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Research Article

Application of activated carbon impregnated composite ceramic filters in cassava mill effluent treatment: prospects and limitations

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Abstract: Disposal of poorly managed cassava mill effluent often results in serious environmental degradation. A low-cost treatment option was developed to alleviate this rising concern prevalent among indigenous processors. Frustum-shaped ceramic filters produced by mixing different proportions of sawdust and activated carbon with equal amounts of clay, kaolin and sherds powder and sintered at 850°C was assessed in this study. The results indicated pollutant removal efficiency ranging from 6.5 to 98.1% with the best removal efficiency obtained for chemical oxygen demand (COD) [97.9 - 98.1%] closely followed by biochemical oxygen demand (BOD) [71.24 - 77.14%] while (24.13 - 30.72%) and (6.5 - 71.7%) were obtained for turbidity and hydrogen cyanide respectively. The filter with 12.8% of sawdust, 5.1% of activated carbon, 7.13% of kaolin, 3.6% of sherds powder and 71.3% of clay gave the best removal efficiency. A maximum flow rate of 0.0035L/H (LPH) was recorded with a corresponding time of the first drop of 216 minutes. The high removal efficiency observed for some parameters, locally available construction materials and wastewater reuse options makes this a viable option for cassava mill effluent treatment, however, further study is required to optimize this technique to meet wastewater permissible limits.

Keywords: *agro-processing, ceramic filter, clay, sawdust, wastewater*

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Introduction

The agricultural drive by the Nigerian government to boost cassava cultivation for domestic and international markets has resulted in the establishment of indigenous cassava processing plants in urban and peri-urban communities. This has also increased the amount of generated effluent and its discharge to the environment (Omotosho and Amori, 2015). Cassava processing is mostly done by 2 to 5 persons processing 1 to 5 tons of cassava tubers, consuming about 2132 litres of fresh water, and generating about 2119 litres of wastewater per ton of fresh cassava roots (Lawal et al., 2017). A typical cassava processing plant generate solid, liquid and gaseous residues from different processing activities such as washing, fermentation/soaking, and dewatering (Okunade and Adekalu, 2014; Nuraini and Felani, 2015). Wastewater generated from washing operation generally contains a substantial amount of inert material with low BOD and COD while that drained from fermented tubers has a higher contaminating load of BOD and COD. The wastewater characteristics is often a function of machine efficiency and adopted processing techniques. Wastewater is often discharged into localized ditches or open fields and allowed to flow freely and settle in shallow depressions and eventually percolates into groundwater or flows into near-by streams resulting in obnoxious odour and serious environmental pollution. The growing awareness and strict regulations by environmental agencies have necessitated the need to treat the effluent promptly and efficiently (Ehiagbonare et al., 2009; Aisien et al., 2010). Several treatment methods have been proposed by researchers. Among these are anaerobic treatment using a horizontal flow filter with bamboo as support, cassava effluent degradation using alkali, and aerobic natural filter combined with an effective microorganism (Colin et al., 2007; Hidayat et al., 2011; Ugwu and Agunwamba, 2012; Omotosho and Amori, 2015). These treatment methods have considerable limitations as they will require specialized skills to operate.

Considering the socio-economic profile of most processors, it is imperative to develop an appropriate low-cost technology that can be easily operated. Point-of-use composite ceramic filter meets these specifications for the treatment of cassava effluent. The production process is simple. The ceramic filter is produced from a mixture of clay, a burn-out material such as rice husk and water. When the filter is fired in a kiln the rice husk burns off leaving pores in the ceramic material (Hagan et al., 2013). They are usually designed in various shapes such as flower pot, disc, and candle (Lamichhane and Kansakar, 2013). The system operates by passing water through the porous ceramic material. Apart from being a promising way to reduce water pollutants, it is affordable, easy to operate and can be manufactured from locally available materials (Agbo et al., 2015). Ceramic filters are majorly used in low turbidity (10 to 53 NTU) drinking water treatment; its application in high turbidity or cassava mill effluent treatment has not been widely researched and reported.

This study is therefore aimed at fabricating point-of-use composite ceramic filters and evaluating their performance in treating cassava mill effluent in terms of reduction of selected biophysicochemical wastewater parameters.

Table 1. Filter composition and additives proportion

Filter Samples	Additives Proportion (%)				
	Sawdust	**Activated Carbon**	**Kaolin**	**Sherds Powder**	**Clay**
SA	0.49	0.20	0.82	0.41	98.09
SB	0.97	0.39	0.81	0.41	97.42
SC	1.45	0.58	0.81	0.40	96.76
SD	1.92	0.77	0.80	0.40	96.11
SE	2.39	0.95	0.80	0.40	95.47

Figure1. Showing the experimental stages and filtrate collection

Materials and Methods

The clay sample used in this study was obtained from clay industries limited, Oregun, Lagos State, Nigeria while the burnout material (hardwood sawdust) was obtained from a local sawmill deposit at Egbeda, Ibogun Ifo local government area of Ogun State Nigeria. Rivera (2004) suggested the use of sawdust from hardwood as the most ideal burnout material as it does not swell and produces uniform pores with fewer defects in the filter. The activated carbon is a brand of JCO chemical product obtained from a local market. The agro-processing effluent (cassava effluent) to be treated was obtained from a cassava-processing centre also located at Ibogun, Ifo Ogun State Nigeria. Other components were purchased from a local market located within the study area. The sawdust was sieved with three sets of sieve size (8/238 µm, 16/119 µm and 18/100 µm) and the material retained on sieve size 16 was used. This is equivalent to particles of diameter less than or equal to 119 µm (Figure 1). The clay was prepared as described by Nnaji et al. (2016).

Table 2. Characterization of raw cassava mill effluent

S/No.	Wastewater Parameters	Mean Values	Permissible Limits	
			WHO	NESREA
1	pH	3.80±0.07	6.5-8.5	6.0-9.0
2	Electrical conductivity	6.63±1.90	400	NS
3	BOD_5	1837±75.82	40	30
4	COD	32000±21166.01	80	60
5	Ca^{2+}	42.84±4.32	200-600	200
6	Mg^{2+}	32.20±6.78	NS	200
7	Na^{+}	47.34±4.80	0.4	200
8	Hydrogen Cyanide	0.46±0.19	0.07	0.01
9	Turbidity	24.87±3.65	5	5

NS = Not Stated

All the parameters are in mg/l except Electrical conductivity (µS/cm) and Turbidity (NTU). Different amount of sawdust and activated carbon were weighed with an electric weighing balance and added to a fixed amount of clay (6 kg), kaolin (50 g) and sherds powder (25 g) used as temper material to prevent cracks and breakage during firing. The filters produced from these proportions were labelled as samples SA, SB, SC, SD and SE respectively as shown in Table 1. The produced filters were allowed to dry in air at an average maximum temperature of 25°C, minimum temperature of 19°C and average relative humidity of 56% for 16 days. The filters were assessed based on removal efficiencies of some biophysicochemical pollution indicators. The filters were later sintered at 850°C in an industrial kiln for 72 hours and allowed to cool gradually in the kiln. This is to further reduce the porosity and increase the filter density and strength (Nnaji et al., 2016). The filters were prepared for filtration as described by Nnaji et al. (2016) and tested by measuring the amount of filtrate that percolated through the filter after 1 hour as reported by Soppe et al. (2015). Filtrate samples were collected in plastic containers and taken to the laboratory for analysis. Biophysicochemical parameters (Electrical conductivity (EC), pH, biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{2+}), Hydrogen Cyanide) of the agro-processing wastewater were analyzed in triplicate before the treatment regime based on APHA Standard Methods of Examination of Water and Wastewater (APHA, 2005). Turbidity was determined using EXTECH® turbidity meter (Model TB400). Filter performance was assessed based on pollutant removal efficiency calculated using equation 1.

$$Re(\%) = \frac{I_C - I_F}{I_C} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where:

I_C = Initial concentration of pollutant

I_F = Final concentration of pollutant

R_e = Removal efficiency

The filter apparent porosity was calculated based on ASTM-C373 (2006) standard as reported by Shukur et al. (2018), using equation 2:

$$Ap(\%) = \left[\frac{W_2 - W_1}{W_2 - W_3}\right] x100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where:

A_p = Apparent porosity

W_1 = Dry filter weight

W_2 = Weight of saturated filter

W_3 = Weight of filter after immersion in water

Results and Discussion

The manufactured ceramic filters are shown in Figure 1. The presence of Iron (III) oxide or ferric oxide (Fe_2O_3) in the clay sample used contributed to the light-dark red colour majorly observed for the final products. This differs from the light golden-brown colouration reported by Akpomie et al. (2012) after sintering at 900°C. This difference can be attributed to the difference in the clay compositions.

Raw cassava mill effluent characterization

The result of raw wastewater characterization is presented in Table 2. All the tested parameters were above local (National Environmental Standards and Regulations Enforcement Agency - NESREA) and international (World Health Organization - WHO) permissible limits except the cations (Ca^{2+}, Na^{+} and Mg^{2+}) which are significantly below the permissible limits. These observed values are comparable with values obtained by other authors in related studies (Hidayat et al., 2011; Nuraini and Felani, 2015; Lawal et al., 2017). An appreciable amount of treatment is therefore required before the wastewater can be disposed to avoid severe environmental pollution.

Filter flow rate and porosity

Filter porosity gives an idea of the ease with which water flows through it. The pore size and pore size distribution, hydraulic head above the filter and the suspended solids (SS) of the source water determine the filters' performance and pollutants removal efficiency. The scrubbing frequency is also a function of the suspended solids load in the source water (Nnaji et al., 2016). The filter flow rate was observed to increase with the increase in the proportion of sawdust and activated carbon as shown in Table 3. This is due to the porous space that is created as the amount of clay decreases and the burnout material increases.

Table 3. Additives proportion, filter flow rate and time of first drop

Filter Samples	Mass of Additives (g)		Flow rate (LPH)	Time of first drop (min)	Porosity (%)
	Sawdust	Activated Carbon			
SA	30	12	**No filtrate**		36.5
SB	60	24			40.6
SC	90	36	0.0018	252	44.0
SD	120	48	0.0027	230	42.3
SE	150	60	0.0035	216	45.7

The combustible materials burn off leaving networked pores that in turn leads to an increase in the flow rate of the composite ceramic filters (Isikwue and Emmanuel, 2011). The flow rates varied from zero to 0.0035 LPH for filters SA and SB with sawdust and activated carbon proportions of 0.49:0.20 and 0.97:0.39 to a maximum value of 0.0035 LPH for filter SE with sawdust and activated carbon proportions of 2.39 and 0.95 respectively (Table 1). The highest water discharge was associated with filter SE that has the highest porosity. Therefore, the rate of water discharged increases with filter porosity. This compares well with similar studies by Lantagne (2001), Nnaji et al. (2016), and Zereffa and Bekalo (2017). In this study, the flow rate dropped significantly with time. This results from the presence of significant amount of organic matter and suspended solids in cassava mill effluent. In similar studies for household drinking water, the flow rate also decreased with time (Franz, 2005). The filters were scrubbed weekly to improve performance. The need for frequent scrubbing and the limited volume of filtrate are major limitations often reported with composite ceramic filters.

Treated cassava mill effluent characterization

Filtrate pH

The effluent pH before and after filtration are presented in Table 2 and Table 4 respectively. This is a measure of the hydrogen ion concentration of the wastewater, and it indicates the level of acidity or alkalinity of the water samples. The pH value of the cassava mill effluent was low (3.8), and this was increased after filtration through all ceramic filters. Filtrate pH ranged from 4.2 to 5.87 (Table 4). A slight increase was observed for the pH from an initial acidic value of 3.8 to a maximum value of 5.87 recorded for filtrate from filter SE with 2.39% of sawdust, 0.95% of activated carbon and 95.47% of clay. The lowest filtrate pH of 4.2 was recorded for filter SD with the additive proportion of 1.92% sawdust, 0.77% activated carbon and 96.11% of clay. The significant improvement recorded for SE is still below WHO and NESREA permissible limits and will require some measure of stabilization before the wastewater can be safely disposed of. The slight decrease observed in the filtrate pH for filter SD may be due to the adsorption of suspended solid particles by the filter composite.

Filtrate electrical conductivity

The ceramic filters were all evaluated for EC improvement after filtration. Significant improvement was observed in the EC values for all the filtrates. EC has been directly related to the number of ions present in a given solution (Werkneh et al., 2015). The raw cassava mill effluent has a low EC of 6.63 µS/cm which is significantly lower than the WHO permissible limit for industrial wastewater. The filtrate EC ranged from 42.5 to a maximum value of 53.63 µS/cm for filter SC corresponding to a removal efficiency of 19.1 to 35.9%. The final EC values fall below the WHO permissible limit of 400 µS/cm. Filter SC with 96.76% of clay, 1.45% sawdust and 0.58% of activated carbon gave the maximum removal efficiency of 53.63%.

Filtrate BOD and COD

Appreciable results were obtained with respect to the performance of all the ceramic filters in reducing BOD and COD concentration. The removal efficiencies of BOD and COD were consistently above 71% for all the filter samples. BOD removal efficiency ranged between 71.2 to 77.1% while COD ranged between 97.1 to 98.1%. The results show that despite the high removal efficiencies achieved for BOD and COD using activated carbon impregnated composite ceramic filters, the filtrate could not attain WHO and NESREA permissible values of 40 and 30 mg/l.

Table 4. Characterization of treated cassava mill effluent

S/No.	Wastewater parameters	Filter Samples		
		SC	SD	SE
1	pH	5.67±0.12	4.2±0.1	5.87±0.06
2	Electrical conductivity (µS/cm)	53.63±5.03	42.5±6.25	44.73±6.66
3	BOD (mg/l)	420.0±2.0	528.33±1.53	464.33±13.58
4	COD (mg/l)	614.67±3.06	619.67±10.79	681.33±5.13
5	Ca^{2+} (mg/l)	21.83±0.29	28.33±0.58	29.27±0.25
6	Mg^{2+} (mg/l)	19.6±0.2	21.7±1.473	21.4±0.1
7	Na^{+} (mg/l)	21.43±0.35	22.67±0.12	24.43±0.25
8	Hydrogen Cyanide (mg/l)	0.13±0.06	0.33±0.06	0.43±0.06
9	Turbidity (NTU)	17.23±1.31	18.5±0.27	18.87±0.06

Table 5. Removal efficiencies of the filter samples

S/No.	Wastewater parameters	Filter Removal efficiencies (%)				
		SA	SB	SC	SD	SE
1	Electrical conductivity (µS/cm)	No Filtrate	No Filtrate	19.1	35.9	32.5
2	BOD (mg/l)			77.1	71.2	74.7
3	COD (mg/l)			98.1	98.1	97.9
4	Ca^{2+} (mg/l)			49.0	33.9	31.7
5	Mg^{2+} (mg/l)			39.1	32.6	33.5
6	Na^{+} (mg/l)			54.7	52.1	48.4
7	Hydrogen Cyanide (mg/l)			71.7	28.3	6.5
8	Turbidity (NTU)			30.7	25.6	24.1

Increase in the amount of sawdust seems to have no significant effect on the BOD removal efficiencies as a slight drop was noticed with increase in filter additives from sample SC to SD (77.1% to 71.2%). Further increase in additives resulted in a slight increase from 71.2% to 74.7% signifying an optimum additive ratio of 1.45% sawdust, 0.58% activated carbon, 0.81% kaolin, 0.40% sherds powder and 96.76% clay for sample SC. Detailed investigation is required to determine the predominant dynamics between the filter additives, particle size distributions and the individual contribution of the various additives towards achieving a better BOD removal efficiency. Despite the low removal efficiency recorded in this experiment, the values obtained are significantly higher than the values reported by Nnaji et al. (2016). They obtained filtration efficiencies of 44.8%, 45.8% and 52.87% when clay-sawdust composite filter was used to treat rain, storm and well water respectively. Hasan et al. (2011) reported a complete removal of BOD and more than 99% removal of COD. The high removal performance was attributed to the long hydraulic retention time with suitable dissolved oxygen conditions. COD removal efficiency was constant with an increase in the quantities of additives and slightly decreased at an additive proportion of 2.39% sawdust, 0.95% activated carbon, 0.80% kaolin, 0.40% sherds powder and 95.47% clay while the maximum removal efficiency of 98.1% was obtained for filter SC and SD with additive proportions shown in Table 1.

Cations (Ca^{2+}, Na^{+} and Mg^{2+}) concentration

The cations concentrations in the raw and treated effluents are low. As shown in Table 5, all the manufactured filters could remove cations (Mg^{2+}, Ca^{2+}, and Na^{+}) in the range of 31.7 to 54.7% efficiency from cassava mill effluent. The highest removal efficiency of 54.7% was obtained for Na^{+} in sample SC while the lowest value of 31.7% was obtained for Ca^{2+} in filter SE. Increase in filter additives (sawdust and activated carbon) resulted in a slight decrease in Ca^{2+} and Na^{+} concentration in the filtrate samples. While an initial increase in filter additives resulted in a slight drop in Mg^{2+} concentration, a slight drop was observed with further increase in the filter additives. This removal might be due to the ion exchange on the ceramic surface, formation of oxide precipitates and adsorption dynamics on the activated carbon media formed in the ceramic body (Zereffa and Bekalo, 2017). The concentration of the cations in the raw cassava mill effluent are below WHO and NESREA limits except for Na^{+} that is above WHO limit of 0.4 mg/l. Mg^{2+} and Ca^{2+} are significantly below the minimum permissible limit of 200 mg/l. A relatively low sodium adsorption ratio (SAR) value (1.3) was obtained for the raw cassava mill effluent while the SAR of the treated effluent fluctuated between 1.4 and 1.5 with the increase in filter additives. Disposing effluent with high concentrations of cations could increase SAR in the soil. Soils irrigated with high cations concentration effluent are adversely susceptible to salinity risk and may affect cultivated crops. The values obtained poses little concern to cultivated soil and plants, however, if this effluent is to be used for crop irrigation, pelletized gypsum should be added to the soil periodically to regulate the soil salinity.

Hydrogen cyanide (CN)

The average hydrogen cyanide content in the treated cassava mill effluent decreased in all the filters with increase in the filter additives (Table 4). Filter SC gave the best removal efficiency of 71.7% while SE gave the lowest (6.5%) removal efficiency. Table 2 shows that the wastewater contained more than WHO and NESREA acceptable level of 0.07 mg/l and 0.01 mg/l. The average level of cyanide obtained for the raw effluent was 0.46 mg/l while an average range of 0.13 mg/l to 0.43 mg/l was obtained for the treated effluent. Filter SC gave the maximum removal efficiency while filter SE gave the minimum value of 6.5%. These results imply that the system requires some measure of optimization to ensure adequate treatment before the water is disposed of or used for crop irrigation.

Turbidity

The values obtained for turbidity removal is shown in Table 4. The turbidity of the raw cassava mill effluent was 24.87 NTU while the turbidity levels in all the filtrates ranged from a minimum value of 17.23 NTU to a maximum value of 18.87 NTU corresponding to removal efficiency range of 24.1% to 30.7%. The maximum turbidity level was obtained in the last filter (SE). This contradicts the maximum turbidity value of 27 NTU recorded in the first filtrates reported by Isikwue and Emmanuel (2011). The pores left by the burnout material were assumed to be widest at this stage and reduces as the filtrations progress. This is due to clogging of the pore spaces during filter operation. The raw and treated effluent turbidity were above WHO and NESREA permissible limit of 5 NTU. Turbidity was observed to have no considerable relationship with the flow rate. This was also observed by Isikwue and Emmanuel (2011). It can be seen in Table 4 that turbidity decreases with an increase in filter additives.

Conclusion

The application of low-cost composite ceramic filters in cassava mill effluent treatment was evaluated in the laboratory. The five filters made from a mixture of sawdust activated carbon, kaolin and sherds powder was adjudged effective in producing filtrate with low COD and BOD concentration. This work is an initial step to demonstrate the application of composite ceramic filters in reducing biophysicochemical parameters from high turbidity wastewater like cassava mill effluent. The management of some reported limitations such as frequent filter clogging and slow flow rates were not systematically evaluated in this study. A direct linear relationship between the flow rate and the quantities of filter additives was observed whereas a defined relationship between the filter performances and quantities of additives was not established for most parameters. The observed reduction efficiency of COD and BOD in the filtrate samples are consistently appreciable with observed values of 70% and 97% respectively. The filters were not cleaned throughout the period of evaluation which necessitates the need to further study the reduction dynamics of the filter and other wastewater parameters under field conditions.

Further studies should focus on improving the flow rate and minimizing the need for frequent cleaning without compromising on the quality performance. The filter, when optimized would be an important component of cassava processing facilities in cassava processing communities. The generated filtrate can also be reused for crop irrigation.

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