Improvement of Wastewater Quality by the Vertical Flow Mechanism Using Biofilters System

By

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Abstract

This paper describes a detailed study of vertical flow of wastewater in two bioremediation options. The anaerobic and aerobic biofilters were studied based on reduction in physio-chemical parameters of wastewater obtained in Port Harcourt. Results reveal that the treatment options improve the percentage reduction in wastewater quality from 30-50% for anaerobic and 50-99.9% for aerobic biofilters. The microbial growth rate follows the exponential phase for all treatment options that involve anaerobic and aerobic biofilters. The physiochemical parameters considered are pH, temperature, nitrate, phosphate, and turbidity, Suspended Solids (SS), Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). The research was conducted from March to April, 2009 within a period of 61 days as shown in the paper. Hydraulic retention time was maintained at 12hours in both anaerobic and aerobic biofilter system. The flow diagram design was developed to achieve reduction in some physiochemical parameters for all cases of biofilter system. The outcome of this work can be used to improve the wastewater discharge into the environment by reducing further environmental degradation. Application of the flow diagram design wastewater treatment shows that the biofilter approach is conditionally stable. The biofilter system can be used to improve wastewater quality in both confined and unconfined flow and transport problems.

Introduction

In the future environmental legislation will require that wastewater generated from offices and industries be subjected to treatment before discharging into the environment. Wastewater used during this investigation came from the Rivers State University of Science and Technology, Port Harcourt located in Niger Delta area of Nigeria. The existing treatment mechanisms for this wastewater consist of coagulation-flocculation to removal suspended solids and fluorides, an alkaline stripping for ammonium removal, ozonation for cyanide and COD decrease and an acid stripping for H_2S and HCN removal. The oxidizing properties of ozone can reduce the concentration of iron manganese, sulphur and reduce or eliminate taste and odor problems in wastewater. Moreover, many organic particles and chemicals can be eliminated through chemical oxidation (Ostroumov, 2003; Ray 2002, Lee, Huffman, & Mao, 2000; Lombi, Stelten, & Wenzel, 2000; Kaiser and Huggenberger, 2003; Mohapatra, Mishra, Roy-Chaydhury & Das, 2006; Ghosh, Saez, & Ela, 2006; Raza, Khan, Khalid & Rehman, 2006; Dubey & Juwarkar, 2001; Pilonsmits, 2005; & Lisbon, Mckean, Shekar, Svoronos & Koopman, 2003). However, since the concentration of parameters under consideration is above the recommended limit there is need to subject such wastewater into further treatment before discharging into the environment in order to save the environment from further degradation.

The mechanism of vertical flow of wastewater using biofilters system properties of aerobic and anaerobic can reduce the concentration of pH, temperature, nitrate, phosphate, turbidity, suspended solids, Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) and reduce or eliminate taste and odor problems in wastewater. Moreover many organic particles and biological/chemicals can be eliminated through biological mechanism of vertical flow of wastewater using biofilter system. However the major disadvantage is that, due to instability of microorganism in the system, there may be microbial loss and the physiochemical parameters may as well inhibits the active site of the microorganism present in the system thereby reducing the effectiveness of the process. (Hahn & Schultz, 2002; Duft, Schulte-Oehlmann, Tillmann, Market & Oehlmann, 2003; Lopes, Pery, Chaumot & Charles, 2005; Forbes & Cold, 2005; Oetken, Satchel, Pfenninger & oehimann, 2005 ; Triffault-Bouchet, Clement & Blake, 2005 Delange, Dehaas, Mass & Peter, 2005 ; Maxam, Rila, Dott, & Eisentraeger, 2000 & Smital, Luckenbach, Saverborn, hamdoun, Vega & Epel, 2004). Other disadvantage of some microorganisms such as anaerobic species is that they find it difficult in producing effluent that can comply with the environment standards (Ukpaka, 2007, 2008, 2009). Therefore, it is of great importance to consider the post-treatment of anaerobic reactors system as a way forward of adopting the treated effluent to these environmental discharge standards. Some of the major attributes of anaerobic process are operational simplicity; low cost effectiveness and low solids particles production together with the environmental conditions of our tropical climate have contributed to highlighting anaerobic systems for the treatment of Rivers State University of Science and Technology (RSUST) wastewater. Nowadays, almost all alternative analysis for wastewater treatment include anaerobic reactors as one of the main options.

As climate change continues to place stress on water resources, communities are increasingly looking towards recycled wastewater as a supplementary water source. However, one of the major barriers to the reuse of the recycled wastewater is the possible health risk of exposing treated wastewater and associated chemical and microbial contaminants to the ecosystems. (Multon & Rahman, 2002; Chakraborti *et al.*, 2003; Banerjec *et al.*, 2004; Fleck *et al.*, 2004 & ASTM, 1986). Hence, identification of process indicators for recycled water is becoming imperative so that recycled water can be used appropriately and with minimal risk to human and environmental health.

Development to a biological treatment processes to remove or reduce some of the physiochemical parameters of wastewater to the recommended international standard has recently attracted great interest. Many researches have focused on processes, such as biological filtration (Sterik, Aa, Austand, & Hanssen, 2004) or membrane reactor (Ueda and Horan, 2000, Shang, Wong, & Chen, 2005 & Lv, Zhen, yang, Zhang, Liu, & Yand-Liv, 2006). However, these wastewater treatment processes are associated with high operational and capital costs. Biological treatment processes have been recognized as the most powerful technology and are widely used in industrial and sewage treatment plants worldwide for reducing the pH, temperature, turbidity, suspended solids, COD, BOD, nitrate, phosphate etc., (Buchanan & Gibbons, 1994; Adam & Stauber, 2004; Backhaus, scholze, & Grimme, 2000 & Gerbardt, Murray, Costillon, Wester, Wood, Kriegi & Philips, 1989).

The aim of the study is to develop a reliable biological treatment system using biofilters (anaerobic and aerobic) system as well as to evaluate the performance of each stage of the process and recommend the best techniques that can enhance high level of effective recycling and improvement of wastewater quality for domestic and industrial uses.

Materials and Methods

Sample Collection

Wastewater samples were collected from staff club canteen of Rivers State University of Science and Technology, Port Harcourt (RSUST). The samples were collected using plastic materials. These samples were transported to the Department of Chemical/Petrochemical Engineering, Rivers State University of Science and Technology (RSUST) laboratory for analysis.

Microbial Isolation and Identification

The samples were mixed in a large reactor (plastic container) and then stirred thoroughly before being subjected to enumeration microbial isolation, identification and characterization of anaerobic and aerobic bacteria within 24hours of sample collection. The ten-fold serial dilution method was employed for the enumeration and isolation of bacteria (Buchanan & Gibbons, 1994).

Preparation of Broth Culture

The preparation of the broth culture was done by inoculating the anaerobic and aerobic bacteria into 500ml of nutrient broth medium containing 220mg/l of BOD, 320mg/l of COD, 18mg/l of suspended solid, 11NTU of turbidity, 8.86mg/l of nitrate and 0.9091mg/l of phosphate with pH of 6.6. The inoculated broth was incubated at 37^oC for 24hours and used for the study. The broth culture was prepared in Microbiology laboratory in the Department of Biology, RSUST , Port Harcourt.

The Coconut

Flow Diagram for the Experimental-Set Up of Anaerobic and Aerobic Biofilter System

The experiment was set-up to allow inflow of wastewater through anaerobic and aerobic bacteria (biofilters) as shown in the flow diagram (Figure 1). The investigation was conducted in the Department of Chemical/Petrochemical Engineering, Rivers State University of Science and Technology, Port Harcourt, Nigeria. The system consists of influent reactor, which was in the form of a plastic bucket with a capacity of 25litres. The influent reactor was connected to the bottom of the anaerobic biofilter and the effluent from anaerobic biofilter was connected to the bottom of aerobic biofilter by a PVC pipe. The biofilter reactor systems contains PVC pipe with the following design parameters of 10.1m by 1.5m of diameter and height. The volume of the reactor was 10litres and a control valve was fixed at the bottom of the reactors for the purpose of removing excess sludge as well as channel for cleaning the reactor. The effluent pipe was connected at the top of the aerobic biofilter and the effluent was collected in plastic container of capacity 25litres as shown in the flow diagram below. The biofilter reactors were housed at a constant mesophilic temperature of 27^{o}C in a walk in temperature controlled room.

The biofilter reactors were fed with fresh wastewater. The wastewater sample was then poured in the overhead influent tank and the inflow was adjusted by regulating the inlet valve. Regular inspection was done to check that the flow rate is maintained so as to make the system continuously work. The detail of the flow diagram for the experiment set-up of anaerobic and aerobic biofilter is as shown in Figure 1.

The research was conducted for a period of 61days starting from 1st March to 30th April, 2009 and the following parameters were measured on a daily basis for the duration of the work. The parameters include: pH, temperature, nitrate, phosphate, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Suspended Solid (SS) and turbidity for both the influent and the effluent samples. The analysis was based on International Standard Methods (Taste) for measuring the physiochemical properties of some parameters present in waste water treatment such as pH (APHA 4500H’8), BOD, and COD (APHA 5220D), Nitrate (EPA 352.1) Phosphate (APHA 4500-PD), Turbidity (APHA 21308), Suspended Solid (APHA 25108) and for anaerobic and aerobic (APHA 92228), the improvement of wastewater quality using biofilter as a mechanism to evaluate the anaerobic and aerobic performance is shown in Figure 1.

Characteristics Analysis on Packs Materials

The experimental analyses on the characteristics of the packing material used: The investigation revealed that for packing material size of 15mm, its porosity was evaluated to be 42%, average pore size of 12mm and specific surface area of $504m^3/m^3$ for both anaerobic and aerobic biofilters.

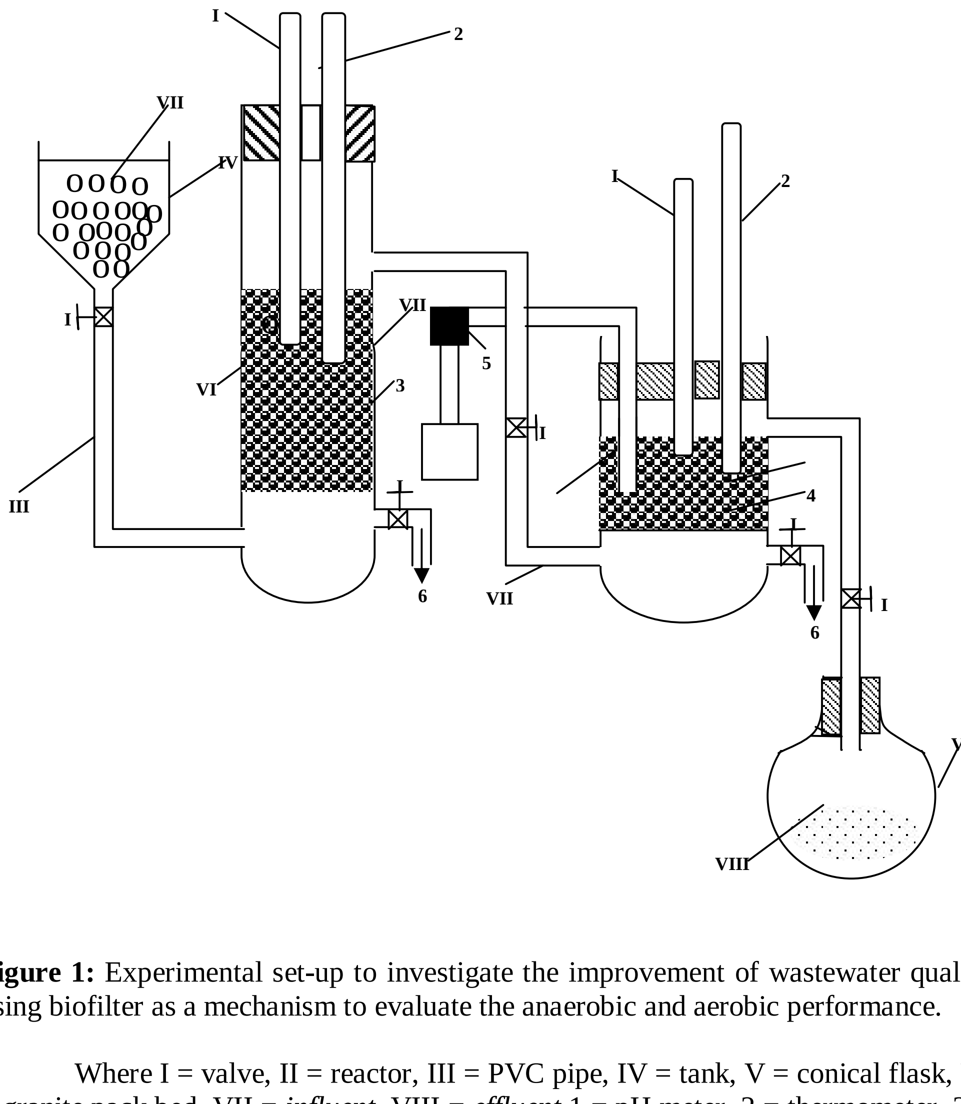

Figure 1: Experimental set-up to investigate the improvement of wastewater quality using biofilter as a mechanism to evaluate the anaerobic and aerobic performance.

Where I = valve, II = reactor, III = PVC pipe, IV = tank, V = conical flask, VI = granite pack bed, VII = *influent*, VIII = *effluent* 1 = pH meter, 2 = thermometer, 3 = anaerobic biofilter packed with granite of size 15mm, 4 = anaerobic biofilter, 5 aeration pump, 6 = cleaning point.

Results and Discussion

Wastewater samples collected from staff club canteen (RSUST), Port Harcourt were analyzed for pH, temperature, nitrate, phosphate, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), turbidity and Suspended Solids (SS) for various samples used during the investigation as shown in this paper, for a period of 61days.

The influent result shows that the concentration of physiochemical parameters under investigation is above the recommended limit (ASTM; 1986 and APHA, 1992). The colour of the influent was grey per each day of sample collection from staff club canteen (RSUST), Port Harcourt. The result of the analysis is shown in Figures.

The colour of the effluent was colourless after final treatment was achieved per each day of sampling. There was excellent reductions in some of the parameters considered for the investigation such as pH, turbidity, suspended solids, nitrate and phosphate.

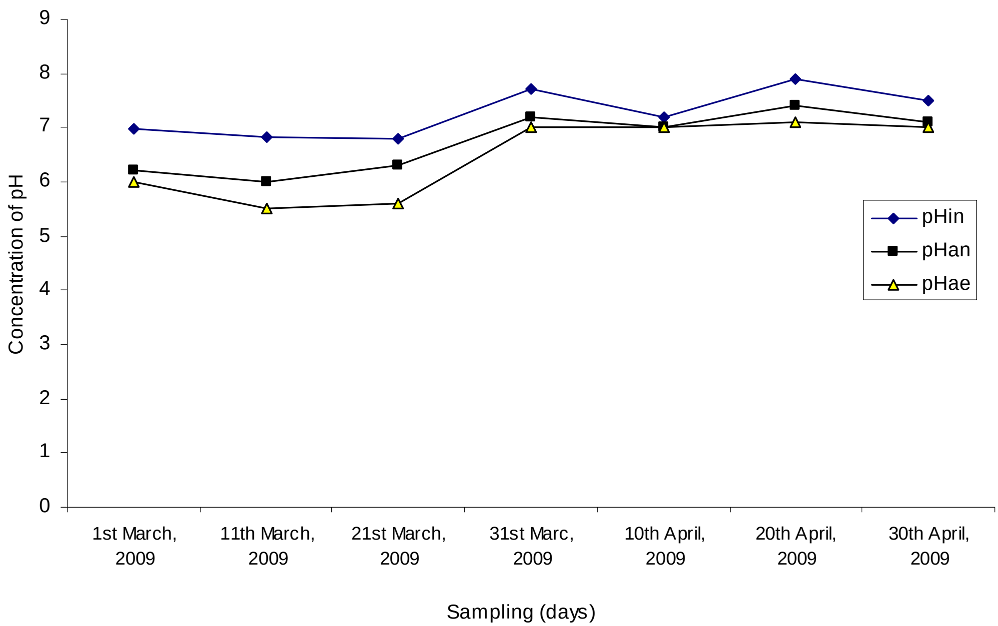

Figure 2: pH concentration versus sampling at various days

The result presented in Figure 2 illustrates the pH concentration at various sampling day. The pH changes as the influent is allowed to pass through the anaerobic and aerobic biofilters. Similarly, from Figure 2, it is seen that the pH concentration is in the following order of magnitude $pH_{in} < pH_{an} > pH_{ae}$. Result reveals high reduction in pH value at each stage of treatment. The treatment of the influent resulted to changes in pH characteristics from weak acid to neutral and alkaline at the end when the samples from the anaerobic biofilter is further subjected into aerobic biofilter. The end result showed alkaline.

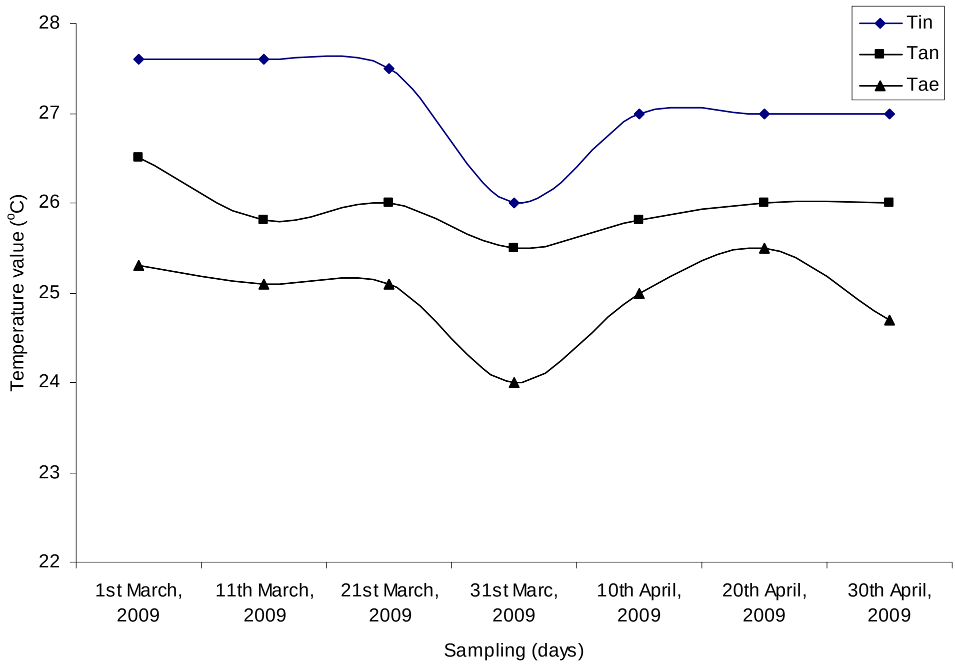

Figure 3:Temperature value versus sampling at various days

Results of temperature were measured on the influent and effluent after anaerobic biofilter and effluent after aerobic biofilter. Figure 3, illustrates the variation in temperature value with variation in sampling day for each stage of analysis. The result showed that $T_{in} > T_{an} > T_{ae}$ for the various days of sampling. It is seen that as the influent is allowed to pass through the two remediation stages, its temperature value reduces as well as increase the effectiveness of the biofilters system.

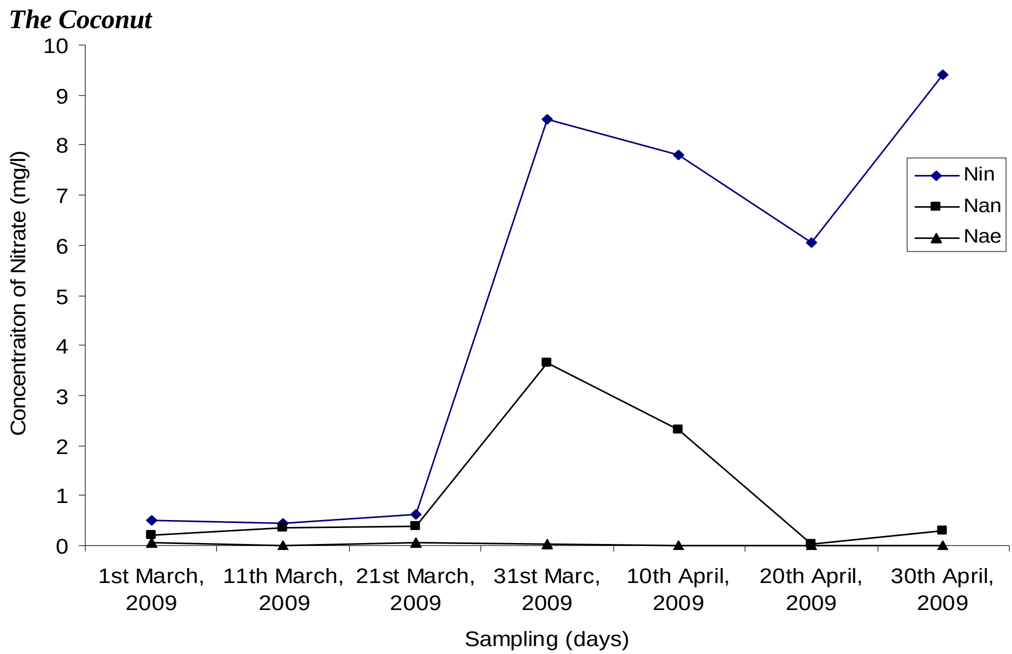

Figure 4: Nitrate Concentration Versus Sampling At Various Days

The decrease in nitrate concentration of $N_{in} > N_{an} > N_{ae}$ as shown in Figure 4, can be achieved when the influent samples were allowed to pass through the anaerobic and aerobic biofiltters. High reduction in nitrate concentration was achieved at the end of aerobic compared to anaerobic biofilter. The result obtained from this research work reveal that biofilters (anaerobic and aerobic) are capable of enhancing treatment of wastewater, since the results obtained show great reduction in the nitrate concentration to acceptable limit as recommended by APHA, (1992).

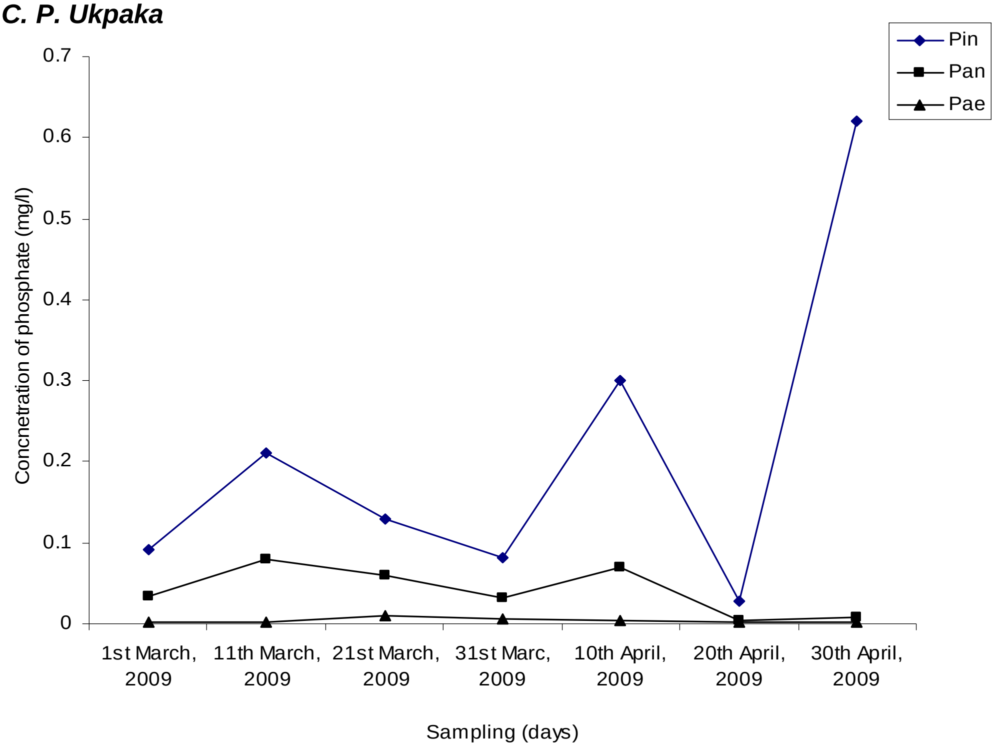

Figure 5: Phosphate Concentration Versus Sampling At Various Days

The phosphate concentration of the influent as shown in Figure 5 is not within the recommended limit by APHA, (1992). Therefore, there is need to subject the influent into treatment to ensure that effluent discharges into the environment is within the recommended standard as well as environmental friendly. Therefore, allowing the influent to pass through both anaerobic and aerobic biofilters as shown in the flow diagram reduces the phosphate concentration into the range of the acceptable limit as shown in Figure 5. From Figure 5, it is seen that $P_{in} > P_{an} > P_{ae}$ indicating the order of phosphate concentration impact on the environment. High reduction in phosphate concentration was achieved after allowing the influent to pass through the various treatment options (remediation options) and results were within the acceptable limit as recommended by APHA, (1992).

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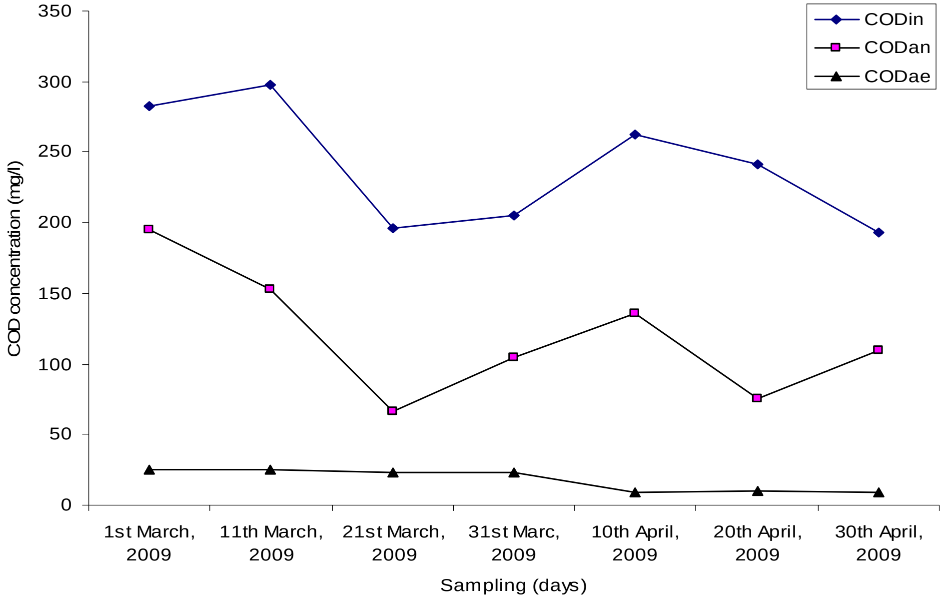

Figure 6: BOD Concentration Versus Sampling At Various Days

Results of the analysis show that the BOD concentration of the influent is not within the acceptable limited as recommended by APHA, (1992). Therefore, there is need to subject the wastewater sample into further analysis, to reduce BOD concentration the acceptable limit as recommended by APHA, (1992). Result presented in figure 6 shows that BOD_{in} > BOD_{an} > BOD_{ae} indicating the level of impact of BOD concentration on the environment. From Figure 6, it is seen that there is a slight reduction on the BOD concentration when the influent is allowed to pass through the anaerobic biofilter. High reduction was further achieved when the output product from the anaerobic biofilter was allowed to pass through the aerobic biofilter, the result obtained is within the acceptable limit as recommended by APHA, (1992).

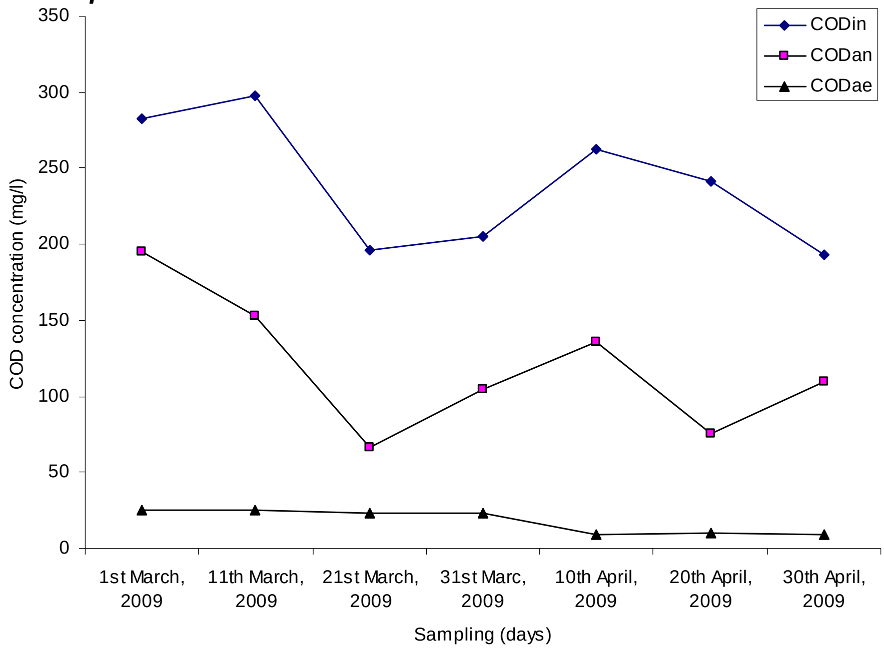

Figure 7: COD Concentration Versus Sampling at Various days

The result presented in Figure 7, illustrates the COD concentration of influent, effluent after anaerobic biofilter and effluent after aerobic biofilter. The influent results obtained are given as 282.40mg/l, 297.50mg/l, 228.30mg/l, 205mg/l, 264mg/l, 241mg/l,2122mg/l, it is seen that the results obtained from the influent are not within the recommended limit or within the acceptable limit of international standard. Therefore, there was the need to subject the influent samples in bioremediation option of anaerobic and aerobic biofilters. Slight reduction was achieved when the influent was allowed to pass through the anaerobic biofilter but higher reduction was achieved when the process was allowed to pass through the aerobic biofilter. The result obtained at the final point was within the acceptable limit as recommended by APHA, (1992).

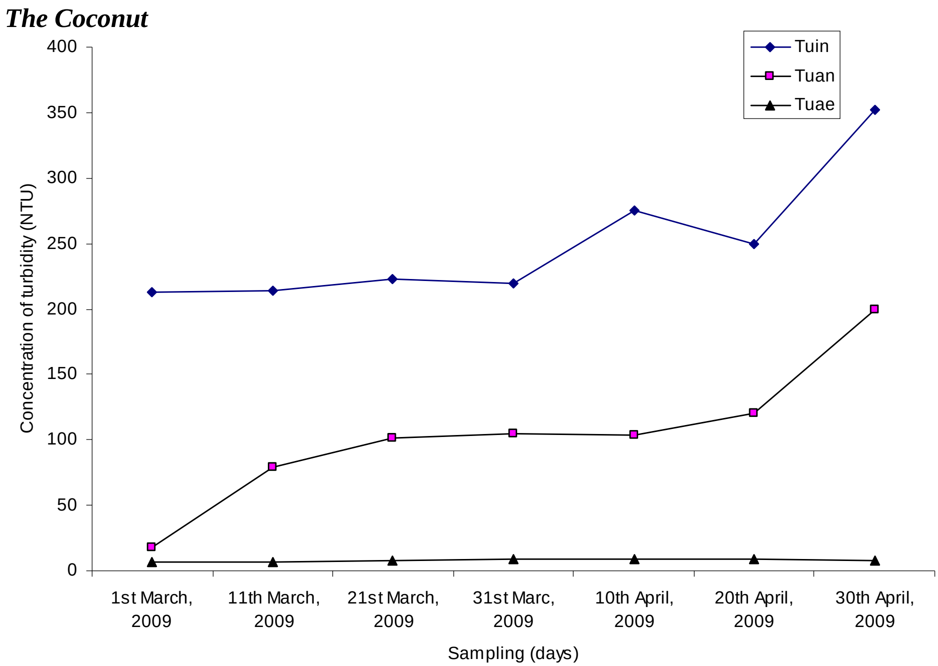

Figure 8: Turbidity Concentration Versus Sampling at Various Days

It is seen that the turbidity of the $TU_{in} > TU_{an} > TU_{ae}$ as shown in Figure 8. The reduction of the turbidity was observed more when the effluent from the anaerobic biofilter system was further subjected to pass through the aerobic biofilter. The results obtained as shown in Figure 8 indicates that the concentration of turbidity was within the acceptable or permissible limit as recommended by APHA, (1992).

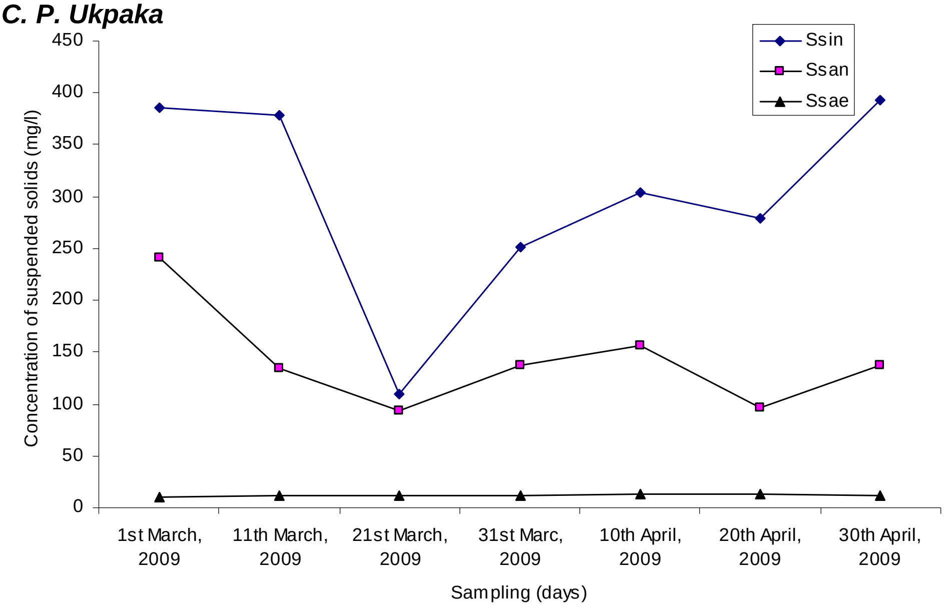

Figure 9: Suspended Solids Concentration Versus Sampling At Various Days

Figure 9, illustrates the suspended solids concentration at various sampling days. The variation in the suspended solids concentration can be attributed to variation in various sampling day. The suspended solids concentration level is given as $SS_{in} > SS_{an} > SS_{ae}$, the result indicate high reduction in Suspended Solids (SS) when the influent is allowed to pass through the biofilter system. The results obtained as shown in Figure 9 indicates that the concentration of suspended solid was within the acceptable limit as recommended by APHA, (1992). The process demonstrates it's useful in monitoring and predicting the wastewater treatment mechanism by vertical flow using biofiltrs system as studied.

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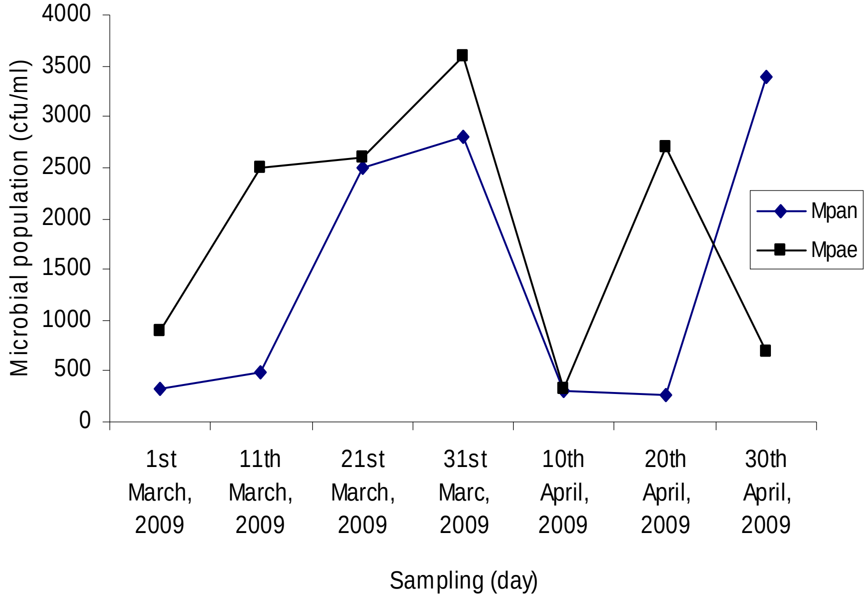

Figure 10: Microbial Population Versus Sampling at Various Days

Figure 10, illustrates the microbial population of anaerobic and aerobic for the various days of sampling. Increase in microbial growth was high on aerobic compared to anaerobic. The variation in the population of anaerobic and aerobic can be attributed to slight reduction on toxic substance present in the influent before it was subjected into the anaerobic biofilter. Before subjecting the effluent from the anaerobic biofilter into the aerobic biofilter some of the toxic substance concentration had been reduced to the minimum level.

Conclusion

In general, the present study clearly shows significant variation in the microbial growth rate of anaerobic and aerobic biofilters in treatment of wastewater as well as the composition of some physiochemical parameters. These variations in the physiochemical parameters of wastewater are certainly achieved by the effectiveness of the anaerobic and aerobic biofilters.

This study has established that:

1. The rapid reduction in some of the physiochemical parameters can be attributed to the effectiveness of the biofilters.
2. The aerobic biofilter is more effective compared to anaerobic biofilter, since microbial activity is high in aerobic system.
3. Bioremediation option is one of the best methods of treating wastewater.
4. The results obtained showed a range of 50-99.9% reduction in concentration of each parameter for both aerobic and anaerobic biofilters.

5. Treatment of industrial wastewater to achieve international standard of recommended quality of water.
6. As a measure to recycle domestic wastewater to achieve high quality of water for human consumption and other industrial uses.
7. As a medium to reduce the effect of the physiochemical parameters as well as a measure to reduce corrosion of pipes.
8. The process required less energy system to operate.

Abbreviation

BOD	=	Biochemical Oxygen Demand (mg/l)
BODin	=	Biochemical Oxygen Demand concentration of influent (mg/l)
BODan	=	Biochemical Oxygen Demand concentration after allowing the influent to pass through anaerobic biofilter (mg/l)
BODae	=	Biochemical Oxygen Demand concentration after allowing the effluent from the anaerobic biofilter to pass through aerobic biofilter (mg/l)
COD	=	Chemical Oxygen Demand (mg/l)
CODin	=	Chemical Oxygen Demand concentration of influent (mg/l)
CODan	=	Chemical Oxygen Demand concentration after allowing the influent to pass through anaerobic biofilter (mg/l)
CODae	=	Chemical Oxygen Demand concentration after allowing the effluent from the anaerobic biofilter to pass through aerobic biofilter (mg/l)
Nin	=	Nitrate concentration of influent
Nan	=	Nitrate concentration after allowing the influent to pass through anaerobic biofilter (mg/l)
Nae		Nitrate concentration after allowing the effluent from the anaerobic biofilter to pass through aerobic biofilter (mg/l)
Pin	=	Phosphate concentration of influent (mg/l)
	=	Phosphate concentration after allowing the influent to pass through

Pan anaerobic biofilter (mg/l)

Pae = phosphate concentration after allowing the effluent from the anaerobic biofilter to pass through aerobic biofilter (mg/l)

pHin = pH concentration of influent

pHan = pH concentration after allowing the influent to pass through the anaerobic biofilter

pHae = pH concentration after allowing the effluent from the anaerobic biofilter to pass through aerobic biofilter (mg/l)

SSin = Suspended Solids Concentration of influent

SSan = Suspended Solids concentration after allowing the influent to pass through the anaerobic biofilter

SSae = Suspended Solids concentration after allowing the effluent from the anaerobic biofilter to pass through aerobic biofilter (mg/l)

Tin = Temperature of influent

Tan = Temperature after allowing the influent to pass through the anaerobic biofilter

Tae = Temperature after allowing the effluent from the anaerobic biofilter to pass through aerobic biofilter (mg/l)

Tuin = Turbidity concentration of influent (NTU)

Tan = Turbidity concentration after allowing the influent to pass through the anaerobic biofilter (NTU)

Tae = Turbidity concentration after allowing the effluent from the anaerobic biofilter to pass through aerobic biofilter (NTU)

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