listing of all the materials to be used in the design of the treatment plant.

14. Conclusion

A model of the design explained was made to test the effectiveness of the design. Wastewater was collected from the same septic tanks used for data collection in chapter 3. This time, the wastewater was mixed to get a single sample. The same parameters that were tested out in chapter 3 were repeated before and after running a sample of the wastewater in the model. Below are the results. The results were tabulated against the standard expected values according to the public health (effluent) regulations of Zimbabwe in Table 8.

Table 8. parameters of the treated water.

Parameter	Before treatment.	After treatment	Public health (effluent regulations)
Ph	8.6	7	6-9
Turbidity (NTU's)	65.17	13	15
BOD (mg/L)	620	6	≤10
COD (mg/L)	1250	57	≤60
Faecal coliforms per 100ml	112 350	38	≤10
Total phosphorous (mg/L)	0.093	0.0005	

The results above indicates that the water is safe to come into contact with humans since the total faecal coliforms have been reduced to a very small amount. Reduction in number of faecal coliforms is an indication that the disinfection process was effective. BOD and COD concentrations have decreased as well to an allowable amount indicating that the design of the aeration tank is acceptable. Water should have a pH of 7 and since the treated water has a pH of 7, the design of the treatment plant can be regarded as effective. The very low turbidity indicates that the water is very clear. This proves that the settling tanks were effective and their design can be accepted. The total phosphorous has also decreased to an amount that can be accepted in the garden. The values are below the standard values indicating that the plant will be in compliance with the public health (effluent) regulations. In conclusion the design is effective and can be used for the treatment of wastewater from septic tanks at Sunny Yi Feng company.

15. Recommendations

Because nutrients like nitrogen, potassium, calcium, magnesium and sulfur that affects the soil were not tested, it is not 100% clear if the water is very fit for irrigation. These nutrients were not tested for because of lack of resources as well as funds. Testing for these nutrients would have given a better and unbiased review of the treated water. I recommend testing for these nutrients and deduce if there is a need to alter the design given in this paper.

Because locating the positions of the treatment plant, the distance between the tanks and the geometrical relationship of the elements of the plant amongst each other was not part of this project, the length of the pipes could not be determined correctly and were as a result of estimation. Therefore, their actual price might differ from the price given in the table above. It is recommend that the actual length of the pipes be calculated to give a correct pricing of the pipes and hence a better cost benefit analysis.

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