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Comparative Performance of Wastewater Treatment with Intermittent Palm Kernel Shells (PKS) and Slow Sand Filtration (SSF)

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Abstract

The impact of effluents from an institutional wastewater treatment plant is of great concern due to high concentration of effluent pollutants than the recommended standard limits. Ability of using a locally available filter material around the point of generation and making use of low-cost technology is highly desirable. The study focused on comparing the performance of laboratory scale intermittent filtration system using granulated Palm Kernel Shell (gPKS) as filter medium with an existing slow sand filtration (SSF) system. The gPKS was collected from Arigbajo Community in Ogun State, Nigeria. The filter depth and loading of the existing SSF of 0.65 m and 0.135 L/min respectively was adopted for the gPKS column. The 5-day Biochemical Oxygen Demand (BOD_5) removal efficiency for the gPKS and SSF were 52.98 and 81.11% respectively. There was a slight increase (7.62 and 0.92%) in the nitrate of the effluents from both the gPKS and SSF also a slight increase of 0.5 and 0.42 mg/l for gPKS and SSF respectively were witnessed for the dissolved oxygen. Total bacteria removal in both systems was 99.9%. It can be concluded that gPKS can serve as a filter medium in intermittent sand filtration for a tertiary wastewater treatment to replace SS.

Keywords

Wastewater treatment; Palm Kernel Shell; Slow Sand Filtration; Total Bacteria; Intermittent Filtration.

1.0 Introduction

The menace of wastewater from tertiary institutions in the society as well as its consequent impact in the environment when not properly managed cannot be underestimated. Curtailing the menace to be created by the improper disposal of the effluent to the environment is a great challenge in the area of soil and water pollution which may affect the public health. The rate of wastewater generation from institutions has been increasing due to increase in population caused by enrolment increase in most of these institutions. Most of the institutions were able to put in place wastewater treatment plant in their institutions to treat the wastewater from their institutions before being discharged to the environment. It has been revealed that the effluents from these treatment plants being discharged into the environment fall below permissible limit of NESREA which can consequently have negative effect on the receiving environment. One of the treatment methods being adopted is constructed wetland which has been in used for more than two decades (Zhang *et al*., 2009; Maine *et al*., 2009 and Murray-Gulde *et al*., 2005).

In order to reduce the stress and cost of material importation, assessment of locally available materials that can replace the use of sand is desirable. The study focuses on the use of granulated Palm Kernel Shell (gPKS), an Agricultural waste, in an intermittent sand filtration system and comparing its performance with a matured Slow Sand Filtration (SSF) put in place for polishing the effluent from Constructed Wetland of Institutional Wastewater in the University of Lagos, South West Nigeria.

2.0 Materials and Methods

The laboratory scale study was carried out in the Granulometric Laboratory of Hydraulic Research Unit, Department of Civil and Environmental Engineering, University of Lagos, Nigeria. The setup for the laboratory scale study involved the use of one filter Perspex material column that has 100 mm diameter and 5 mm thickness. The column base was sealed with Perspex of 10 mm thickness. The Palm Kernel Shell used was collected from Arigbajo community of Ogun State, Nigeria. It was washed, dried and crushed in the Ceramic and Material Laboratory of Federal Institute of Industrial Research, Oshodi to have the recommended effective size and coefficient of uniformity values for intermittent sand filter (0.35 – 1 and <3.5 respectively); and sieved in the Laboratory. The particle size distribution curve for the gPKS aggregate was plotted as shown in **Figure 1** and the corresponding grading properties: d_{10}, d_{30} and d_{60} and coefficient of uniformity (C_u) of the PKS were determined with the values of 0.34, 0.55, 1 and 2.94 respectively. These values are within the recommended values (USEPA, 1980).

The laboratory scale set up is presented in **Figure 2** and the column was filled with underlaying material to 7.5 cm and gPKS to 65 cm. The column was preconditioned and saturated by pumping water into it followed by draining prior to loading the set up with wastewater from the effluent of the wetland. Effluent from the wetland that served as influent to the SSF was collected and used as the influent for the laboratory intermittent sand filtration set up. On **Figure 2**, the part labelled 1 is a tank containing influent wastewater, part labelled 2 is a peristaltic Pump used for loading the wastewater during dosing while the part labelled 3 is the granulated palm kernel shell (gPKS) filter medium in the column.

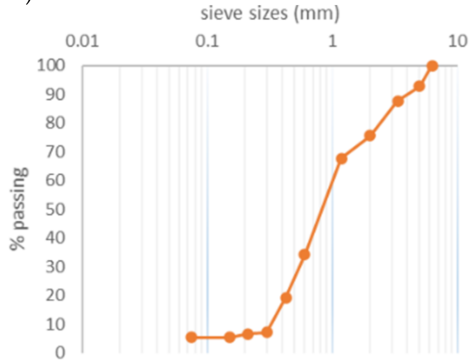

Figure 1: *Particles size distribution curves of Arigbajo Palm Kernel Shell (PKS)*

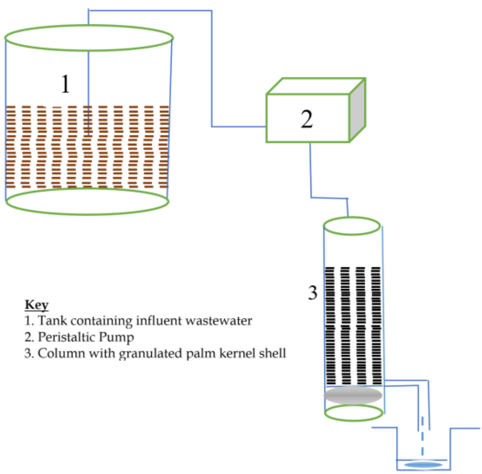

Figure 2: *Experimental Setup*

The sample was applied to the filter from the top using peristaltic pump. The pump operation was for 15 minutes duration for each batch at the hydraulic loading rate of 0.135 L/min, being the flow rate of the SSF. The batching of the column was 4 times a day for 90 days. The samplings of the effluent from the column and the Slow Sand Filtration were done once weekly for laboratory analysis. The following parameters were tested for, pH, BOD, NO_3, DO and Total Bacteria. All parameters were evaluated using standard methods of measurement (APHA, AWWA, WEF, 2005).

The loading was done in six hourly intervals making it four batches. Each batch ran for 15 minutes and the system was allowed to rest for five hours and forty-five minutes (5 hrs. 45 mins). The resting period was to allow for the enhancement of re-oxygenation of the filter media to aid microbial activities in breaking down organic matter in the wastewater. The schematic diagram of the loading is as shown on **Figure 3**.

The bound and linear inequality constraints were written, linprog was used to solve the problem, and the result was validated.

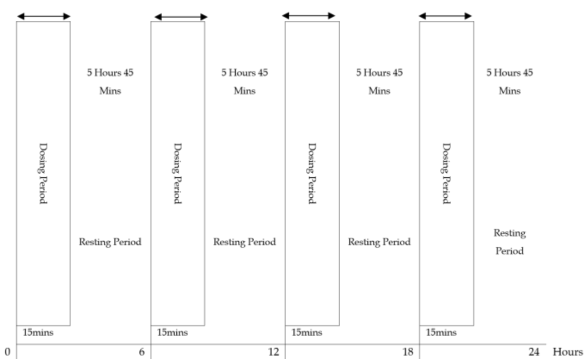

Figure 3: *Schematic Diagram of the Experiment Loading*

3.0 Results and Discussion

The summary of obtained results is as shown on **Table 1**. The pH of the wastewater was on the average 7.0, the effluent pH from the SSF slightly reduced to an average pH of 6.95 and that of PKS reduced to an average of 6.67. This reduction of effluents alkalinity from PKS may not be unconnected with the gPKS material base which contains higher proportion of saturated fatty acid from traces of palm oil (Sodamade *et al*. 2019) . The reduction of pH in the SSF effluent is due to operating system of the SSF on site unlike in Sodamade *et al*. (2014) where sand material was used as medium in intermittent sand filtration, with a slight increase in the pH value. The pH values indicated that the system operate optimally for biological activities.

The temperature of effluent from the system (PKS and SSF) averagely ranged between 25 and 28^{o}C and found to be within the WHO standard for effluent to be discharged into the environment (WHO, 2006). These values are less than the 40^{o}C limit set by FEPA (1991) and thus favour the system for biochemical reaction. The average turbidity, as indicated on **Table 1**, of the effluent from the gPKS increased slightly unlike the great reduction noticed in the effluent of the treated wastewater from SSF. The increment noticed in the effluent from gPKS was due to the released gPKS into the treated water.

The weekly results of BOD_5 for the adopted wastewater and collected effluents are shown in **Table 2**. From the table, the BOD_5 of the wastewater collected from the effluent of the Constructed Wetland used as the influent for the intermittent and SSF varied between 4.2 mg/l and 90.4 mg/l. The variation is influenced by the population of students in the hostel. Between weeks 1 and 8, the students were in the hostels within the school campus which led to generation of higher organic load entering the constructed wetland and consequently production of effluent with higher BOD_5 values than the limit value of 30 mg/l recommended by FEPA (1991) from the constructed wetland. When the students were not on campus, the effluent BOD from the wetland was within 4.2 and 25.8 mg/l which is within the recommended value by WHO and FEPA, hence during this period, tertiary treatment is not required and the effluent can be discharged into the receiving water body without the organic load affecting the water. However, when students are on campus, the Constructed Wetland cannot remove the pollutants completely, hence, the organic loads in its effluent require tertiary treatment.

Averagely, the BOD_5 removal efficiency of gPKS was 52.98% while the SSF was 81.11%. This result, although showed that gPKS removal efficiency of BOD_5 was lower than SSF, however, it was also a good result compared with the SSF that have developed the 'dirty skin' around the filter media which aided in the removal of organic matter. Based on this result, it could be expected that gPKS can attain the percentage BOD removal over a long time and hence may perform at par with SSF where availability of suitable sand material cannot be made.

Table 1: Performance of PKS filter and SSF

Parameters	Influent	Average Effluent Values	
		PKS	SSF
Temperature (°C)	24	25	28
pH	7	6.67	6.95
Turbidity (NTU)	8.64	8.86	1.21
DO (mg/l)	2.4	2.9	2.82
BOD_5(mg/l)	35.34	18.47	8.39
NO_3-N (mg/l)	1.742	1.875	1.758

Table 2: BOD_5 Removal in treated effluent from PKS and Treated effluent from SSF

Weeks	Wastewater (mg/l)	Effluent (PKS) (mg/l)	Treated Effluent (SSF) (mg/l)	PKS % Removal	SSF % Removal
1	67.6	30.6	17.6	54.73	73.96
2	90.4	25.2	15	62.13	84.41
3	56.8	21.4	18.5	62.32	64.96
4	53	21.6	12	59.25	77.36
5	53.4	12	6	77.52	88.76
6	59.4	23	18	61.28	69.70
7	39.2	18.4	12.5	53.17	68.11
8	62.2	28.4	10.5	54.34	83.12
9	11	7.4	1	32.73	91
10	18	12.2	1.5	32.23	91.67
11	4.2	2.8	0.7	33.34	83.34
12	25.8	12.2	0.8	52.72	96.9
Max.	90.4	30.6	18.5		
Min.	4.2	2.8	0.7		
Ave.	35.34	18.47	8.39	52.98	81.11

3.1 Total Bacteria (TB)

The dissolved oxygen in wastewater dictates the degree of purity or breakdown of the organic matter in the wastewater. The results as shown in **Table 3** showed that DO in the wastewater is low, it was within the range of

1.7 and 3.6 mg/l while those of the effluents from PKS and SSF were within the range of 1.5 and 3.8 and 2.4 and 3.8 mg/l respectively. There was a reduction in the values of DO in PKS effluent in the first one week, this shows that the degree of formation of slime on the filter medium had not picked up enough to allow an increase in DO. After two weeks, DO in gPKS column started to slightly increase in value than the influent water. The same slight increase was experienced in SSF effluent. This result corroborates earlier findings of Sodamade *et al*. (2014) where slight increases in DO of effluent coincided with organic decomposition by microbes within the filtration system. This increased dissolved oxygen in the effluent wastewater after treatment indicates reduction in organic pollution load, occasioned by biomat entrapment and continuous mixture with atmospheric oxygen as suggested by Prasad *et al*. (2006).

Table 3: Comparison in performance of PKS and SSF in oxygen absorption

Weeks	Influent Waste-Water (mg/l)	PKS effluent (mg/l)	SSF Effluent (mg/l)
1	3.6	3	3.78
2	2.3	1.5	2.66
3	1.7	3.7	2.65
4	2.8	3.8	3.59
5	3.1	3.2	3.38
6	2.8	3	3.42
7	1.7	2.8	2.6
8	2.5	2.7	2.6
9	2	2.9	2.7
10	2.7	3.1	2.9
11	2.4	2.3	2.4
12	2.2	2.9	3.8
Average	2.4	2.9	2.82

The concentration of Total Bacteria in the influent ranged between 11,300 and 52 log(cfu/100 mL) with the highest value measured during the first week and the least in week 9 as shown in **Figure 4**. The removal capacity of the slow sand filter system is relatively constant, indicating the maturity stage of the system. The concentration of the Total Bacteria in the effluent of the gPKS was higher in the first week with an efficiency removal close to zero which extended to fifth week. The low efficiency removal between the first and fifth week was due to slow formation of dirty skin around the filter medium which could have aided entrapments and subsequent removal of the bacteria from the wastewater. The treatment ability of the PKS commenced after week 5, an indication that the maturity of the medium commenced at 5th week. This ability improved weekly till the end of the experiment due to microorganisms that are partially being retained in the system as the wastewater is passing through Sand, Sen and Khilar (2006).

The retained microorganism helped in digestion of the biodegradable as observed by Eturki *et al.* (2012). In week 9, it was discovered that the Total Bacteria in the SSF and PKS effluent were nearly close to that of the effluent, this may not be unconnected to the low organic loading of the system due to students' population in the hostel. As the students started resuming to school, the organic load started increasing this also affected the total bacteria in the effluent as noticed in weeks 10 to 12. Generally, PKS can also serve as medium for the removal of Total Bacteria.

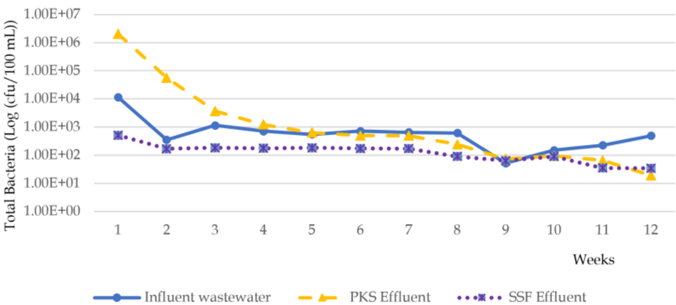

Figure 4: *Removal of Total Bacteria by PKS and SSF treated effluent*

3.2 Nitrate Removal (N-NO$_3$)

According to Isikwe *et al.* (2011), nitrate indicates the most stable form of nitrogenous matter contained in wastewater. Nitrate is a natural form of nitrogen found in the soil. It is formed when microorganism breakdown from inorganic fertilizer, decaying plants, manures or other organic matter. In wastewater the emergence of nitrate is due to nitrification of ammonium to nitrate under a favourable pH values of between 7 and 8, Tchobanoglous and Burton (2003).

The average nitrate from the effluent of the constructed wetland that served as influent wastewater for the SSF and laboratory scale ISF was 1.742 mg/l, this is slightly lower than the one recorded by Sodamade *et al.* (2014) for the effluent from septic tanks. This slight difference might not be unconnected with the treatment of the effluent from the anoxic anaerobic environment, through the intake by the plant within the Constructed Wetland system.

From **Table 4**, the average increase of nitrate in gPKS was 1.88 mg/l and 1.76 mg/l was recorded as average value for the SSF effluent. This shows that for both media, there were slight increases (7.62 and 0.92% respectively for gPKS and Sand) in the nitrate values compared to the influent which was due to low DO which caused low DO inhibition of nitrification as reported by Piluk and Byers (2001). This slight increase in value of nitrate in the effluent occurred due to absence of anoxic condition in both the systems that will denitrify the nitrate into nitrogen gas. Also, the value of nitrate increase recorded in the gPKS-ISF system was due to re-oxygenation process that was taking place during the process which does not allow anoxic condition to occur compared to the formation of 'dirty skin' on the surface of the filter medium that can create a slight anoxic condition.

Table 4: Performance in $N\text{-}NO_3$ removal in PKS and SSF

Weeks	Influent Wastewater (mg/l)	PKS (mg/l)	SSF Treated Effluent (mg/l)
1	**0.9**	**8.4**	**2.5**
2	**1.2**	**0.9**	**1.5**
3	**3.1**	**3.3**	**2.9**
4	**2.4**	**1.9**	**5**
5	**5.2**	**0**	**0.7**
6	**1.3**	**1.5**	**1.5**
7	**1.9**	**1.3**	**1.2**
8	**0.9**	**0.8**	**2.6**
9	**1.1**	**0.7**	**0.6**
10	**0**	**0.5**	**0.1**
11	**1.7**	**1.7**	**1**
12	**1.2**	**1.5**	**1.5**
Avg.	**1.742**	**1.875**	**1.758**

4.0 Conclusion and Recommendation

The performance of intermittent filtration using gPKS as filter medium with slow sand filtration in polishing the wastewater effluent was assessed. The percentage BOD removal of the PKS was averagely 52.98% after the twelve weeks of dosing compared with the 81.11% of SSF that has been in use for more than a year. The removal of total bacteria in the two systems was close to 99.99% an indication of both being effective. The nitrate and dissolved oxygen increased slightly an indication that nitrification and re-oxygenation was taking place in the systems.

The obtained results show that gPKS can also perform as a filter material for removal of BOD_5, $N\text{-}NO_3$and TBC. It is suggested that more research needs to be done on the usage of gPKS for slow filtration. The study also revealed that in the treatment of institutional wastewater, gPKS can be adopted where sand material is not available.

5.0 Acknowledgements

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