# Efficacy of Slow Sand Filtration System Embedded with Activated Carbon for Agro-Industrial Wastewater Treatment

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## Abstract

*Indiscriminate disposal of untreated cassava wastewater is a major environmental challenge faced by communities hosting indigenous cassava processors in Nigeria. This study is therefore aimed at assessing the effectiveness of a simple slow sand filtration system embedded with activated carbon layer for cassava wastewater treatment. The filters were loaded in layers with graded sand, gravel, and varying thickness of activated carbon bed. Cassava wastewater was obtained from a processing site at Ibogun, Ogun State, Nigeria. The filters were filled and left for about two weeks for "schmutzdecke" to form on the top surface of the sand bed and then operated at room temperature (28-34 °C) at hydraulic retention times of 6, 12, and 24 h. The result showed that collected wastewater had a mean value of 1357 NTU, 385, 31.87, and 716 mg/L of turbidity, biochemical oxygen demand (BOD), hydrogen cyanide (HCN) content, and chemical oxygen demand (COD), respectively. These values were above the permissible limit set by the local and international regulatory agencies. The filters with activated carbon showed a drastic reduction in the pollutants load (BOD: 38%-57%, COD: 26%-46%, HCN: 79%, and NTU: 96.5%-98%). This is corroborated by P-values <0.05 of 2.84 x $10^{-32}$ and 1.69 x $10^{-29}$ for COD and BOD, respectively. The obtained result also disclosed that some parameters did not conform to the acceptable limit but there was a reduction in key pollutants of cassava wastewater. Therefore, the filter can be used as a low-cost treatment mechanism for cassava wastewater prior to disposal.*

***Keywords**:* cassava wastewater, water quality, pollutant reduction efficiency, physicochemical parameters

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## 1. Introduction

Clean water remains an important need of all living things. Their reliance on the water supply from water bodies cannot be overemphasized. Water bodies provide humans with food in the form of aquatic animals and plants. They also serve as good source of supplementary irrigation water. However, human and industrial activities have become sources of wastewater that is disposed either directly or indirectly into water bodies – this disposal activity is highly prevalent in developing nations (Dareioti *et al*., 2009).

Industrial processing and production of goods and services, utilizing agricultural inputs, generate a lot of wastewater that is disposed untreated into the environment leading to pollution (Dareioti *et al*., 2009). In a developed nation like Spain, the estimated volume of wastewaters from food-processing industry in 2008 was 190,000,000 $m^3$ (Posadas *et al.*, 2014). The physicochemical characterization of agro-industrial wastewater shows a high concentration of phosphorus, nitrogen, organic matter, and variable pH (Drogui *et al*., 2008).

Cassava (*Manihot esculenta*), a widely cultivated crop in West Africa with Nigeria being the largest producer, is mostly consumed as a staple food (Olutosin and Barbara, 2019). It is estimated that Nigeria cultivates about 3.7 million hectares of cassava, thereby generating 75 to 90 million cubic meters of cassava wastewater (Food and Agriculture Organization of the United Nations, 2019). In Nigeria, cassava roots processing mainly produces staple food like *gari*, *lafun*, *fufu*, tapioca, starch, and flour (Olayanju *et al.*, 2019). These processing techniques, which are mostly indigenous, utilize a large volume of freshwater resulting in the generation of high level of toxins in the wastewater (Lawal *et al*., 2019a).

Water consumption is high in large-scale or highly clustered small or medium-scale cassava processing factories. As shown in Figure 1, wastewater generation stems from the pre-cleaning process of cassava tuber to remove dirt by washing of peeled tubers, and grating and mechanical dewatering process of meshed cassava tuber. Processing a ton of cassava roots produces about 8.85 and 10.62 metric tons of cassava wastewater (Zhang *et al*., 2016). Freshly harvested cassava roots contain cyanogenic glucoside in various concentrations manifesting into hydrogen cyanide during processing (Eze and Onyilide, 2015). Wastewater from cassava processing centers poses a high risk to biodiversity as it contains different pollutants affecting both water and soil physicochemical parameters (Adegoke *et al*., 2020).

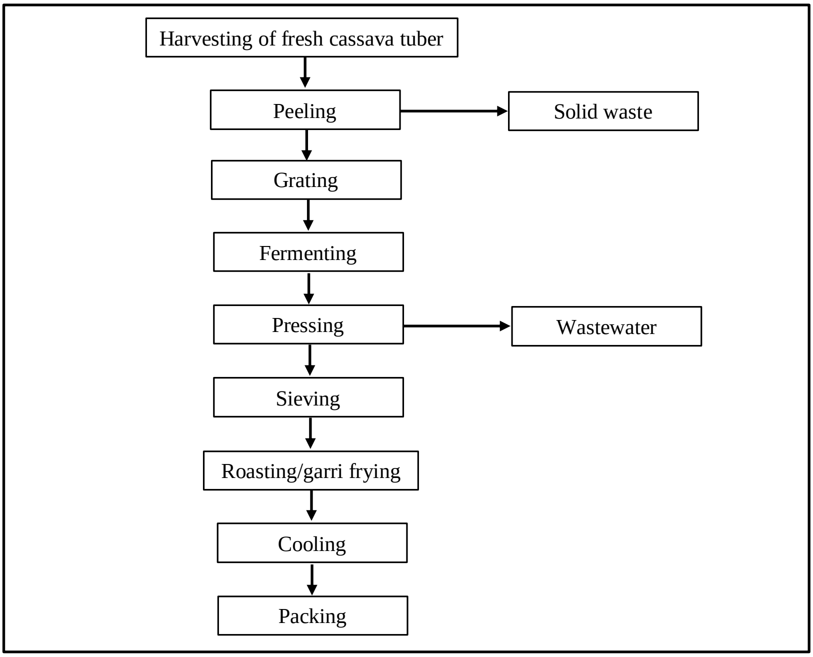


Figure 1. *Gari* processing flow chart (Asogwa *et al*., 2017)

Slow sand filtration (SSF) has been researched frequently to encourage the reuse of water. It was employed in nurseries and greenhouses to increase the water use efficiency by reducing the amount of fresh irrigation water needed (Nyberg *et al*., 2014). In other studies, this technique was found to be useful in removing and eliminating propagules of plant pathogens, namely *Phytophtora nicotianae* (Nyberg *et al*., 2014), species of Fusarium (Lee and Oki, 2013), and *Escherichia coli* (Unger and Collins, 2008). Relatively low-cost requiring low maintenance, sand filtration systems can be easily operated and can remove both turbidity and propagules of pathogens, thereby improving the quality of the water (Ufer *et al*., 2008). However, its efficacy to eradicate other compounds is yet to be investigated.

The inappropriate and improper disposal of cassava wastewater is threatening as there exist a serious danger to the environment if left unexplored. Therefore, this study determined the potential of SSF system embedded with activated carbon in treating cassava wastewater. This study also evaluated the treatment efficacy of the system on different pollutants in cassava wastewater prior to disposal or reuse.

## 2. Methodology

*2.1 Study Area and Cassava Wastewater Sample Collection*

The cassava wastewater was collected from a cassava processing site in Fashina, Ibogun, Ifo, Ogun State, Nigeria. Its geographical coordinates are 6° 49'0" N, 3° 7'0'' E with 73 m elevation above sea level; its original name (with diacritics) is Ibogun Adina. The study area was selected due to the observed level of environmental degradation caused by indiscriminate cassava wastewater disposal by processing clusters within the area as recorded by Lawal *et al*. (2019b). Samples were collected directly after washing of peeled cassava roots, placed in a container to maintain the sample's integrity and immediately transported to the laboratory.

*2.2 Analysis of Cassava Wastewater*

The cassava wastewater was analyzed to determine some physicochemical parameters. These parameters included pH, EC, turbidity (NTU), biochemical oxygen demand (BOD), $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, hydrogen cyanide (HCN) content, and chemical oxygen demand (COD). The results of these parameters were compared with standard limits of the World Health Organization (WHO) and National Environmental Standards and Regulation Enforcement Agency (NESREA) – Nigeria.

*2.3 SSF System Setup*

Figure 2 below shows the schematic view of the slow sand filter setup. Each unit comprised a bucket with 33, 26, 30.6 cm height, bottom diameter and top diameter, respectively, filter medium, and valve. The main raw materials used in the production of slow sand filter were graded sand, containing fine grain and coarse sand, and gravel, in conformity with the standards set by the American Water Works Association (2001) and granulated activated carbon (Li *et al*., 2018). The graded sand was used to treat the organic matter in the wastewater; organic matter particles attach to grain surfaces and are trapped in crevices and spaces between grains (Nyberg *et al*., 2014). The vegetable-derived carbon activated with sodium palmitate used in the study is a product of IOI PAN Century Oleochemicals, manufactured in Johor, Malaysia and sourced from chemicals village at Ojota, Lagos, Nigeria.

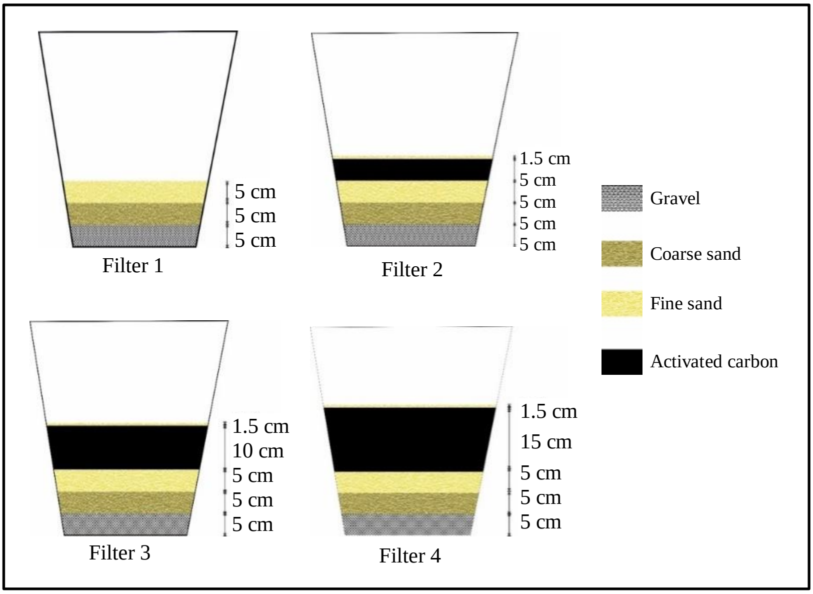


Figure 2. Schematic view of experimental setup

The volume of bucket was calculated using Equation 1.

$$Volume = \pi h/3(r^2 + rR + R^2) \quad (1)$$

where:

$h$ = height of the bucket (cm)
$r$ = radius of the lower base of bucket (cm)
$R$ = radius of the upper part of bucket (cm)

Sand filters varied in size due to the scale of the project evident in different established municipal treatment plants. For the filter, the thickness of gravel, coarse, and fine sand was 5 cm (Jenkins *et al*., 2011). Activated carbon with different thickness was sandwiched in the filters with reference to the work of Li *et al*. (2018). A 1.5-cm thickness of fine sand was placed above the activated carbon layer in every filter except for filter 1, which was used in the generation of schmutzdecke. The summary of the different thickness of the material's layer is presented in Table 1. Coarse sand was utilized because it strains out particulates (contaminants or colonies) as the wastewater passes through the grain particles. It also has a well-defined surface area which promotes the growth of slime that helps in the decontaminating of wastewater as it passes within the system (van Loosdrecht *et al*., 1990). While it may seem counterintuitive to use gravel to remove phosphorus from wastewater, gravel was still selected as it was shown having the potential to eliminate such chemical element from wastewater (Nyberg *et al*., 2014).

Table 1. Thickness of the filter media

| | Thickness of the material layer (cm) | | | | | | |
|---|---|---|---|---|---|---|---|
| Filter | Gravel | Coarse Sand | Fine Sand | Activated Carbon | Fine Sand | Particle size | Range (mm) |
| Filter 1 | 5 | 5 | 5 | 0 | 0 | | |
| Filter 2 | 5 | 5 | 5 | 5 | 1.5 | Fine sand | 0.1 – 1.18 |
| Filter 3 | 5 | 5 | 5 | 10 | 1.5 | Coarse sand | 1.92 – 2.36 |
| Filter 4 | 5 | 5 | 5 | 15 | 1.5 | Gravel | 6.92 |

*2.4 Experimental Procedure*

The tests were conducted at the Environmental Control Laboratory, Agricultural Engineering Department, Olabisi Onabanjo University, Ibogun Campus, Ifo, Ogun State. A test run was done on the filtration systems (Figure 3) for two weeks for schmutzdecke (a hypogeal biological layer) to develop on the sand bed, aiding effective filtration of wastewater, before the implementation of the normal tests. The test was carried out in three batches for three hydraulic retention times (HRT) of 6, 12, and 24 h taking a cue from Ewemoje *et al*. (2015). At the end of each retention time, 0.75 cL of effluents were collected from each filter system, which is then labeled samples A, B, and C. The physicochemical properties of the filtrate of each batch collected from every filter were determined and that of high interest were subjected to analysis of variance (ANOVA) on Microsoft Excel statistical tool to serve as a good source of comparison.

Figure 3. SSF systems with activated carbon layer

*2.5 Sodium Adsorption Ratio (SAR)*

The SAR of the collected wastewater was evaluated to determine its usability as source of irrigation water. The SAR of cassava wastewater effluent collected from the sample collection point was calculated with values obtained from laboratory results using the Equation 2 as suggested by Asadollahfardi *et al*. (2013).

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}} \tag{2}$$

where:

$Na$ = sodium $Na^{+}$
$Ca$ = calcium $Ca^{+}$
$Mg$ = magnesium $Mg^{2+}$

It is important to determine the level of these cations to assess the relationship between soluble sodium (Na) and soluble calcium (Ca) and magnesium (Mg), which is used to predict the exchangeable Na fraction and salinity level. Highly saline irrigation water was observed to cause a reduction in seed germination, rooting, growing and fruiting of plants, lowering the osmotic potential of the soil solution, and reducing plant's available water among others (Asadollahfardi *et al*., 2013).

*2.6 Flow rate*

Estimated using Equation 3 (Anon, 2016), the flow rate of each slow sand filter was determined. The flow rate tests were carried out by filling the system with untreated water that flows through the filters and out of the system for a few hours. After which, the quantity of filtrate was estimated.

$$Q = \frac{V_w}{t} \tag{3}$$

where:

$Q$ = liquid flow rate ($m^3/s$)
$V_w$ = working volume ($m^3$)
$t$ = HRT (s)

## 3. Results and Discussion

### *3.1 Characterization of Cassava Wastewater*

The cassava wastewater before filtration had a milky color because of the suspended, dissolved particles and other organic content. After the filtration process, the wastewater attained a transparent color. Figure 4a and 4b show the milky wastewater and the obtained samples after the filtration was done, respectively.


Figure 4. Untreated (a) and treated cassava wastewater (b)

Table 2 shows the result of the physicochemical parameters of cassava wastewater from cassava processing plants. These parameters are in agreement with the ones obtained by Horsfall *et al*. (2003). The results of the analysis of the wastewater's physicochemical parameters (BOD, COD, HCN, turbidity and others) were compared against the standard limits set by the World Health Organization (WHO) and National Environmental Standards and Regulations Enforcement Agency (NESREA) – Nigeria. It was revealed that the obtained results exceeded both standards. It was also found out that the cassava wastewater had a SAR value of 8.86. This value falls within the range of acceptable limit for irrigation water as reported by Satish-Kumar *et al*. (2016) in accordance with United States Department of Agriculture. However, the said SAR value is very close to the critical non-permissible value of 9 (Akinyemi and Souley, 2014).

Furthermore, majority of the physicochemical parameters in the cassava wastewater were found inappropriate to be used in irrigation; thus, emphasizing that need for treatment before applying it on crops or in other alternative use.

Table 2. Physicochemical parameters of cassava wastewater

| S/No | Wastewater Parameters | Values | Permissible Limits | |
|---|---|---|---|---|
| | | | WHO | NESREA |
| 1 | pH | 8.6 ± 0.1 | 6.5 – 8.5 | 6-9 |
| 2 | EC (μS/cm) | 377.67 ± 0.58 | 400 | NS[a] |
| 3 | Turbidity (NTU) | 1357 ± 11.14 | 5 | 5 |
| 4 | BOD (mg/L) | 385 ± 0.58 | 40 | 30 |
| 5 | $Ca^{2+}$ (mg/L) | 5.99 ± 0.08 | 200 – 600 | 200 |
| 6 | $Mg^{2+}$ (mg/L) | 2.51 ± 0.21 | NS[a] | 200 |
| 7 | $Na^{+}$ (mg/L) | 18.27 ± 0.06 | 0.4 | 200 |
| 8 | HCN | 31.87 ± 0.04 | 0.007 | 0.01 |
| 9 | COD (mg/L) | 716 ± 2.08 | 80 | 60 |
| 10 | SAR | 8.86 | | |

NS[a] – not stated

### *3.2 Performance of the SSFs*

#### 3.2.1 Turbidity and pH

The results of the filtrates' turbidity, obtained by employing a suspended solid test, showed that the turbidity decreased with a reduction of thickness of the activated carbon depth as shown in Figure 5. Generally, the filters were found to be very effective in removing suspended solids from the cassava wastewater. Turbidity values, when compared with that of NESREA permissible limit (5 NTU), exceeded the set limit. The high level of turbidity in the untreated effluent maybe due to high levels of suspended and dissolved particles in the homogenized cassava wastewater. The filters gave turbidity reduction efficiency ranging from 96.5 to 98.3%, which resulted in a clearer treated effluent at the filter taps.

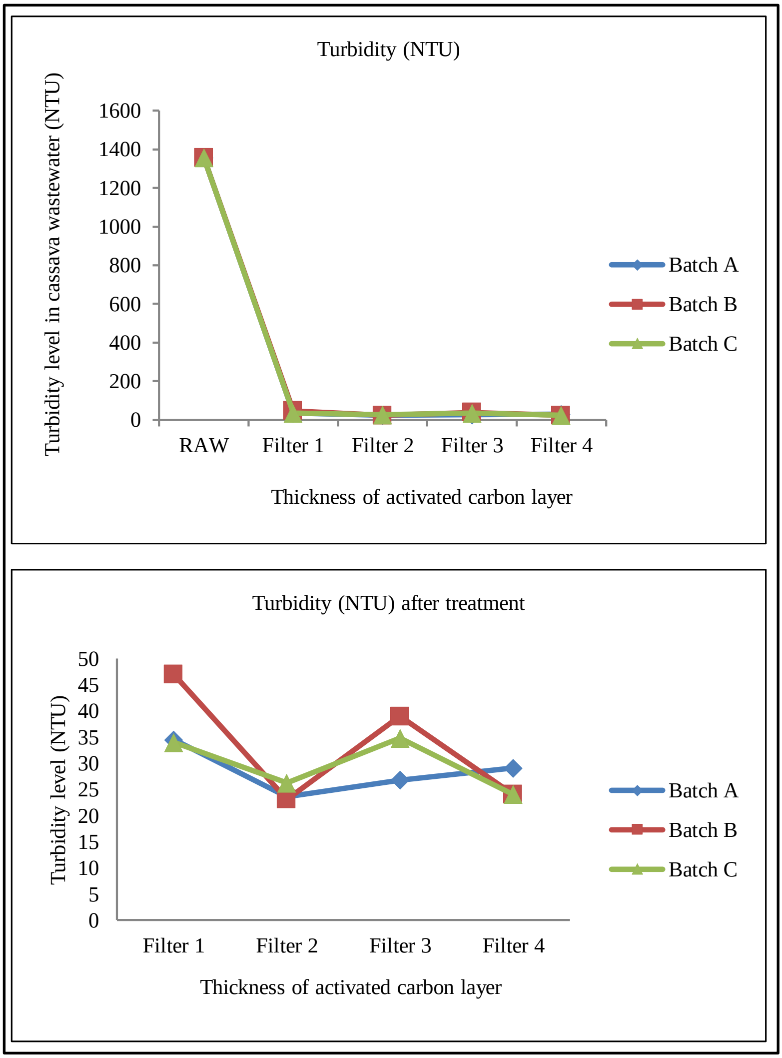


Figure 5. Effect of SSF system on turbidity

The pH values, as presented in Figure 6, showed a similar trend in after-treatment of the cassava wastewater across all treatment batches (HRT) with values tending towards the value of 7, making it near to neutral point with reduction efficiency ranging from 12 to 30%. The pH value that is lesser than 5.5 can be dangerous to plant; therefore, the treated effluents from filters are suitable for irrigation purposes.

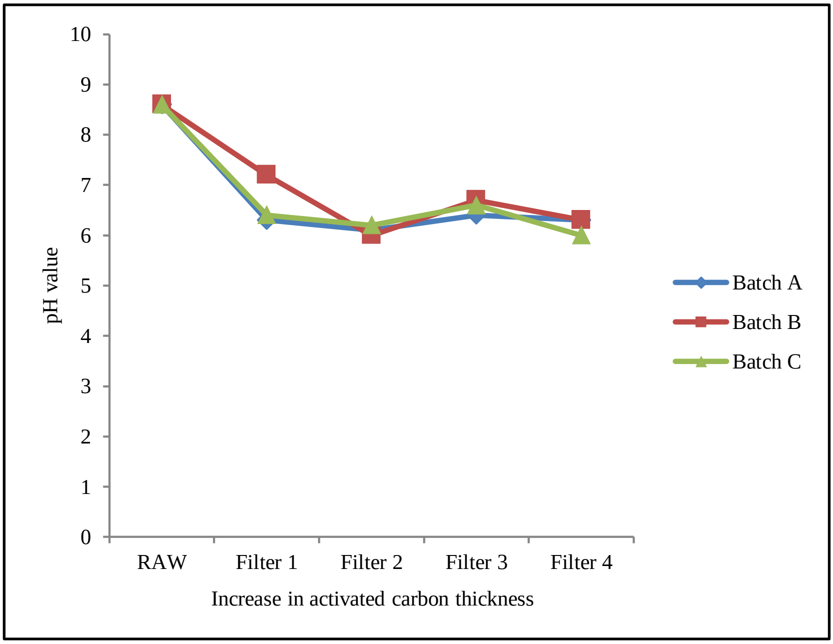


Figure 6. The pH value of filtered effluent

### 3.2.2 Electrical Conductivity (EC)

The EC was not stated in the NESREA's permissible limit (Table 1). The high EC value in the influent could be attributed to the high concentration of dissolved ions present in the wastewater. The EC of irrigated water is determined by the level of salt content in the sourced water; excess of which results in a condition termed physiological drought.

Based on the result (Figure 7), EC values obtained after treatment ranged between 500 and 1000 µS/cm, which are within none (water for which no detrimental effects will usually be noticed) to some (water that may have detrimental effects on sensitive crops) hazard level according to Zaman *et al*. (2018). Also, it can be observed that the EC value decreased with an increase in the activated carbon bed in the systems having a reduction efficiency of 26% at Batch A to 29% at Batch C. The reduction efficiency is in tune with the one reported by Gottinger *et al*., (2011).

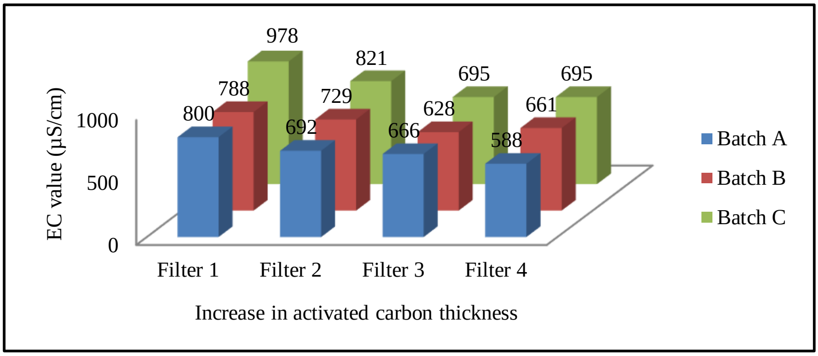


Figure 7. ECs of sampled filter effluent

3.2.3 Soluble Cations (+)

In Figure 8, the Na content and bed of activated carbon increased while the control had the lowest value. This occurrence may be caused by sodium palmitate serving as the activator in the activated carbon in the filtration system. Also, the value of calcium increased drastically when introduced into the first filter but slowly reduced in the succeeding filters as shown in Figure 9.

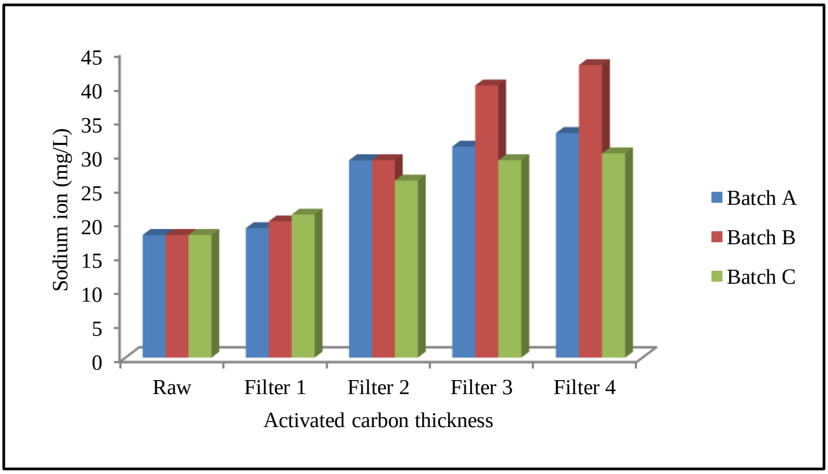


Figure 8. Effect of HRT and AC thickness on sodium ion of treated wastewater

Figure 10 shows a negligible increase in the value of Mg from the values directly obtained from the cassava wastewater. The filtered effluents exhibited negative reduction efficiencies ranging from -3.98 to -9.16% at Batch A to

Batch C, respectively. Although there was a slight increase in the values of $Mg^{2+}$, $Ca^{2+}$, and $Na^{+}$ in the treated cassava wastewater, these values (Table 2) are still within the permissible limits set by NESREA.

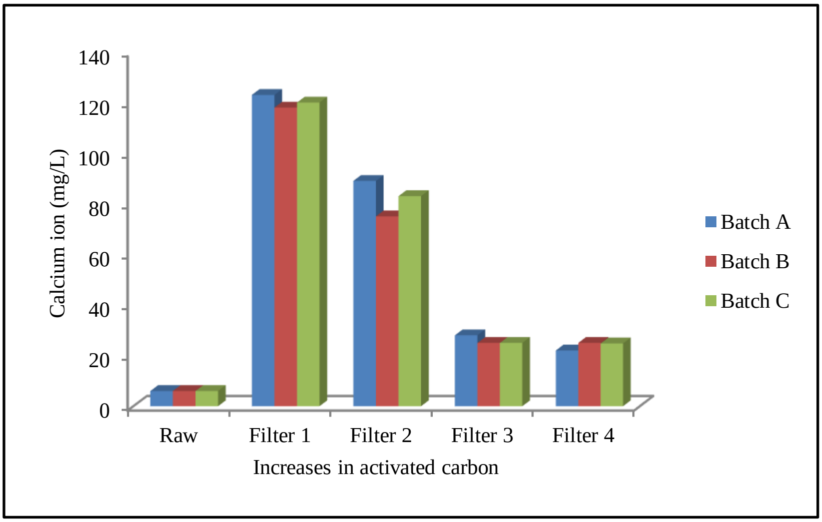


Figure 9. Calcium ion of the treated cassava wastewater

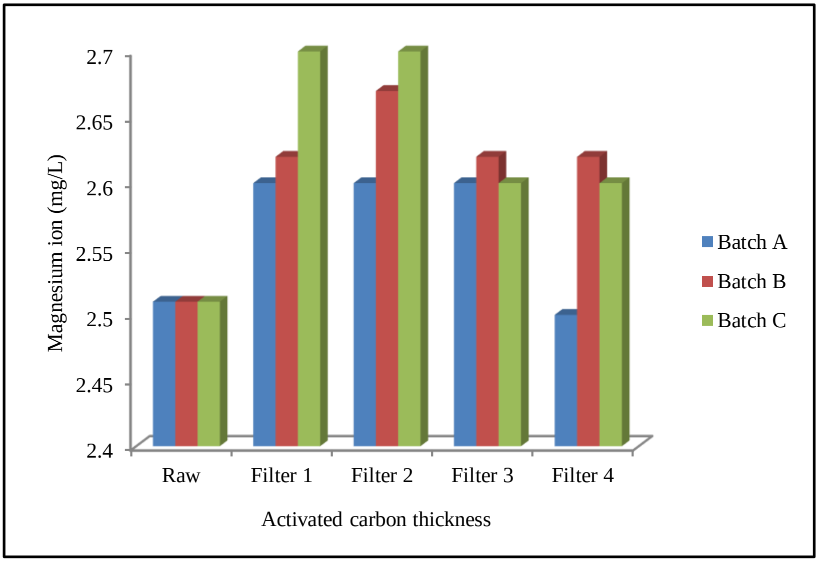


Figure 10. Magnesium ion of the treated cassava wastewater

### 3.2.4 BOD and COD

The BOD, part of the wastewater components, served as an indicator of biodegradable pollutants. According to Ewemoje *et al*. (2017), a COD value greater than 2.5 mg/L is regarded as poor for drinking purposes but can be utilized for irrigation if within the limit set by NESREA. The performance of the filters concerning turbidity removal was very high when compared with EC, COD, and BOD. The more the retention time and increase in the thickness of the activated carbon bed, the better the value of COD and BOD is attained as shown in Figure 11 and Figure 12, respectively.

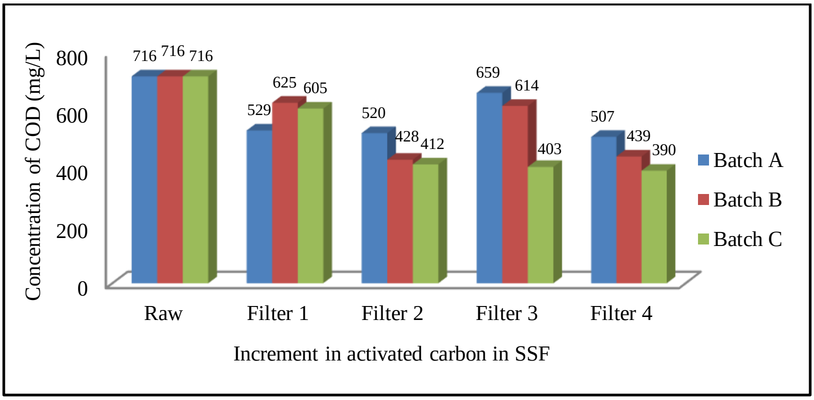


Figure 11. Effect of HRT and AC thickness on COD

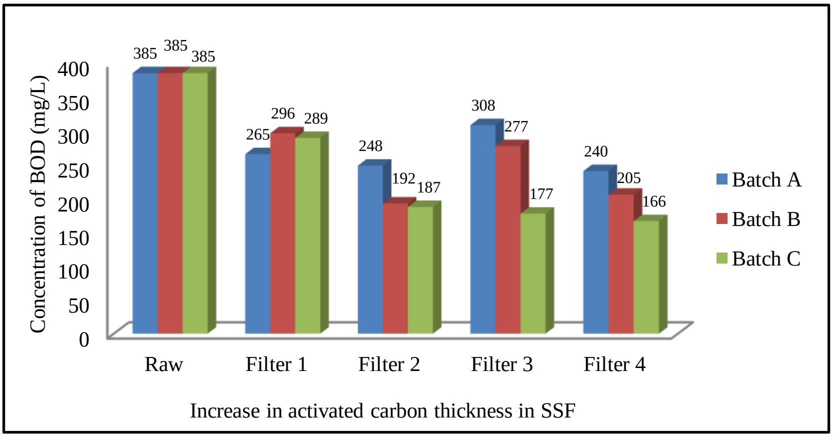


Figure 12. Effect of HRT and AC thickness on BOD

The SSF system attained a reduction of 38-57% in BOD load from the wastewater. This result is in agreement with that of Logsdon *et al*. (2002), who stated that a noticeable reduction in pollutant loads is achieved when slow sand filter is used in small water system treatment. The SSF system showed a ranging reduction efficiency values of 26-46% in COD pollution load across all treatment batches. This result is consistent with the result obtained by Egbon *et al*. (2013) as reported by Bryant and Tetteh-Narh (2015).

3.2.5 HCN Content

Processing of fresh cassava root has been estimated to generate between 8.85 and 10.62 metric tons of effluent, and 1.12 metric tons of peels per ton of fresh cassava roots processed (Zhang *et al*., 2016). This large volume of effluent naturally contains a high level of HCN. In the present study, the filters were very effective in reducing the HCN content from the wastewater. The HCN reduction efficiency in all the filters was between 12 and 79% after treatment. Samples from Batch C reduced the HCN content greatly; the more the retention time to increase the thickness of the activated carbon bed, the lesser the value of HCN was attained by filtered effluent. As shown in Figure 13, Batch C with HRT of 24 h and activated carbon thickness of 15 cm gave the best filtrate value of HCN (79%).

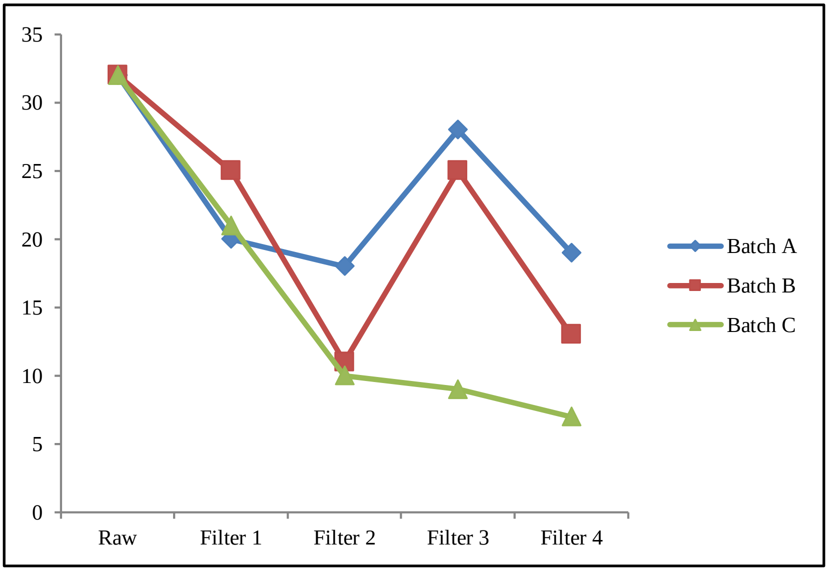


Figure 13. Effect of HRT and AC thickness on HCN content

### *3.3 ANOVA of Activated Carbon Layer Effect on Pollutant Loads*

Table 3 shows the result of the two-way ANOVA with sample replicates obtained from the experimental treatment batches to confirm the variations in the results. The P-value < 0.05 showed that all the parameters were significantly different. This simply means that difference in thickness of the activated carbon sandwiched inside the filter resulted in the difference in the value of pollutant parameters at filtered effluents; no two values can be achieved with a difference in the activated carbon bed. The result of the treated wastewater from the filter without activated carbon was different from the one having activated carbon. Continuous pollutant reduction in the cassava wastewater was obtained as activated carbon thickness was increased. Statistically, the effect of HRT per batch on pollutants reduction in the treated cassava wastewater was significantly different at P-value < 0.05. This means that increase of HRT in the system had a direct effect on the cassava wastewater parameters. The result showed a consistent reduction in parameters as the long reaction time created an avenue for pollutants removal through the filters' active pollution reduction components.

Table 3. ANOVA result

| Parameter | P-values < 0.05 | | |
|---|---|---|---|
| | AC Thickness | Retention Time | Interaction |
| Turbidity | 8.68E-20 | 6.25E-32 | 4.02E-25 |
| EC | 2.14E-20 | 3.95E-25 | 1.42E-13 |
| pH | 1.17E-11 | 4.29E-17 | 2.83E-13 |
| COD | 2.84E-32 | 1.29E-35 | 1.23E-32 |
| BOD | 1.69E-29 | 7.78E-32 | 1.45E-27 |
| HCN | 3.84E-55 | 1.51E-56 | 1.38E-52 |

## 4. Conclusion

The SSF system embedded with activated carbon was designed and developed to reduce the pollutant components from cassava wastewater and improve its quality before discharge or reuse. The different HRTs and varied thickness of activated carbon layers filter were evaluated to determine its effectiveness. Turbidity, EC, BOD, COD, and HCN content reduced by 96.5-98.3%, 26-

29%, 38-57%, 26-46%, 12-79%, respectively. The results obtained from filter effluents showed a reduction of pollutant load from the cassava wastewater. This signals that the filter can be used to reduce water pollution – causing waterborne diseases – and soil contamination. This can also help in ensuring sustainable water supply and usage particularly in developing countries.

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