OPEN ACCESS
Saudi Journal of Civil Engineering
Abbreviated Key Title: Saudi J Civ Eng
ISSN 2523-2657 (Print) |ISSN 2523-2231 (Online)
Scholars Middle East Publishers, Dubai, United Arab Emirates
Journal homepage: https://saudijournals.com/journal/sjce/home

Original Research Article

Time Series Analysis of the TSS, TDS, BOD, COD, and Turbidity of Waste Water in a Pre-filtration Chambers of Enhanced Household Septic Tank

Okonkwo Victor O[1], Mbachu Victor M[2*], Bosah Nneka C[3], Mbachu Williams A[3], Alukwe Uche J[3]

[1]Department of Civil Engineering, Nnamdi Azikiwe University, Awka, Nigeria
[2]Department of Industrial and Production Engineering, Nnamdi Azikiwe University, Awka, Nigeria
[3]Department of Applied Microbiology and Brewing, Nnamdi Azikiwe University, Awka, Nigeria

DOI: 10.36348/sjce.2023.v07i05.001 | **Received:** 29.04.2023 | **Accepted:** 08.06.2023 | **Published:** 30.06.2023

***Corresponding author:** Mbachu Victor M
Department of Industrial and Production Engineering, Nnamdi Azikiwe University, Awka, Nigeria

Abstract

Beyond copious production of biogas, household septic tanks present largely untapped potentials for waste water recycling, especially in area with difficulty in getting sustainable supply of water and energy. The black water (the faeces and urine from the toilets) and grey water (the waste water from the bathrooms, kitchen and laundry) in the septic tank can be harnessed for biogas production and could be recycled for use in irrigation and other domestic uses. In this work, an enhanced septic tank system was designed and implemented in the preliminary treatment of domestic waste water. From the results obtained the system has the ability to significantly reduce the TDS, turbidity, and BOD of a given sample prior to filtration. The COD and TDS of the sample decreased and increased with time due to pressure buildup. This informs the timing for fluid transfer into the next phase of the recycling – sand filtration. Optimization of the design and operations of the new enhanced septic tank system is important in the actualization of the goal of having efficient bio-waste recycling and conversion.

Keywords: Septic tanks, biogas, waste water, water treatment, bio-digester.

1.0 INTRODUCTION

Household septic tanks present largely untapped potentials for waste water recycling and even copious production of biogas, especially in area with difficulty in getting sustainable supply of water and energy. Most organic biomass can generate biogas once the right pretreatment and operating parameters are put in place (Mbachu *et al.*, 2021). The paper submitted that sustainability of feedstock supply is germane in having a productive replacement of fossil based fuel with biogas. Alemayehu (2015) even recommended expansion of the list of possible feed-stock for biogas production beyond cow dung and manure.

The black water (the faeces and urine from the toilets) and grey water (the waste water from the bathrooms, kitchen and laundry) in the septic tank can be harnessed for biogas production and could be recycled for use in irrigation and other domestic uses.

In the traditionally constructed septic tank system, the used or waste water is made to move through the soak away pit into the soil and sometimes contaminate the ground water. Preliminary laboratory test carried out on a number of such septic tanks showed staggering amounts of parasites, COD, TSS and BOD. There is the risk of these pathogens going back to our food chain through infested water, sea food, domestic animals etc.

Several redesign or improved version of the septic tank system is in place, Anaerobic Baffled Reactor (ABR) (see Figure 1) and Up flow Anaerobic Sludge Blanket reactor (UASB) (see Figure 2.). With a view to tackle the challenges of these two designs, a new enhanced septic tank system is being design to generate biogas and recyclable water. The new design incorporates a tripartite solution set – energy generation, and recycling of waste water, and salvaging the environment and the food chain, which are germane in achieving the Millennium Development Goal (MDG).

Considering the dynamic nature of the substrates in a continuous feeding system, it is important to study the interplay between the characteristics of the substrate in the pre-filtration phase and the incoming substrates, as well as the duration of substrates in the chamber. The time and operating parameter dependent reactions or changes in the characteristics of the substrate was studied. This relationship provides vital information for the design of the filter media.

2.0 Waste Treatment Techniques

There have been well documented attempts to improve the quality of discharge from the septic tank through improvements in their designs. The Anaerobic Baffle Reactor (ABR) comprises a series of up flow and down flow baffles in the tank forcing the waste water to flow through a series of sludge blanket reactors. The increased level of contact between anaerobic biomass and the waste water consequently improves the water treatment. It has shown a moderate efficiency in BOD removal and in the removal of suspended solids. BOD removal can be as high as 90%. It is also a compact system and so can be installed in places with limited space. It is however not suitable for places with a high water table as it is mainly buried underground. A high water table increases the risk of water infiltration into the system which will disrupt its processes. There is also risk of ground water pollution in such a situation. ABR is also not known to be efficient in the removal of pathogens.

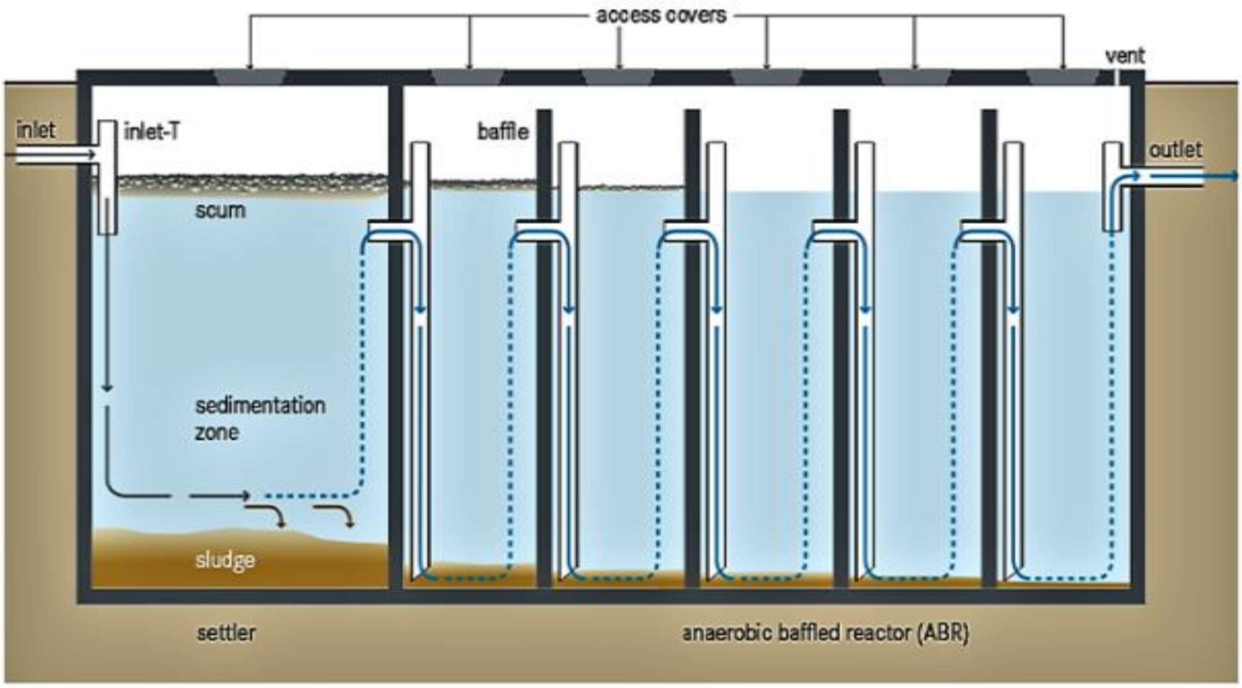

Figure 1: Schematic of the Anaerobic Baffled Reactor
(Source: Tilley *et al*., 2014)

Meanwhile, in the Up flow Anaerobic Sludge Blanket reactor (UASB), the waste water is gradually passed upwards through an anaerobic sludge blanket that consists of microbial particles. During this upward flow the organic matter in the waste water is broken down by the bacteria and the gas released help in mixing the sludge. As the bacteria are fed, larger granules are formed which begins to serve as a filter material. The very light granules are washed off. The biogas released is tapped at the top. UASB is more efficient in both biodegradation of organic matter and in the treatment of waste water than the traditional septic tank system. The technology behind its operation is simple; however, it requires constant water and electricity supply to work properly. Its application in the treatment of domestic waste is still new. It has however been used extensively in the treatment of high strength industrial waste water, most especially in brewery, food processing and paper production (Cruz-Salmon *et al*., 2017; Enitan *et al*., 2018; Mainardis and Goi, 2019).

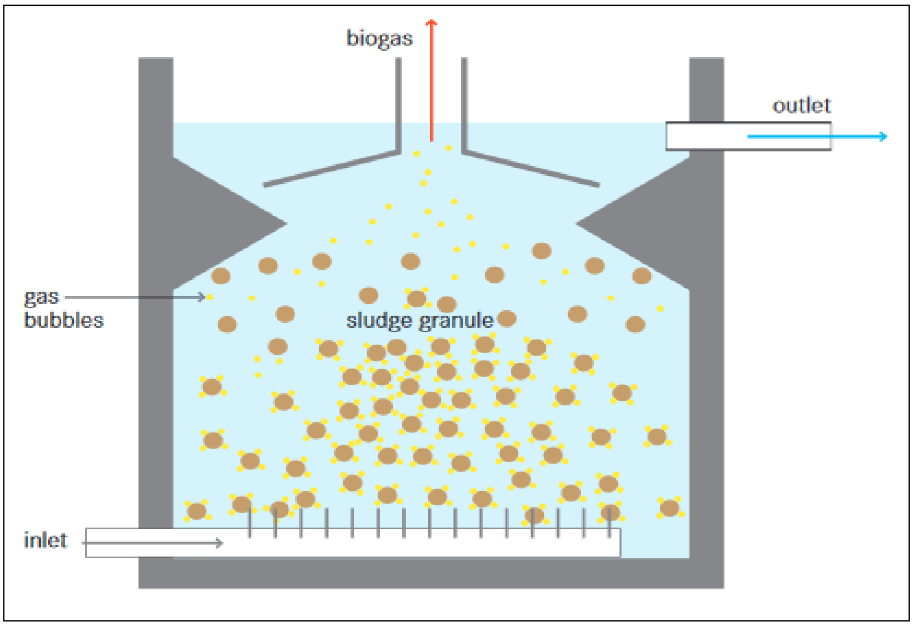

Figure 2: Schematic of an Up flow Anaerobic Sludge Blanket reactor
Source: Tilley *et al*., 2008

For granules sizes of 12mm to 55mm and a flow rate of 2.8m/day, 50% to 80% BOD removal from waste water can be achieved (Tilley *et al*., 2008. It however has limited effect on nutrients especially nitrogen and phosphorus (Vassalle *et al*., 2020). This has necessitated the need for a post-treatment of the effluent, such that is suggested in Chong *et al*., (2012), to take care of the nutrients and pathogens.

The ABR and UASB are both primary treatment methods for waste water treatment. A less popular primary treatment method is the pond system. It has been successfully used in some low and middle income countries such as India. Pond system is discouraged because it is occasionally associated with unpleasant odours and presents breeding ground for mosquitoes. Beyond the primary treatment of waste water which involves majorly the removal of settleable solids. The less/slowly settleable solids and dissolved matter can only be removed through a secondary treatment. Secondary treatment can be aerobic or anaerobic. What is common is the use of a filter media. The treated waste water is passed through the filter media where the micro organisms in the filter media attack and biodegrades organic matter and pathogens in the waste water. The filter media provide a large surface area for bacteria to breed and produce biofilms which are essential for the efficiency of this process. The filter media materials are usually made of different beds of sand and gravel. Anaerobic filters are usually used for treating high strength waste waters (Cakir and Stenstrom, 2003). A summary of the different treatment methods, their merits and demerits are presented in Table 1.

2.1 The Nigerian Experience

In Nigeria, the use of septic tanks for the treatment of our waste is still very common. In Abuja 70.4% and 29.6% use onsite (septic tank) and offsite (connected to the sewer) for the treatment of domestic waste respectively. This agrees with the position of the Abuja Environmental Protection Board (AEPB) that only 30% of Abuja is connected to a central sewer. In Ibadan 51% use the pit latrines while 47% use septic tanks and 0.5% use VIP latrines. In 2015, a world bank sponsored survey of water supply and sanitation in Port Harcourt showed that 90.5% has a pour flush toilet connected to a septic tank. Others relied on hanging latrines over waterways (5.3%) and pit latrines (1.8%) (World Bank 2017).

There is however no framework for fecal sludge management in Nigeria. The sanitation related state policies are such that do not encourage private sector participation and citizen ownership of the schemes. (www.wateraid.org/ng). The success of a Fecal Sludge Management (FSM) will depend on the level of community ownership and level of financial sustainability that is built into the implementation process. There is therefore need for the development of an improved septic tank with enhanced waste management efficiency, such that is affordable and can be deployed by individuals, and communities.

Table 1: Merits and Demerits of the different Waste water treatment methods

Treatment System		Advantages	Disadvantages
Primary Treatment	Sedimentation	1) There is Gravity separation 2) Decomposition is anaerobic	1) Sludge accumulation reduces volumetric capacity of the tank 2) Frequent desludging required: Every 2-5 years
	Anaerobic Baffled Reactor (ABR)	1) It is resistant to organic and hydraulic shock loads. 2) Requires no electricity supply. 3) Can also treat grey water concurrently. 4) Built and repaired with locally available materials. 5) Has a long service life. 6) Limited/zero real problems of flies or foul smell. 7) High reduction of organic matters. 8) Moderate capital costs, moderate operating costs depending on emptying; can be low cost depending on number of users.	1) Requires a most complex Construction and maintenance than septic tanks 2) Costs more than the traditional septic tank system 3) Requires constant source of water. 4) Effluent requires secondary treatment and/or appropriate discharge. 5) Expert design and construction required. 6) Waste needs to be Pre-treated to prevent clogging.
	Up flow Anaerobic Sludge Blanket Reactor (UASB)	1) High reduction in organic matter. 2) It can withstand both high organic loading and high hydraulic loading rates. 3) Sludge production is low reducing the rate of desludging.	1) It is hard to maintain a proper hydraulic conditions. 2) Long The start up time is long. 3) Treatment may be unstable with variable hydraulic and organic loads. 4) Constant electricity supply is required. 5) Some materials requires for it construction might not be available locally. 6) The design and construction requires some expertise.
	Pond System for Primary Treatment	1) It has been well tested and proven in low and middle-income countries.	1) Pond systems are usually unpleasant and Emit odours 2) Offers a perfect environment for mosquitoes if not well-operated and maintained 3) Not recommended by WHO (2005) guidelines for safe use of excreta and grey water. 4) Requires a Septic or sedimentation tanks for primary treatment.
Secondary Treatment	Anaerobic Filtration	1) Good performance in removal of suspended dissolved solids. 2) Has a high resilience to hydraulic and organic shock loads. 3) sludge development is slow.	1) Long-term experience with grey water treatment is still lacking 2) Nutrient and pathogen removal is slow.
	Pond system for secondary treatment	1) Ponds can be used for large scale applications.	1) Not recommended as a primary treatment method for grey water from households due to mosquito breeding and bad odour.

Source: Modjinou (2014)

3.0 The Working Principle of the New Enhanced Septic Tank System

This new design aims at taking advantage of the merits and demerits of the already reviewed septic tank systems. Beyond biogas production, the septic tank needs to be enhanced for efficient water treatment and recovery of water of recyclable quality in an economic and self sustaining manner.

From the review of ABR and UASB it is clear that the contact between waste water and the bacterial rich sludge is beneficial to the treatment of the waste water and it is also instrumental to the mixing of sludge which enhances bacteria activity and therefore biogas production. The new design therefore incorporates these features.

The use of sand filters for secondary treatment of waste water is an age long adoption in waste water treatment. It essentially consists of carefully selected graded sand placed upon gravel. It is expected that the sand particles should be of uniform sizes. The most effective size for sand filtration is between 0.35mm and 0.15mm and with a uniformity coefficient that is less than 2 (Logan *et al*., 2001). The main factors affecting the efficiency of sand filtration are the sand particle size and the hydraulic rate of flow, while the small particle size is more effective in removal of nano-sized particles and freely suspended viruses, the lower hydraulic rate is germane to the removal of pathogens (Maurya *et al*., 2020). The sand does the filtration while the gravel underneath protects the sand from being eroded. As water seeps through the sand filter it gets cleaned through mechanical straining, sedimentation, adsorption and bacterial action. For a slow sand filter the depth of the sand can be up to one meter and sand preferably rounded and with a diameter of 0.2mm to 0.3mm was used, since the the finer the sand the more the contact surface and the better the treatment. This also applies to the depth of sand column. The rate of filtration was 0.1 to 0.4$m^3/h/m^2$.

The slow sand filter that is very effective in pathogen removal and has recorded approximately 99% removal of coliform under ideal conditions (Clark *et al*., 2012), was adopted. The high success rate of the slow filter is because of the cleaning power of a layer of bio-film known as the schmutzdecke. These bacteria attack other bacteria in the wastewater as they pass through the biofilm. It has been proven that when properly operated and managed sand filtration produces a very high quality effluent.

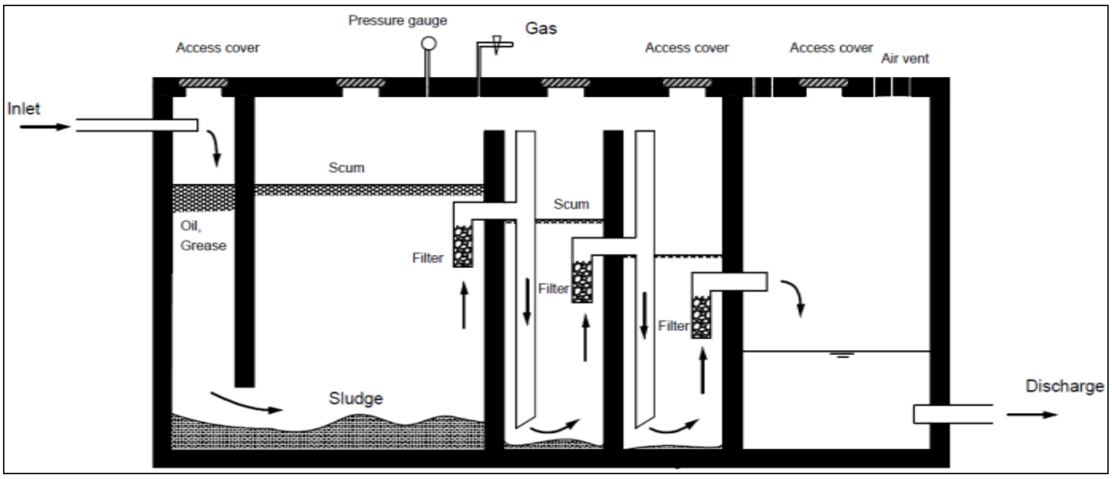

Figure 3: Schematic diagram of the enhanced septic tank design

A particle size analysis of typical river sand in Anambra state (Onitsha sand) is presented in Table 2. The table shows the particle sizes in a specific volume of sharp sand and its proportion relative to others.

Table 2: Particle size analysis of 8.92kg Onitsha river sand

S/N	Particle Sizes (mm)	Weight (kg)	Percentage of total weight (%)
1	4.75 – 2.00	0.21	2.354
2	2.00 – 1.18	0.042	4.709
3	1.18 – 0.85	0.53	5.942
4	0.85 – 0.60	1.08	12.108
5	0.60 – 0.425	2.40	26.906
6	0.425 – 0.30	2.25	25.224
7	0.30 – 0.15	1.97	22.085
8	0.15 – 0.075	0.36	40.359
9	0.075 – 0.00	0.06	0.673

It can be seen that particle sizes of 0.425mm to 0.15mm represented about 47.3% of the total weight of the sand. These are incidentally the best sizes for use in sand filtration. This suggests that the sand of required particle size is readily available.

Merits of the new designs

The proposed septic tank design, which is presented in Figure 3, incorporates the positive features of the primary and secondary treatment facilities. The first chamber was introduced to eliminate the negative effects of grease and oils on methanogenesis. Oils reduce the activities of methanogens and consequently lead to lower organic matter biodegradation and biogas yield (Patra and Yu, 2012; Vargas *et al*., 2020). Waste water with high lipid concentrations are also known to cause clogging, floatation of sludges and release of bad odours (Mainardis *et al*., 2020). The first chamber takes its contents down into the treated waste to encourage mixing of waste water with the sludge and the anaerobic bacteria. Likewise all the flows into subsequent chamber were made to have contact with the bacteria rich sludge.

Sand filters used mainly in the secondary treatment of waste water is installed and used as the waste water flows from one chamber to the other. The flow through the filter bed is made upwards as this helps in reducing the risk of clogging and also the risk of having the active biomass in the filter media washed off. Sedimentation in the filter causes particle to drop downwards under gravity to the bottom of the bio-digester. The repeated sedimentation, filtration and microbial action will remove most BOD and pathogens and increase flocculation of organics. In order to maintain a uniform flow through the filter media a head of about 0.3m is maintained between successive chambers.

The design can be easily optimized by introducing more chambers/filtration units in order to have a higher number of sand filtration and sedimentation time. This is can be done to attain effluent of the desired quality. The design is also scalable. Where an increase in volume of treated water or the speed of operation is of interest, the volume of flow through the filter sand can be increased without increasing the flow rate by increasing the surface area of the filter bed.

The design is also environmentally friendly as it does not involve the addition of inorganic chemicals as part of the treatment process. For areas with high water table or places vulnerable to flooding this enhanced septic tank is more ideal. It can be factory produced with plastics. As plastics are impermeable there will be no percolation of ground water into the system to disrupt the process, likewise untreated or partially treated waste water will not leak into the ground water.

Its construction and operation are cheap and easy as our ambient temperature in Nigeria is within the mesophilic range. It will not require any external heating. It can also be constructed with locally available materials like bricks or concrete. The filter media (sand) is readily available.

Because of its effectiveness in the treatment of waste water, it is ideal for places where water availability is scarce, as the treated water can find a fresh use as flush water hence reducing the water demand in the maintenance or operation of the toilets.

A pilot implementation of this design for the treatment of household wastewater was carried out (see Figure 4). The experimental set was fed with a fixed volume of kitchen effluent for a period of 19 days. The effluent was first poured into a receptacle (a suspended bucket) from where they were discharged into the first chamber. Just before discharge into the first chamber the waste water was tested for total suspended solids (TSS), total dissolved solids (TDS), chemical oxygen demand (COD), biological oxygen demand (BOD) and Turbidity. The test results are as presented in Table 3 below.

Figure 4: Experimental set-up of the treatment tank

Table 3: Test results on untreated kitchen waste

	TSS (mg/l)	TDS (mg/l)	COD (mg/l)	BOD (mg/l)	Turbidity (NTU)
Day 1	300	17.1	480	610	1060
Day 4	10.4	5	224	558	930
Day 7	4.1	6.7	416	268	1050
Day 10	2	5.1	208	244	559
Day 13	1.6	1.2	176	164	84
Day 16	0.6	1.8	288	156	853
Day 19	2.8	2.8	230.4	132	663

From Table 3 it can be seen that the kitchen waste were of varied values of TSS, TDS, COD, BOD and turbidity. This is the reality in practice. Kitchen waste constituent varies, depending on food, waste generated and the detergent used in washing, among others.

From the receptacle the waste water is discharged into the first chamber under anaerobic conditions. Test on the contents of the first chamber commenced on the 4th day and was carried out every three (3) days. The test results are presented in Table 4 below.

Table 4: Test results on kitchen waste in the bio-digester

	TSS (mg/l)	TDS (mg/l)	COD (mg/l)	BOD (mg/l)	Turbidity (NTU)
Day 4	14.7	7.5	256	386	960
Day 7	2.6	2.3	288	200	903
Day 10	0.6	1.2	192	194	908
Day 13	0.8	1	128	136	423
Day 16	0.6	3.2	224	144	379
Day 19	1.4	3	160	96	593

Assuming zero or insignificant chemical reactions between the particle constituents of the waste water and that the relative rate of removal of any of the parameters TSS, TDS etc are the same irrespective of the kitchen waste, we can from Tables 3 and 4 calculate the values of each parameter for the first wastewater (released into the first chamber) over the 18 day period.

Let the test results of the first waste water after n days in the first chamber be A_n, where A stands for first wastewater while n is for the number of days it spent in the first chamber before it was tested, i.e. the pre-filtration phase. Likewise the test results of the second waste water after n days in the first chamber is B_n. In the same manner the test results of the third waste water after n days in the first chamber is C_n and so on.

We can from a simple substitution calculation find out the values of each of the tests parameters on the first samples after 3, 6, 9, 12, 15and 18 days (i.e A_3, A_6, A_9, A_{12}, A_{15}). From Table 3 the value of TSS for the first influent just before discharge into the first chamber A_0 = 300mg/l. From Table 4 the value of TSS for the first influent after three days in the first chamber A_3 = 14.7mg/l. From Table 4 the value of TSS for the mixture of the first and second influent in the first chamber $(A_6+B_3)/2$ = 2.6mg/l. The value of TSS for the mixture of the first, second and third influent in the first chamber $(A_9 + B_6 + C_3)/3$ = 0.6mg/l and so on.

Let $a_{0\text{-}3} = A_3/A_0 = B_3/B_0 = C_3/C_0 = D_3/D_0$ …… (1a)

$a_{3\text{-}6} = A_6/A_3 = B_6/B_3 = C_6/C_3 = D_6/D_3$ …….. (1b)

$a_{6\text{-}9} = A_9/A_6 = B_9/B_6 = C_9/C_6 = D_9/D_6$ …...... (1c)

From equation (1a-c) and tables 3 and 4 we obtain the values of test parameter (TSS) for the first influent (A) for day 0, 3, 6. 9, 12, 15 and 18. The same method is applied to other test parameters and their values for the first influent (A) for days 0, 3, 6. 9, 12, 15 and 18 obtained. These are presented in table 5 below.

Table 5: Calculated values of test parameters on the first influent (A) after different number of days in the first chamber

n (days)	TSS (mg/l)	TDS (mg/l)	COD (mg/l)	BOD (mg/l)	Turbidity (NTU)
0	300.00	17.10	480	610	1060
3	14.70	7.50	256	386	960
6	4.69	2.41	456.53	46.90	963.74
9	1.44	0.26	141.08	369.51	927.51
12	2.99	0.84	67.57	30.98	217.33
15	2.77	5.92	674.50	286.78	201.25
18	8.20	14.94	204.55	40.93	628.12

The information in Table 5 is better understood when presented in the form of line plots as shown in Figure 5 (a-e).

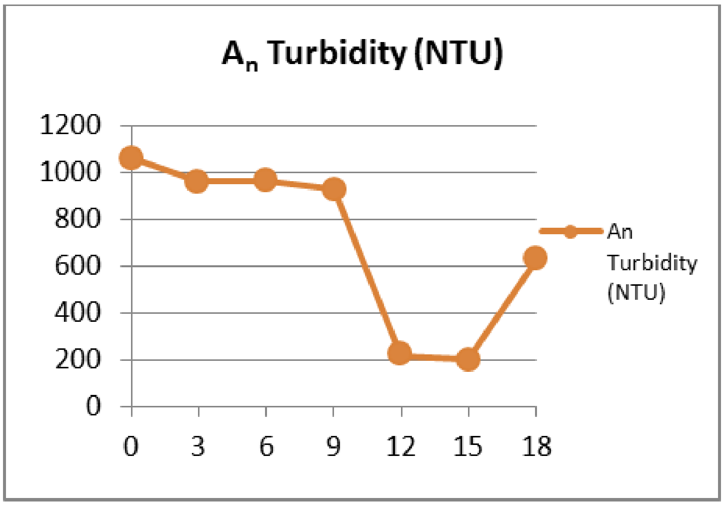

Figure 5a: Plot of A_n Turbidity values against time

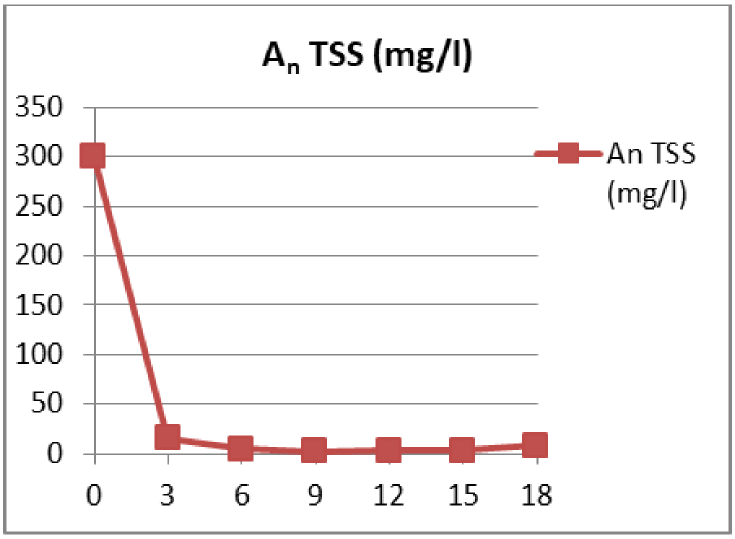

Figure 5b: Plot of A_n TSS values against time

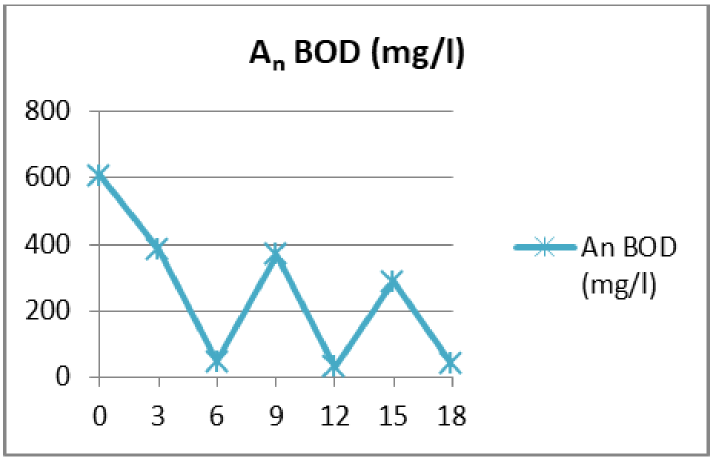

Figure 5c: Plot of A_n BOD values against time

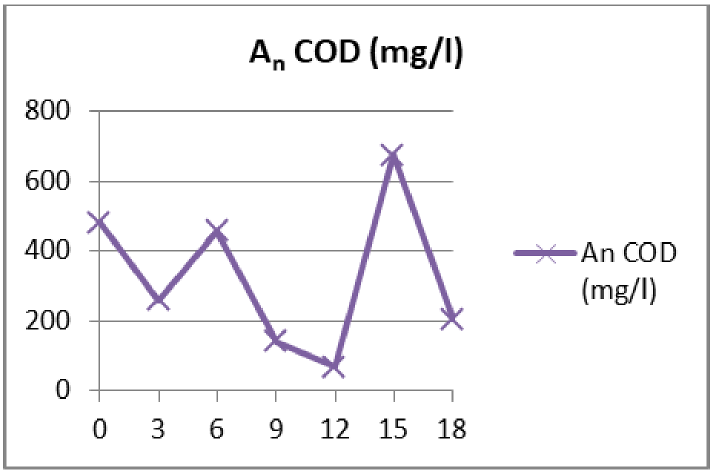

Figure 5d: Plot of A_n COD values against time

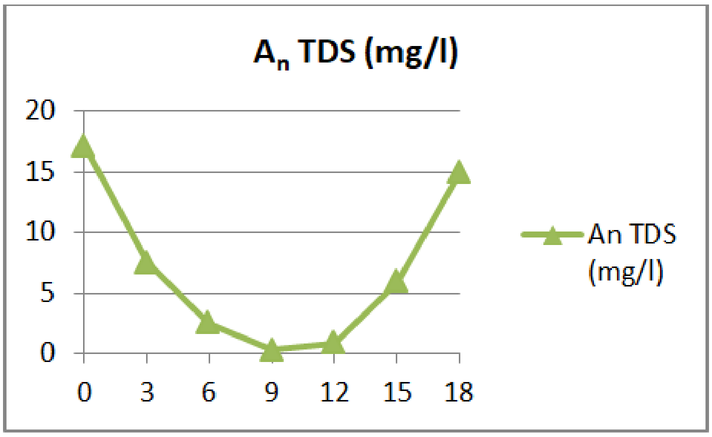

Figure 5e: Plot of A_n TDS values against time

From the graph we see that there was a drop in the values of TSS and TDS as number of days (n) increased. This is expected due to sedimentation. At the 18th day the TSS appeared to increase. This could be as a result of the buildup of pressure in the chamber. The effect of pressure on the cleaning potential of the chamber is more pronounced in the TDS results. From the 9th day the values of the TDS began to increase. Turbidity results followed the same trend with TSS and TDS results. COD and BOD seem unaffected by the number of days. Hence the sand filtration component of the experimental set is needed to remove the COD and BOD.

CONCLUSION

Waste management and disposal is critical to the overall health of the people. In developed climes water borne diseases like typhoid has been completely eliminated due to the installation of effective water treatment schemes and good access to clean water. This is achievable in poorer nations if cheaper and yet effective schemes are designed and implemented. From the results obtained the system has the ability to significantly reduce the TDS, turbidity, and BOD of a given sample prior to filtration. The COD and TDS of a given sample decrease and increase with time due to pressure buildup. This informs the timing for fluid transfer into the next phase of the recycling – sand filtration. Optimization of the design and operations of the new enhanced septic tank system is important in the actualization of the goal of having efficient bio-waste recycling and conversion.

ACKNOLWEDGEMENT

The authors acknowledged the financial support provided by Tertiary Education Trust Fund (TETFund) through Institution Based Research (IBR) intervention [grant reference number: NAU/VC/68/VOL.III/176].

REFERENCES

- Alemayehu, Y. A. (2015). Enhancement and optimization mechanisms of biogas production for rural household energy in developing countries: a review. *International Journal of Renewable Energy Development*, *4*(3), 189-196.
- Cakir, F. Y., & Stenstrom, M. K. (2003). A dynamic model for anaerobic filter. *Journal of Environmental Science and Health, Part A*, *38*(10), 2069-2076. doi:10.1081/ese-12002333

- Chong, S., Sen, T. K., Kayaalp, A., & Ang, H. M. (2012). Performance enhancements of Up flow anaerobic sludge blanket (UASB) reactors for domestic sludge treatment- A state-of-art review, *Water Res*, 46, 3434-3470, doi:10.1016/j.watre.2012.03.066
- Clark, P. A., Pinedo, C. A., Fadus, M., & Capuzzi, S. (2012). Slow-sand water filter: Design, implementation, accessibility and sustainability in developing countries. *Medical science monitor: international medical journal of experimental and clinical research*, *18*(7), RA105-117.
- Cruz-Salomón, A., Meza-Gordillo, R., Rosales-Quintero, A., Ventura-Canseco, C., Lagunas-Rivera, S., & Carrasco-Cervantes, J. (2017). Biogas production from a native beverage vinasse using a modified UASB bioreactor. *Fuel*, *198*, 170-174. doi:10.1016/j.fuel.2016.11.046
- Enitan, A. M., Kumari, S., Odiyo, J. O., Bux, F., & Swalaha, F. M. (2018). Principal component analysis and characterization of methane community in a full-scale bioenergy producing UASB reactor treating brewery wastewater. *Physics and Chemistry of the Earth, Parts A/B/C*, *108*, 1-8. doi:10.1016/j.pce.2018.06.006
- Logan, A. J., Stevik, T. K., Siegrist, R. L., & Rønn, R. M. (2001). Transport and fate of Cryptosporidium parvum oocysts in intermittent sand filters. *Water Research*, *35*(18), 4359-4369. doi:10.1016/s0043-1354(01)00181-6
- Mainardis, M., & Goi, D. (2019). Pilot-UASB reactor tests for anaerobic valorisation of high-loaded liquid substrates in friulian mountain area. *Journal of Environmental Chemical Engineering*, *7*(5), 103348. doi:10.1016/j.jece.2019.103348
- Mainardis, M., Buttazzoni, M., & Goi, D. (2020). Up-flow anaerobic sludge blanket (UASB) technology for energy recovery: a review on state-of-the-art and recent technological advances. *Bioengineering*, *7*(2), 43. doi:10.3390/bioengineering7020043
- Mauryo, A., Singh, M. K., & Kumar, S. (2020). Biofiltration technique for removal of water borne pathogens In: Waterborne Pathogens, Butterworth-Heinemann, pp 123-141. doi:10.1016/B978-0-12-818783-8.00007-4
- Mbachu, V. M., Ovuworie, G. C., Okwu, M. O., & Tartibu, L. K. (2023). Modelling sustainability of a demand-based biomass to biogas conversion system: a bio-mimicry feedstock inventory-based approach. *Biomass Conversion and Biorefinery*, *13*(6), 4957-4963. https://doi.org/10.1007/s13399-021-01581-z
- Modjinou, M. (2014). Domestic septic tanks for treating sewage and biogas generation, Kwame Nkrumah University of Science and Technology, Unpublished MSc thesis.
- Patra, A. K., & Yu, Z. (2012). Effects of essential oils on methane production and fermentation by, and abundance and diversity of, rumen microbial populations. *Applied and environmental microbiology*, *78*(12), 4271-4280. doi:10.1128/AEM00309-12
- Sridhar, M. K. C., Wahab, B., Oloruntoba, E. O., & Idachaba, A. (2011). Landscape Analysis and Business Model Assessment in Fecal Sludge Management: Extraction and Transportation Models in Africa. *Nigeria Study Report.* www.susana.org/_resources/documents/default/2-1671-nigeria-fsm-study.pdf
- The World Bank Group. (2008). www.climateknowledgeportal.worldbank.org/country/nigeria/climate-data-historical. [accessed on 11th October 2022]
- Tilley, E., Ulrich, L., Luthi, C., Reymond, P., & Zurbrugg, C. (2008). Compendium of Sanitation Systems and Technologies, 2nd Edition, Eawag Swiss Federal Institute of Aquatic Science and Technology, Switzerland.
- Tilley, E., Ulrich, L., Luthi, C., Reymond, P., & Zurbrugg, C. (2014). Compendium of Sanitation Systems and Technologies, 2nd Edition, Swiss Federal Institute of Aquatic Science and Technology, Switzerland.
- Vargas, J. E., Andrés, S., López-Ferreras, L., Snelling, T. J., Yáñez-Ruíz, D. R., García-Estrada, C., & López, S. (2020). Dietary supplemental plant oils reduce methanogenesis from anaerobic microbial fermentation in the rumen. *Scientific Reports*, *10*(1), 1613. doi:10.1038/s41598-020-58401-z
- Vassalle, L., Díez-Montero, R., Machado, A. T. R., Moreira, C., Ferrer, I., Mota, C. R., & Passos, F. (2020). Upflow anaerobic sludge blanket in microalgae-based sewage treatment: Co-digestion for improving biogas production. *Bioresource Technology*, *300*, 122677. doi:10.1016/j.biortech.2019.122677
- World Bank. (2017). Sustainable WSS Services in Nigeria, Fecal Sludge Management (FSM) in Nigeria. Report No:0000053.

