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Assessment of a submerged membrane bioreactor with composite ceramic filters for cassava wastewater treatment

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Abstract: Cassava processing activity is characterised by the generation of an enormous quantity of toxic wastewater with detrimental effects on the environment if disposed of without adequate treatment. To alleviate this concern, lab--scaled cylindrical-shaped composite ceramic filters produced from rice husk and clay mixed with equal proportions of activated carbon, kaolin and sherd powder were produced and assessed in a membrane bioreactor. The permeate obtained from the filter with 2.39% rice husks, 0.95% activated carbon, 0.80% kaolin, 0.40% sherd powder and 95.47% clay gave the optimum pollutant removal efficiency. The average removal efficiencies of the chemical oxygen demand (COD), biochemical oxygen demand (BOD), turbidity and hydrogen cyanide (HCN) were 98.32, 78.93, 37.81 and 56.52%, respectively. The pH increased from 3.8 to a maximum value of 6.5. The flux ranges from 0.005 [$m^3 \cdot (m^2 \cdot d^{-1})$] to a maximum value of 0.108 [$m^3 \cdot (m^2 \cdot d^{-1})$] obtained for the filter with 1.45% rice husks. The availability of low-cost construction materials and the ease of operation makes the concept a promising option for treating cassava wastewater, however, an optimisation study is required to improve the filter performance and enhance the field applications.

Keywords: rice husk; environment; clay; environmental pollution; activated carbon

The cassava agro-processing industry is adjudged to be a fast-growing industry resulting from a policy drive to increase the cassava cultivation and processing in Nigeria. This growth has resulted in the generation of an enormous amount of solid and liquid waste with high organic contents (Agwaranze et al. 2018). About 5–11 m^3 of freshwater is needed to process one tonne of fresh cassava root resulting in about 40–60 m^3 of wastewater (Akhirruliawati, Shofiyatul 2009). In developing countries, local cassava processing clusters are often located near water bodies from where freshwater is easily obtained. The wastewater generated from the processing clusters is mostly discharged into the available watercourse due to the absence of wastewater treatment facilities. This practice often results in an obnoxious odour around processing centres and serious environmental pollution (Adeyemo 2005; Nwabueze et al. 2007; Lawal et al. 2018). In most cases, the soil and water microbiological properties are seriously altered and communities living near the processing clusters and processors are exposed to health risks (Akani et al. 2006; Kaewkannetra 2011; Lawal et al. 2019).

The treatment of cassava processing wastewater (CPW) has generated interest and has been widely studied by researchers. Various treatment techniques

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proposed by researchers include physical (Rashid et al. 2010; Hidayat et al. 2011; Kandasamy et al. 2013), biological (Gijzen et al. 2000; Siller, Winter 2004; Colin et al. 2007; Kaewkannetra et al. 2011) and chemical adjustment techniques (Emmanuel, Jonah 2012; Jideofor 2015; Omotosho, Amori 2015). A combination of physical and nature-based methods has also been developed and applied in treating cassava mill effluent (Hien et al. 1999; Fettig et al. 2013). A non-conventional technique like a microbial fuel cell was also applied to degrade the cassava-based effluent (effluent generated from the wet *fufu* paste mill); the authors generated electricity and hydrogen in the process (Kaewkannetra et al. 2011; Giwa et al. 2017). More recently, researchers have explored a membrane bioreactor (MBR) as a promising option in degrading the cassava mill wastewater (Subagjo et al. 2015; Truong et al. 2018). The advantages of this system include a system compactness, a high effluent quality, a low sludge production and higher volumetric loading rates. The fouling tendency which lowers the membrane flux was majorly reported as a drawback of this treatment technique (Metcalf, Eddy 1972; Yamamoto et al. 1989). Despite the satisfactory performance achieved in the laboratory and large-scale applications, the technique is characterised by high investment costs and operational skills which local processors often lack. Therefore, a simplified replica of this technique with an appreciable removal efficiency will be most welcomed by small and medium-sized cassava processors operating in rural communities.

An innovative approach is the use of submerged open-end composite ceramic filters impregnated with activated carbon as the filter membrane. Generally, ceramic filters are locally available at affordable prices. The treatment technique involves passing water through porous ceramic materials made from locally sourced materials. This technique has been used to reduce water-borne diseases (Agbo et al. 2015). Ceramic filters are often designed in various shapes and sizes which includes flower pot designs, disc designs, and filter candles (Lamichhane, Kansakar 2013). They are produced from a mixture of natural clay, burn-out materials (such as rice husks, sawdust, wheat bran) and kaolin. They are sometimes impregnated with other absorbents to enhance their performance (Soppe et al. 2015). When the clay filter is sintered in a kiln, the largely organic burn-out materials burn out leaving tiny pores in the ceramic material (Hagan et al. 2013). A major disadvantage of ceramic filters is their slow rate of filtration which often decreases with time due to clogging. This results in low quantities of the filtrate. Scrubbing has been shown to temporarily increase the flow rate, but they hardly return to their original flow rate after scrubbing and flow rates continually decrease over time to less than 0.5 L·h^{-1}. The current filtering rate ranges from 1 to 3.5 L·h^{-1} for most ceramic filters (Van Halem 2007).

This study is, therefore, aimed at investigating the performance of a simple membrane bioreactor (MBR) with open-end submerged composite ceramic filters (produced by mixing rice husks and activated carbon with an equal proportion of kaolin, sherd granules and clay) as the membrane module in treating CPW. The authors are not aware of any documented studies reporting on the use of this treatment technique in treating CPW.

MATERIAL AND METHODS

Filter production. Rice husks was selected as the burn-out material due to its availability as agricultural waste in many rice-producing communities. It constitutes about 20–23% by weight of the processed paddy and Nigeria was reported to generate about 1 032 993.6 metric tonnes of rice husks annually (NAERLS/PCU 2004; Kumar et al. 2013). Activated carbon (AC) refers to a group of crystalline absorbing substances with large internal pore structures with absorbent properties (Hu, Srinivasan 2001). It is mostly produced from agricultural-based materials such as coconut shells, palm kernel shells, wood chips, sawdust, corn cobs and animal bones (Yusufu 2012). The base material is carbonised to obtain the carbonaceous material which is then activated in the absence of oxygen at about 700 °C to produce activated carbon (Dileck, Oznuh 2008). Actiated carbon has been used to improve the aesthetic nature of water and in domestic and industrial wastewater treatment with major applications in areas such as de-colourisation, odour removal, taste, heavy metals and organic contaminants from water (Mendez 2006).

The major raw material of ceramic filters (natural clay) is widely available in many parts of Nigeria (Fasuba 2001; Omowunmi 2001; Aye 2013). Natural clay was obtained from a local clay mining factory at Oregun Ikeja, Lagos State South West Nigeria while the rice husks were obtained from a rice milling industry in Ogun State Nigeria. The clay and sherd samples were crushed and milled into a fine powder. All the raw materials (clay, sherds and activated carbon) were sieved through a 0.5 mm mesh

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sieve as described by Hasan et al. (2011), Soppe et al. (2015) and Nnaji et al. (2016). The rice husks were dried and sieved using a 1 mm mesh as described by Hasan et al. (2011). The activated carbon is a brand of a JCO (Journées de Chimie Organique) chemical product obtained from a local market. The cassava mill effluent was obtained from a local cassava-processing cluster at Ibogun, Ifo, Ogun State Nigeria. A different amount of rice husks and activated carbon were weighed with an electric weighing balance and added to a fixed amount of clay (6 kg), kaolin (50 g) and sherd granules (25 g) used as the temper material to prevent cracks and breakage during firing. The variation of the quantity of rice husks is expected to vary the filter porosity. Open-end cylindrical-shaped filters (160 mm height, 300 mm outer, 140 mm inner diameter and 15 mm thickness with one side closed) were produced with various proportions using carved wood as mould. The filters were labelled as samples RA, RB, RC, RD and RE respectively as shown in Table 1. Five sets of filters were produced for each additive composition to allow for their replacement resulting from breakages during sintering. The filters were allowed to dry at room temperature (19–25 °C) and an average relative humidity of 56% for 14 days and later sintered at 850 °C for 60 h in an industrial kiln. They were allowed to cool to room temperature in the kiln; this is to further reduce the porosity and increase the filter density and strength (Nnaji et al. 2016). The produced composite ceramic filter is estimated to cost about \$3.40 per sample.

Experimental set-up and operating conditions. The study was conducted in a cylindrical PVC (polyvinyl chloride) column reactor with a 23 cm inner diameter and 23 cm in height equivalent to a working volume of 9.6 L. The filter membrane has a total surface area of 0.0113 m^3. Its dimensions are shown in Figure 1. A 7 cm thick inert block was placed inside the reactor to support the ceramic filter membrane. A rubber tube was attached to the side of the filter membrane for the permeate collection and submerged in the column with its open end above the effluent level as shown in Figure 1. The filters were prepared for filtration as described by Nnaji et al. (2016). To obtain the flux, the permeate volumes were measured after 30 min of filtration for each filter sample set, while the flux was obtained by dividing the permeate volume by the corresponding filtration time (30 min) as described in a similar study by Hasan et al. 2011. In this study, 10 h was chosen as the hydraulic retention time (HRT) to represent a slightly high organic loading rate (OLR) condition. This choice was informed by a previous study by Meng et al. (2007). The authors reported a negative impact on the MBR performance resulting from a very low HRT (4–5 hours). The column reactor was cleaned after each experimental run and the ceramic filter membrane was successively changed to test the different additive compositions (RA, RB, RC, RD and RE). The filter membranes were not cleaned throughout the experiments during all the runs as described by Hasan et al. (2011). The experiments were performed with a constant effluent height above the filter membrane (16 cm); corresponding to a hydrostatic pressure of 0.1025 MPa. The set-up was closely monitored with the different filters in place while the permeate through the filter membrane was obtained from the rubber tube outlet by gravitational pressure. The samples were analysed for the biochemical oxygen demand (BOD_5), chemical

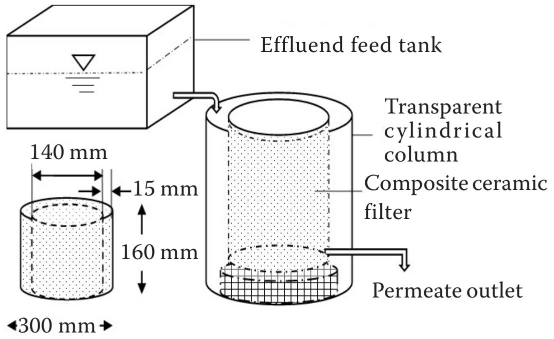

Figure 1. A simple schematic representation of the treatment set-up

Table 1. The filter composition and additive proportions

Filter samples	Additives proportion (wt.%)				
	rice husk	activated carbon	kaolin	sand	clay
RA	0.49	0.20	0.82	0.41	98.47
RB	0.97	0.39	0.82	0.41	97.47
RC	1.45	0.58	0.82	0.41	96.47
RD	1.92	0.77	0.82	0.41	96.47
RE	2.39	0.95	0.82	0.41	95.47

oxygen demand (COD) and Hydrogen Cyanide based on the APHA (American Public Health Association) Standard Methods of Examination of Water and Wastewater (APHA 2005). The turbidity was determined using a turbidity meter (Model TB400, EXTECH® Instruments, USA) while the permeate pH was monitored using a pH-009 (1) pen-type pH meter (HINOTECK laboratory equipment, China).

The filter performance was assessed based on the pollutant removal efficiencies calculated using Equation (1):

$$R_e(\%) = \frac{I_{\text{initial}} - I_{\text{final}}}{I_{\text{initial}}} \times 100 \quad (1)$$

where: I_C – initial concentration of the pollutant; I_F – final concentration of the pollutant; R_e = removal efficiency.

The filter apparent porosity was calculated based on the ASTM C373 – 88 (2006) standard as reported by Shukur et al. (2018), using Equation (2):

$$A_P(\%) = \left[\frac{W_2 - W_1}{W_2 - W_3}\right] \times 100 \quad (2)$$

where: Ap – apparent porosity; W_1 – dry filter weight; W_2 – weight of the saturated filter; W_3 – weight of the filter after immersion in water.

The hydrostatic pressure was determined using Equation (3):

$$P = P_{\text{atm}} + \rho g H \quad (3)$$

where: P – hydrostatic pressure; P_{atm} – atmospheric pressure; ρ – density of water (assumed to be 1 000 KPa at room temperature); H – depth of the effluent (from the filter membrane bottom to the top of the column).

RESULTS AND DISCUSSION

Raw cassava mill effluent characterisation

The result of the raw wastewater characterisation is summarised and presented in Table 2. All the tested parameters fall short of the local (National Environmental Standards and Regulations Enforcement Agency – NESREA) permissible limits. The values compare well with values obtained by Nuraini, Felani (2015) and Lawal et al. (2018). An appreciable amount of treatment is, therefore, required before the wastewater can be safely disposed to avoid any environmental pollution. The presence of ferric oxide (Fe_2O_3) in the clay samples resulted in the dark red colouration observed in the produced filters (Akpomie et al. 2012).

Table 2. The characterisation of the raw cassava processing wastewater

S/No.	Parameters	Values
1	pH	3.80 ± 0.07
2	BOD_5	1 837 ± 75.82
3	COD	32 000 ± 211 66.01
4	hydrogen cyanide	0.46 ± 0.19
5	turbidity	24.87 ± 3.65

All the parameters are in mg·L^{-1} except pH (no unit) and turbidity (NTU).

Ceramic filter flux performance

The flux gradually decreased from the beginning of each experimental run. Hasan et al. (2011) observed a similar trend during the removal of arsenic from groundwater using a ceramic filter as a membrane. The authors reported that some changes in the effluent condition and growth of worms in the reactor column could be responsible for the observed decrease. A maximum flux of 0.108 m^3·m^2·d^{-1} was obtained for the RE filter with 2.39% rice husks and 0.95% activated carbon while a minimum value of 0.005 m^3·m^2·d^{-1} was obtained for the RA filter with 0.49% rice husks and 0.20% activated carbon, respectively. Despite obtaining a permeate throughout the experimental runs, as observed by Hasan et al. (2011), the flux also decreased with time. This may be caused by an increase in the filtration resistance due to the production and accumulation of biopolymers in the reactor. This phenomenon affects the gravitational filtration when using ceramic filters in membrane bioreactors. The flux can be increased by increasing the hydrostatic pressure or with the introduction of a pump (Hasan et al. 2011). The filter porosity is a function of the pore size distribution and determines the filters' ability to remove micro-sized polluting particles and pathogens from the water (Bielefeldt et al. 2009). Furthermore, filter clogging is largely dependent on the filter porosity. Filters with low porosity could remove micro-sized particles and organisms more efficiently (Zereffa, Bekalo 2017). As indicated in Table 3, the porosity of the produced filter ranges from 36.5 to 45.7% and increases with an increase in the additive proportions (Table 3).

Removal Performance

*Permeate BOD and COD***.** The appreciable removal efficiencies were obtained for the BOD and COD concentrations. The removal efficiency of the

Table 3. The additive proportions, filter flow rate and time of the first drop

Filter samples	Rice husk	Activated carbon	Flux [$m^3·(m^2·d^{-1})$]	Apparent porosity (%)
	mass of additives (g)			
RA	30	12	no permeate	36.5
RB	60	24	0.005	40.6
RC	90	36	0.015	44.0
RD	120	48	0.049	42.3
RE	150	60	0.108	45.7

BOD ranged from a minimum value of 72.91% for the RB filter with 0.97% rice husks to a maximum value of 78.93% for the RE filter with 2.39% rice husks. The reduction efficiency of the COD was consistently satisfactory, since the removal efficiencies were above 98% for all the filter samples. The results for the COD removal were slightly above 95% obtained by Subagjo et al. (2015) with the use of a synthetic fibre ultrafiltration membrane. The use of composite ceramic filter gave a better removal efficiency of the COD from cassava processing effluent compared with previous methods reported by Colin et al. 2007 (87.1%), Rajasimman and Karthikeyan 2007 (95.6%) and Thanwised et al. 2012 (55%). An increase in the amount of rice husks and activated carbon had a slight effect on the BOD and COD removal efficiencies. A slight increase was observed with the increase in the filter additives for all the filter samples (Table 4 and Figure 2). Despite the high removal efficiencies achieved for the BOD and COD, the permeates still fall below the local permissible limits of 40 and 30 mg·L^{-1} (Table 4). Optimisation studies are, therefore, required to determine the dynamics between the filter additives and the particle size distributions of the various filter membranes towards achieving a better BOD and COD reduction. The appreciable performance could be attributed to the long hydraulic retention time and suitable dissolved oxygen conditions in the reactor.

*Filtrate pH***.** The effluent pH before and after the experiment is presented in Table 2 and Table 4, respectively. The permeate pH was observed to improve with an increase in the filter additives for all the filters with an appreciable improvement observed for the RD and RE filters. The pH value of the raw cassava mill effluent was increased from an acidic value of 3.8 to a maximum near-neutral value of 6.57 for the RE filter (Table 4). The lowest value (4.70) was obtained for the RB filter with 0.97% rice husks, 0.39% activated carbon and 97.47% clay. An increase in the filter additives seems to enhance the pH improvements. There was a significant difference in the permeate pH obtained from the ceramic filters produced from the different additive compositions of clay to rice husks ($P < 0.05$). The appreciable result obtained with the RE filter brings the effluent within the local permissible limits for the pH. The slight decrease observed in the permeate pH for the RC filter may be due to the low flux and slow adsorption of the suspended solid particles by the filter composite.

Hydrogen cyanide (CN) and turbidity. The average hydrogen cyanide concentration of the permeate decreased for all the filters. However, the RB and RC filters gave similar results with final permeate concentrations of 0.3 mg·L^{-1} corresponding to a 34.78% reduction (Table 4 and Figure 2). The RE filter gave the best removal efficiency of 56.52% closely followed by the RD one with 42.03% and a final concentration of 0.27 mg·L^{-1} (Figure 2). The final value is still above the acceptable level of 0.01 mg·L^{-1} implying the need for a further reduction before it could be safely discharged or used for crop irrigation.

The final values obtained for the turbidity removal is shown in Table 4. The turbidity levels in the final

Table 4. The characterisation of the permeate from the membrane reactor

Filter Sample	pH	BOD	COD	Hydrogen cyanide	Turbidity
RA	no permeate				
RB	4.70	497.67	611.67	0.30	17.53
RC	5.63	457.33	600.33	0.30	16.87
RD	6.23	401.67	588.67	0.27	16.17
RE	6.57	387	535.33	0.20	15.47

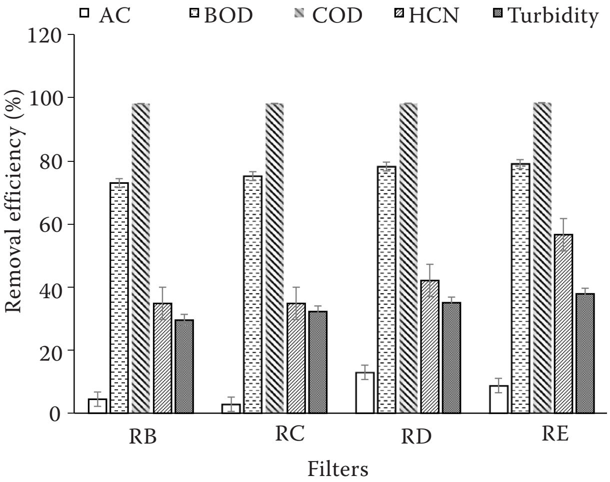

Figure 2. The removal efficiencies of the various membrane filters

BOD – biochemical oxygen demand; COD – chemical oxygen demand

effluent ranged from a minimum value of 15.47 NTU to a maximum value of 17.53 NTU corresponding to a removal range of 37.81–29.50%. The highest turbidity removal was obtained with the use of the RE filter. The pores left by the burnt-out material in this filter were presumed to be optimum under the filtration conditions and decrease as the filtrations progress. The raw and treated effluent turbidity were above the local permissible limit of 5 NTU. The turbidity was observed to have a considerable relationship with the filter flux, which increases with an increase in the turbidity removal and additive compositions as shown in Table 3 and Table 4.

CONCLUSION

This study demonstrates the application of laboratory-scaled low-cost composite ceramic filters as an MBR for the cassava mill effluent treatment under gravitational pressure. The filters were adjudged effective in reducing the concentration levels of the selected parameters with the highest removal efficiency of 98.33% obtained for the COD while the BOD removal efficiency ranged between 72.91 and 78.93%. The management of commonly reported limitations, such as filter clogging and fouling was not evaluated in this study. However, a linear relationship between the filter flux and removal efficiencies was observed across the filter samples. A defined relationship between the filter performances and additive compositions was also established for all the parameters except for hydrogen cyanide with a slight deviation. Further studies should focus on improving the flux and minimising the need for frequent scrubbing without compromising on the filter treatment performance. The filter would be well suited in MBR facilities in developing countries where processing industries are located mostly in rural communities and often lack basic education.

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