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Research Article

Degrading cassava mill effluent using aerated sequencing batch reactor with palm kernel shell as medium

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Abstract: Local cassava agro-processing industries in Nigeria generate toxic organic effluent with negative environmental impact if disposed without adequate treatment. This study examines the performance of a lab-scale aerated sequencing batch reactor (SBR) in degrading cassava mill effluent using palm kernel (*Elaeis guineensis*) shell (PKS) as biofilter media. Wastewater samples were collected before and after flowing through each compartment at hydraulic retention times of 3, 5 and 7 hours. Continuous aeration and nature-based degradation of the effluent recorded overall removal efficiencies of 73.5% (Hydrogen cyanide), 70.59% (BOD), 69.18% (COD), 29.93% (Turbidity), 4.92% (Sodium), 25% (Magnesium) and 14.32% (Calcium) respectively. Effluent electrical conductivity (EC) slightly increased by 7.84%. The Sodium Adsorption Ratio (SAR) of the treated wastewater ranged from 6.9 to 7.3 while the final pH ranged from 4.5 to 4.6. The values of EC, BOD and COD were significantly different ($P<0.05$) along the treatment sequence, confirming the effectiveness of the chambers in reducing these pollutants. Despite achieving high removal efficiencies, the final values of most parameters still fall short of the local permissible limit signifying operational limitations and the need to optimize the system to reduce key contaminants to safe disposal limits.

Keywords: *agro-processing, degradation, effluent, pollutants, sequencing batch reactor*

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Introduction

Nigeria is currently the leading producer of cassava tubers globally with 20% of annual production and about 37% of Africa's annual production (Lawal et al., 2018). Its inclusion in confessionary, animal feed, pharmaceuticals and a wide range of industrial products is gradually shifting its cultivation and utilization from the current subsistence level to commercial cultivation and processing (Blagbrough et al., 2010; Lei et al., 2012). Indigenous cassava processing is done in clusters by small and medium scale processors converting the tubers into varieties of products often consumed locally. Virtually all the stages of local cassava processing require huge amount of fresh water resulting in the generation of substantial amount of wastewater with high organic and physical pollutants mostly exceeding permissible limits (Hien et al., 1999; Thanwised, 2017). The composition of cassava processing wastewater has been reported widely, largely depending on the adopted processing techniques, processing machine efficiency, cassava breed and the desired product (Oliveira et al., 2001; Colin et al., 2007; Lawal et al., 2018). Despite having a high range of organic pollutants and a low pH, the generated wastewater is susceptible to biodegradation by physical and biological-based processes (Hien et al., 1999; Gijzen et al., 2000; Kanghuai et al., 2010). According to Hien et al.

(1999), about 12 m^3 of wastewater is generated to produce 1 ton of starch in Vietnam while a much lower freshwater range of 1.11 to 2.13 m^3 is consumed by local processors in Nigeria discharging about 1.37 to 2.10 m^3 of wastewater per ton of fresh cassava root (Lawal et al., 2018). Generated wastewater is usually discharged into open drains and near-by streams posing considerable health hazards to nearby residents (Nweke, 1992; Omotioma et al., 2013; Jideofor, 2015). This necessitates the need to develop a low-cost non-conventional wastewater treatment option that can be operated and maintained by local processors.

A viable efficient option that fits this description is the combination of physical and nature-based treatment techniques. This treatment technique has been applied by researchers in lab scale and real-time studies. It compares well with other physical and chemical treatment methods with good cost-benefits, low secondary pollution, low operating cost and low environmental risk. Aerated gravity flow sequencing batch reactor (SBR) was perceived and specifically adopted by the authors to degrade cassava processing wastewater due to its benefits. Gravity flow feeding mechanism was adopted to enhance the batch treatment sequence which promotes solids immobilization and effluent degradation as observed by Cuzin et al. (1992). Despite the inhibiting activity of some degrading methanogens reported by Kanghuai et al. (2010) during the degradation of cassava processing wastewater, the treatment system adjusts itself to decompose and absorb organic carbon of cyanide and other compounds during the process.

Researchers have reported the use of agricultural by-products as biofilter media in wastewater treatment. Examples of such materials include elephant grass stalk, sugarcane waste stalks, rice straw, wood chips, orange trees, date palm fiber, conifer wood chips and conifer bark (Lens et al., 1994; Daifullah et al., 2003; El Sergany, 2009; El Sergany, 2012 and El Nadi et al., 2014; Lawal et al., 2018).

Despite their successful application, they are often limited due to their susceptibility to biodegradation. Palm kernel shell was perceived as an alternative bio-inert filter media material due to its availability, low cost, low susceptibility to biodegradation and high inert composition. The nut has a red fatty outer husk at maturity while the hard seed coat (endosperm) has a hard shell that is about 2 to 3 mm thick. The shells are often disposed of as a by-product of palm oil and palm kernel oil processing. It has been reported as a good base material for the production of activated carbon widely used in water purification plants (Inegbenebor et al., 2012).

This study is therefore aimed at investigating the performance of a gravity flow aerated sequencing batch reactor (SBR) packed with palm kernel (*Elaeis guineensis*) shell as filter media to degrade cassava processing effluent generated by small-scale cassava processing clusters in Ogun State Nigeria.

Materials and Methods

The treatment set-up consists of five interconnected chambers (raw effluent feed tank, sedimentation chamber I, bio-filtration, aeration and sedimentation chamber II) designed as a plug vertical flow system with a dimension of 1.10 × 0.4 × 0.51 m and a total design capacity of 1.44 m^3/day. The pre-treatment sedimentation chamber was incorporated to reduce the total suspended solids (TSS) which makes up about 25% the COD prior to biological treatment (Fettig et al., 2013). The unit was constructed with 4 mm thick clear acrylic Perspex sheet. The biofiltration unit was parked with graded palm kernel shell (PKS) as substrate media with the liquid level maintained at approximately 1 cm above the top of the media as described by Colin et al. (2007). The treatment unit was equipped with inlet and outlet valves for feeding and collection of treated effluent. A Shengzhe B-410, double outlet digital aerator pump with 3.5 litres/min capacity was used to supply air into the aeration chamber through an inert air-stone of diameter 0.075 m that help to diffuse air uniformly. As reported by Hidayat et al. (2011), the aeration rate plays a crucial role in the development of microorganisms, therefore; the aeration rate was limited to an optimum value of 2.8 litres/min. The raw effluent tank was loaded manually and allowed to flow into the other chambers by gravity. The treatment unit was operated at a room temperature range (27°C to 30°C). Figure 1 shows the schematic representation of the treatment set-up. Treated samples were collected from the outlet port of each compartment and then analyzed.

Material collection and experimental start-up

The raw cassava wastewater was collected from the fermentation tank of a cassava-processing cluster located at Agbowo in Ibadan the Oyo State, Nigeria and transported to the laboratory in a plastic cooler maintained at 4°C. PKS sample was collected from a local market within the same locality and prepared as described by Adebayo et al. (2016). It was oven-dried, crushed and graded with a set of sieves to obtain 4.75 mm particle sizes. Inocula material was obtained from a poultry slaughterhouse wastewater treatment plant located at Ibadan, Oyo State, Nigeria. The set-up was inoculated and left for about 22 days under continuous aeration as described by Rajasimman and Karthikeyan (2007). This is to enhance microbial film formation on the support medium. It was operated in a continuous treatment mode for three days as reported by Colin et al. (2017) before switching to a batch treatment mode.

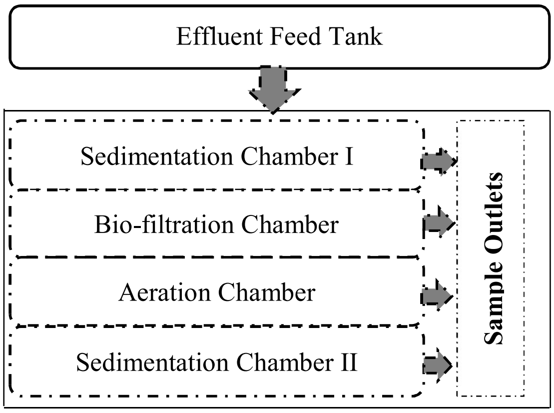

Figure 1. Schematic representation of the treatment set-up

Sample characterization and analysis

Raw and treated wastewater samples were analyzed for BOD_5, COD, Turbidity, Hydrogen cyanide Calcium, Magnesium and Sodium based on APHA Standard Methods of Examination of Water and Wastewater (APHA, 2005). Sample pH was determined using pH-009(1) pen type pH meter. Electrical conductivity was measured using a pen-type TDS & EC E-1 portable meter. SPSS statistics 20 was used to estimate the independent t-test for 3 trials with the level of significance set at $P<0.05$. Values of reported parameters are presented as arithmetic means of three replicates ± standard deviation.

Results and Discussion

The wastewater generated from washing of peeled tubers and other processing operations largely contain inert materials with low polluting loads that pose no threat to the environment, therefore the wastewater from fermentation and retting tank is of great concern due to its huge amount of polluting organic matter and its huge potential to cause serious pollution to the receiving surface and groundwater around processing centres. Wastewater samples collected from the fermentation and retting tank were characterized and the result is presented in Table 1. The result shows that most of the investigated parameters were above the local permissible limit by National Environmental Standards and Regulations Enforcement Agency (NESREA) except for Calcium (103.3 mg/l) and Sodium (43.3 mg/l) salts, which were below the permissible limit. Other parameters were consistent with values obtained from similar studies (Colin et al., 2007; Kanghuai et al., 2010; Okunade and Adekalu, 2013; Thanwised, 2017; Lawal et al., 2018).

Table 1. Characterization of raw cassava effluent

S/No.	Parameters	Raw Effluent (Mean ± SD)	NESREA
1	pH	4.9 ± 0.1	6.0 – 9.0
2	EC (µS/cm)	862.0 ± 1.15	NS*
3	BOD (mg/l)	532.3 ± 1.41	30
4	COD (mg/l)	1006.7 ± 10.61	60
5	Turbidity (NTU)	18.2 ± 0.12	5.0
6	Hydrogen Cyanide (mg/l)	1.6 ± 0.23	0.01
7	Ca^{2+} (mg/l)	103.3 ± 0.15	200
8	Mg^{2+} (mg/l)	43.3 ± 0.31	200
9	Na^{+} (mg/l)	311.7 ± 0.11	200

Note. NS* (Not Stated); SD (Standard Deviation); NTU (Nephelometric Turbidity Unit)

The effluent pH and COD were relatively low (4.0 and 1006.7 mg/l) which may be due to the large volume of fresh water and a relatively low turbidity (18.2 NTU). The low turbidity indicates a low total suspended solids concentration in the wastewater. Electrical conductivity (EC) is mostly used to classify irrigation water. Excessive salts can affect plant growth and soil structure, permeability and aeration. Water with EC value below 700 µS/cm causes little or no threat to most crops while EC value greater than 3000 µS/cm may result in soil salinity and directly limit plant growth. An EC value of 862.0 µS/cm is considered high and disposal of this effluent on agricultural soil can lead to the formation of saline soil.

The low pH results from the commencement of acidification of starch in the fermentation and retting tank leading to the production of lactic acid. The ratio of BOD to COD (0.53) was slightly comparable to the value obtained by Rajasimman and Karthikeyan (2007) and Colin et al. (2007). It indicates that the wastewater can be effectively degraded biologically. The relatively low hydrogen cyanide content (1.6 mg/l) suggests that the available microbial population would readily adjust itself to the inhibiting property of toxic cyanide as suggested by (Gijzen et al., 2000). Generally, a cyanide concentration of ±1.0 mg/l has been reported to be harmful to fish and other aquatic animals (Bridgwater and Mumford, 1979). Therefore, with a cyanide concentration of 1.6 mg/l, the wastewater falls above the local permissible limit of 0.01 mg/l and is considered unsafe for disposal without adequate treatment. The concentration of Calcium and Magnesium salts were below the local permissible limit of 200 mg/l while a slightly moderate value of 6.5 was obtained for the Sodium Adsorption Ratio (SAR). This value largely determines the suitability of surface water for irrigation purposes (Karanth, 1987). SAR value less than 10 is classified as excellent for irrigating agricultural crops and poses no threat to soil and surface water bodies if discharged without treatment (Table 1). Although prolong disposal can result in the accumulation of these salts leading to soil salinity which can adversely affect salt-sensitive crops.

Treated wastewater pH

Treated water pH varied between 4.5 and 4.9 for all the treatment chambers. Variation of treated wastewater pH is presented in Figure 2. With the pH value falling below the permissible range of 6-9 (Table 1), an appreciable amount of treatment is therefore required before the effluent can be safely discharged. Noticeable improvement was not observed in the effluent pH in the first treatment phase (sedimentation I) as shown in Table 2. However, a 6.12% and 2.17% drop (from 4.9 to 4.6 and 4.9 to 4.5) were recorded in the biofiltration and aeration phases of treatment. The slight drop in the final pH value (from 4.9 to 4.5) may be attributed to the metabolism of some biodegradable residue by acidogens resulting in the production and accumulation of organic acids in the system. A similar drop was observed and reported by Wang et al. (2012) and Selvamurugan et al. (2010) during anaerobic acidogenic fermentation of cassava residue and aeration of biomethane in coffee processing wastewater.

Electrical conductivity (EC)

Electrical conductivity (EC) was consistently increased from an initial value of 862 µS/cm in the feed tank to a final value of 986 µS/cm in the second sedimentation chamber (Figure 3). This corresponds to an overall reduction efficiency of 7.84% (Table 3). Recorded improvements of 6.07% and 5.40% (Table 2) were also achieved in the sedimentation chamber I and biofiltration chamber. A similar increase was observed by Arienzo et al. (2009) when treating winery wastewater. The EC values were significantly different ($P<0.05$) along all the treatment chambers indicating the possibility of improving the electrical conductivity of the wastewater with the treatment techniques (Table 2). The slight improvements observed across the chambers may be attributed to evapoconcentration and the leaching of salts from the palm kernel shells by the acidic wastewater. The final value (986 µS/cm) was above the permissible limit of 330 µS/cm recommended for wastewater irrigation by FAO (1985). Therefore, it is essential to further reduce the EC value before disposing or using the wastewater to irrigate agricultural crops.

BOD and COD

A steady decline in BOD and COD values was observed across the treatment chambers resulting in an overall reduction efficiency of 70.59% and 69.18% respectively. This corresponds to a drop of BOD and COD values from 532.3 mg/l and 1006.7 mg/l to final values of 114.7 mg/l and 238.3 mg/l. The high removal efficiency may be traced to the long hydraulic retention times and improved dissolved oxygen conditions (Sun et al., 2006). From the analysis presented in Table 2, the BOD and COD values were significantly different ($P<0.05$) in all the treatment chambers. This suggests the effectiveness of the treatment measures (Table 2). The major improvements were observed in the biofiltration and aeration phases (Table 2 and Figure 4), while the two sedimentation phases had slight effects (26.73% and 20.9%; 23.18% and 22.30%) on the BOD and COD values. Aerating wastewater has been reported to enhance BOD and COD load reduction. The growth of degrading bacteria is largely influenced by the amount of dissolved oxygen available for combination with carbon to form carbon dioxide (Metcalf and Eddy 2003).

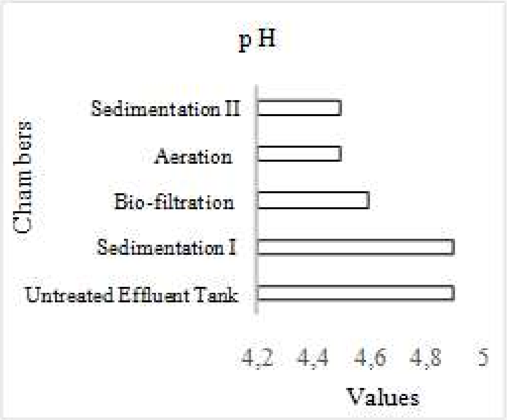

Figure 2. Variation of pH values in the treatment chambers

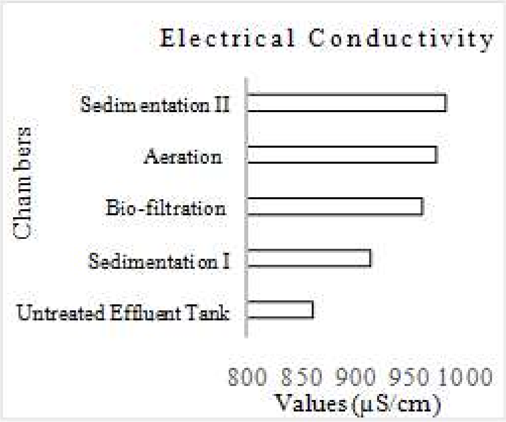

Figure 3. Variation of EC values in the treatment chambers

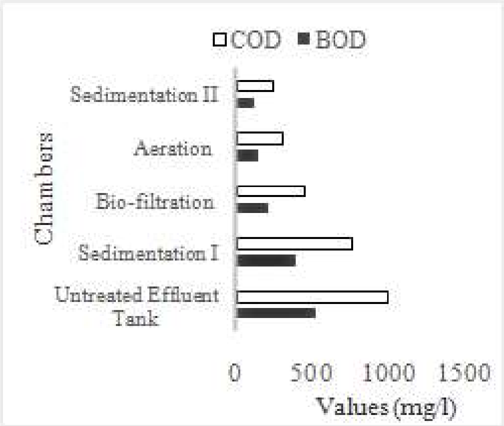

Figure 4. Variation of COD and BOD in the treatment chambers

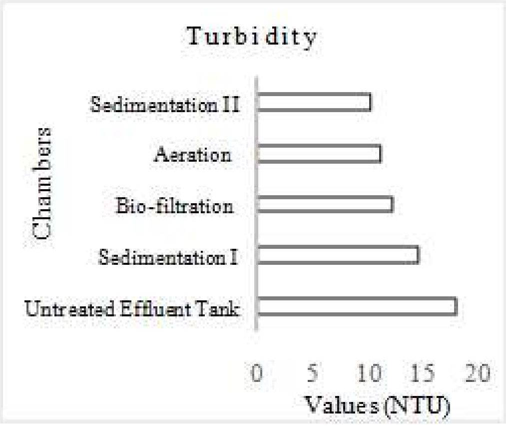

Figure 5. Variation of Turbidity in the treatment chambers

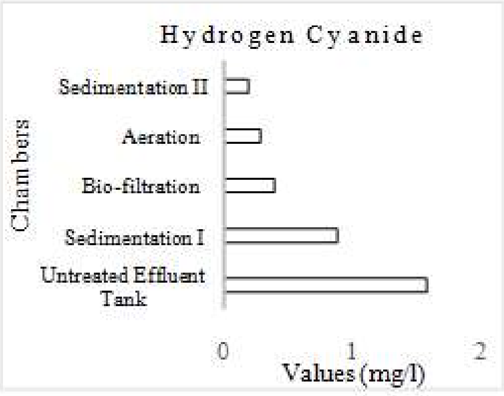

Figure 6. Variation of Hydrogen Cyanide in the treatment chambers

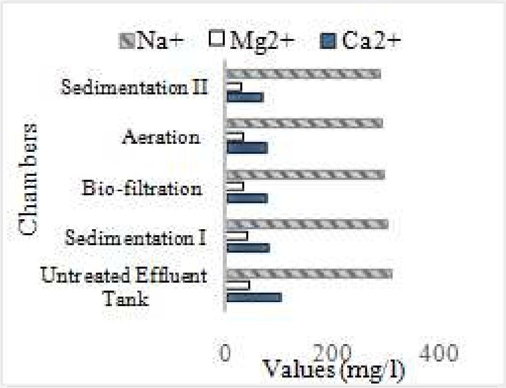

Figure 7. Variation of Na^+, Mg^{2+} and Ca^{2+} salts in the treatment chambers

Continuous air supply during wastewater treatment also increases the microbial growth and accelerates the degradation of high organic wastewater (Rashid et al., 2010). The inhibiting effect of the acidic medium on the microbial load may be responsible for the low performance of the system (Solomonson, 1981). Although the final effluent quality could not attain the local permissible limits of 30 mg/l (BOD) and 60 mg/l (COD), the final values can be reduced under optimized conditions with higher hydraulic retention times to meet local permissible limits

Turbidity

The treatment chambers had slight effects on the effluent turbidity as presented in Table 2 and Figure 5. The turbidity was observed to slightly decrease across the chambers yielding an overall reduction efficiency of 29.93% (Table 3). The greatest improvement (19.23%) was obtained in the first sedimentation chamber closely followed by the biofiltration chamber (16.33%). Slight improvements (8.94% and 8.04%) were observed in the aeration and second sedimentation tank. The different turbidity concentrations in the last two chambers (aeration and sedimentation II) did not indicate a clear effect of the treatment measures ($P>0.05$). This signifies that the aeration and a second sedimentation sequence had no effect on the wastewater turbidity. However, the values obtained from the previous treatment measures were significantly different ($P<0.005$), indicating the effectiveness of these measures. The final effluent turbidity (10.3 NTU) was slightly more than twice the permissible limit of 5.0 NTU as shown in Table 1. Though the treated effluent can safely be used to irrigate crops, further treatment may be required for safe disposal.

Hydrogen Cyanide (HCN)

Figure 6 shows the sequential decline of cyanide concentration in the wastewater from an initial value of 1.6 mg/l to a final value of 0.2 mg/l. This corresponds to an overall reduction efficiency of 73.56%. The highest removal efficiency of 55.56% was recorded in the biofiltration chamber. Hydrogen cyanide concentrations in the biofiltration, aeration and the second sedimentation chambers were not significantly influenced ($P>0.05$) by this treatment sequence (Table 2). Contrary to the result observed in the biofiltration chamber, Siller and Winter, (2004) and Mai (2006) reported the reduction of cyanide from cassava effluent by anaerobic microorganisms which confirms the degrading potential of the biofiltration chamber on HCN concentration (Naveen et al., 2011). The presence of a group of single-celled anaerobic cyanide degrading microorganisms in the chambers with the highest population perceived to be resident in the biofiltration chamber may account for this performance. Cyanide degradation by anaerobic and aerobic bacteria was also examined and reported by Gurbuz et al. (2004) and Gurbuz et al. (2009). The degrading effect of the treatment measures on hydrogen cyanide is presented in Table 2 and Table 3.

The sedimentation chambers had an appreciable influence on hydrogen cyanide reduction as shown in the percentage reduction values (43.75% and 33.33%). The low removal efficiency (25%) observed in the aeration chamber shows that cyanide degradation is slightly influenced by aeration. Despite the high overall removal efficiency recorded for the treatment system, it is still adjudged limited in reducing the cyanide concentration to the permissible limit since the final concentration of 0.2 mg/l still falls above the permissible limit of 0.01 mg/l as shown in Table 1. Higher hydraulic retention time in the chambers could further reduce the cyanide concentration to an acceptable limit. The treatment by the first sedimentation chamber had no effect on the sodium salt concentration ($P>0.05$) compared to the concentration in the raw wastewater tank.

Table 2. Physicochemical characteristics of the wastewater samples

Parameters	Raw Wastewater	Sedimentation Chamber I	Biofiltration Chamber	Aeration Chamber	Sedimentation Chamber II
pH	4.90^1	4.90^1	4.60^1	4.50^1	4.50^1
EC (µS/cm)	862.00_a	914.33_b	963.67_c	975.67_d	986.00_e
BOD (mg/l)	532.33_a	390.00_b	212.33_c	145.00_d	114.67_e
COD (mg/l)	1006.67_a	773.33_b	451.67_c	306.67_d	238.33_e
Turbidity (NTU)	18.17_a	14.67_b	12.33_c	11.17_d	10.33_d
Hydrogen Cyanide (mg/l)	1.63_a	0.87_b	0.43_c	0.30_c	0.23_c
Ca^{2+} (mg/l)	103.33_a	81.67_b	$76.67_{b,c}$	$75.00_{b,c}$	70.00_c
Mg^{2+} (mg/l)	43.33_a	$40.00_{a,b}$	$33.33_{b,c}$	$33.33_{b,c}$	30.00_c
Na^+ (mg/l)	311.67_a	$305.00_{a,b}$	$298.33_{b,c}$	$293.33_{b,c}$	290.00_c

Note: Values in the same row not sharing the same subscript are significantly different at $P< 0.05$ in the two-sided test of equality for column means. Tests assume equal variances. [1]This category is not used in comparisons because there are no other valid categories to compare

Table 3. Progressive percentage improvements in the treatment chambers

Parameters	Percentage Improvements in the Treatment Chambers				Overall System Efficiency (%)*
	Sedimentation I	**Biofiltration**	**Aeration**	**Sedimentation II**	
pH	*NI**	6.12	2.17	*NI*	8.16
EC (µS/cm)	6.07	5.40	1.25	1.06	7.84
BOD (mg/l)	26.73	44.28	33.27	20.90	70.59
COD (mg/l)	23.18	41.59	32.10	22.30	69.18
Turbidity (NTU)	19.23	16.33	8.94	8.04	29.93
Hydrogen Cyanide (mg/l)	43.75	55.56	25.00	33.33	73.56
Ca^{2+} (mg/l)	20.91	6.12	2.22	6.67	14.32
Mg^{2+} (mg/l)	7.62	16.75	*NI*	9.91	25.00
Na^{+} (mg/l)	2.15	2.20	1.68	1.13	4.92

Note: *NI** (No improvement). All parameters are in mg/l except Turbidity (NTU), EC (µS/cm) and pH (No Unit). The Overall System Efficiency (%)* was obtained by using the initial and final values

The lowest reduction efficiencies were recorded for sodium salts (Na^+) across the treatment chambers with the highest value (2.20%) recorded in the biofiltration chamber closely followed by 2.15% in the first sedimentation chamber although its concentrations were not significantly different in these chambers ($P>0.05$). Reduction efficiencies of 1.68% and 1.13% were further obtained in the aeration and second sedimentation chamber. The concentrations of Na^+ in these chambers were also not significantly different ($P>0.05$).

The final sodium adsorption ratio (SAR) was observed to be 7.3. Typically, irrigation water with a SAR value below 2.0 is considered very safe for plants especially if the sodium concentration is below 50 mg/l. The treated wastewater SAR is less than 10 and can be classified as excellent for disposal and crop irrigation. However, the excessive sodium salt concentration leads to the displacement of Ca^{2+} and Mg^{2+} and the adsorption of sodium ions by clay particles. This ion exchange reduces soil permeability and eventually results in poor internal drainage (Wilcox, 1955). If desired for irrigation purpose, it can only be used for irrigating sodium sensitive crops such as avocados but with caution. Further treatment or dilution is required before it can be safely disposed of or used for crop irrigation.

Conclusion

The degradation of cassava mill effluent in the reactor gave BOD, COD and HCN removal efficiencies of 70.59%, 69.18% and 73.56% respectively. Despite obtaining pollutants with final values falling above the permissible limits, the system showed an appreciable performance in degrading key pollutants. Effective optimization of key system variables such as the hydraulic retention time (HRT), aeration rate and mode of operation can improve the system performance. The system can be used as an economically and technically viable option for treating wastewater generated by small and medium scale cassava processors. Treated effluent can also be diluted slightly and used for agricultural purposes.

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