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TABLE OF CONTENTS

CHARACTERIZATION AND EFFICACY OF ACTIVATED CARBON FROM *IRVINGIA GABONENSIS* ENDOCARP FOR WASTEWATER TREATMENT: A CASE OF AQUACULTURE EFFLUENT TREATMENT

Ogbozige, F.J.

Civil Engineering Department, Federal University Otuoke, Nigeria.
E-mail: engr.ogbozige@gmail.com

ABSTRACT

The high demand for fish has led to an increase in fishponds which in turn has increased the volume of aquaculture effluents discharged into water receiving bodies. In most cases, fish farmers feel reluctant to properly treat the effluents before discharging, due to the high cost associated with conventional treatment methods. Hence, this research investigated the suitability of using the low-cost activated carbons prepared from the endocarp of bush mango (*Irvingia gabonensis*). The activated carbon was characterized thereafter, some selected physiochemical parameters including total suspended solids (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrate and phosphate were analysed before and after adsorption using standard methods. Results showed that the prepared activated carbon had a bulk density, pH, surface area and pore volume of 0.32 g/cm^3, 8.4, 776.05 m^2/g and 0.38 cm^3/g respectively while the ash content, moisture content and carbon yield were 4.51%, 3.39% and 56.01% respectively. Results also revealed that the concentrations of the selected parameters in the raw effluent were higher than discharge limits but were drastically reduced after treating with the prepared activated carbon as adsorbent. The percentage removal of the selected parameters by the adsorbent ranged from 59.58 – 82.27%. Hence, it was concluded that the use of activated carbon made from the endocarp of bush mango (*Irvingia gabonensis*) as adsorbent in treating aquaculture effluents is highly efficient and necessary recommendations were made.

Keywords: Adsorption, BET, Bush mango, DFT, Seed shell

INTRODUCTION

This The discontent with the consumption of red-meat due to its high content of cholesterol that has negative health effects especially on adults has led to increase in the demand of fish thus, making fish farming a lucrative business. Most fish farming productions are conducted in ponds (Fig. 1) hence draining of the water especially during harvest is necessary. Also, regular draining of water and refilling with new is very vital at certain times as the fishes grow (Mramba and Kahindi, 2023). Past literatures including Adekanmi *et al.* (2020) has revealed that aquaculture (fish farming) effluents contain high concentrations of nutrients such as phosphorous (P) and Nitrogen (N) as well as oxygen demanding parameters among others. Yet, such effluents are disposed or drained into the environment (Fig. 2) without any form of treatment in most developing countries due to the cost accompanying the use of conventional methods of treating effluents. Besides, the technology involved in operating and maintenance of conventional treatment methods are setback to farmers in most developing countries. Hence, there is need to develop affordable and sustainable techniques that could be conveniently managed by farmers in developing countries.

The use of activated carbons in treating wastewater via adsorption process has gained relevance due to the successes recorded by different researchers including Ahmadpour (2022), Dasanayaka (2021) and Agrawal *et al*. (2017). In most cases, the adsorption techniques are applied on industrial effluents using commercial granulated activated carbon, with emphasis on heavy metals. Hence there is need to look into aquaculture effluents which presently has very scanty literatures with respect to activated carbons despite the potential danger it could cause to receiving streams if not properly treated. Notwithstanding, Alves *et al.* (2021) have reported that in spite of the efficient use of the commercial granulated activated carbons in treating wastewater, it has a limitation of high production cost due to its conventional production method. This greatly affect farmers in the low-income countries thus, causing researchers to investigate means of reducing the production cost of activated carbons. One of such means is the use of biomass as precursor material to replace mineral coal being used conventionally at the moment (Malini *et al.,* 2022; Gan, 2021). The use of abundantly available agro-waste biomass as raw material will further reduce the production cost as the cost of purchasing it will be minimal.

Fig. 1: Fish pond

Fig. 2: Effluent drain of pond

Irvingia gabonensis, commonly called bush mango, African mango or wild mango (Fig. 3) but locally known as *"ogbono"* in Nigeria, is an African indigenous tree that grows naturally in rainforests and canopied jungles. The mesocarp (fleshy layer of the fruits) are usually eaten fresh while the seeds are mostly used as thickening and flavouring agent in soups, however, the endocarp (seed shell) are often considered as waste in many West African countries. Hence, it is important to investigate its potentials in treating aquaculture effluents especially in most regions in West African countries such as Southern Nigeria where it is abundantly available, yet aquaculture effluents are hardly treated by farmers due to many factors including treatment cost associated with conventional methods.

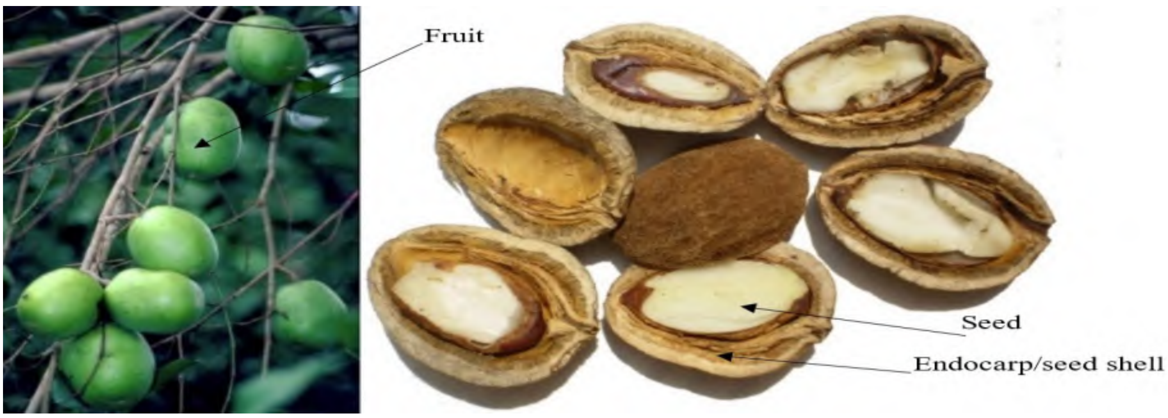

Fig. 3: Endocarp and seed of *Irvingia gabonensis* fruit

METHODOLOGY

Endocarps (seed shells) of *Irvingia gabonensis were* obtained at Akoloman community in Ogbia Local Government Area of Bayelsa state, Nigeria and were pulverised by means of a laboratory grinding machine (EcoMet 30). The pulverised particles were thoroughly sieved through a 250μm mesh then carbonised in a laboratory muffle furnace (LMF–C60) at 500 °C for 10 minutes. Thereafter, it was washed with distilled water, oven dried at 100 °C for 17 hours, impregnated, activated with phosphoric acid in line with Kra *et al.* (2019). The resultant activated carbon was characterized based on the bulk density, pH, ash content, moisture content, carbon yield, surface area and surface morphology. These were done to fully understand the effectiveness of the activation process and also for comparison with previous research on activated carbon.

The bulk density was determined by weighing and recording an empty graduated cylinder thereafter, the graduated cylinder was filled with the prepared activated carbon and then reweighed. The density in g/cm^3 was calculated using Equation (1) as:

$$Bulk\ density\ = \frac{W_2 - W_1}{V} \quad (1)$$

Where: W_1 is the weight of empty graduated cylinder in gram, W_2 is the weight of graduated cylinder containing activated carbon in gram while V is the capacity of graduated cylinder used in cm^3.

The pH was determined by weighing 1.0 g of the prepared activated carbon into a beaker containing 100 mL of distilled water. This was followed by stirring it at 100 rpm for 30 minutes thereafter, the pH was measured via a pocket-sized pH meter (pHep01®) after allowing the stirred sample to stabilized. Ash content was known by weighing and recording an empty preheated cooled crucible. Thereafter, 2.5 gram of the prepared activated carbon was weighed into the crucible and the entire weight of the crucible with its contents was recorded. This was followed by heating it in a laboratory muffle furnace at 600 ^{0}C for 3 hours, then allowed to cool to 100 ^{0}C and finally cooled in a desiccator to room temperature before weighing and recording the crucible with the ash in it. The percentage ash content was calculated through Equation (2). Similarly, the moisture content was determined by weighing 2.5 gram of the prepared activated carbon into a previously heated cooled crucible and the entire weight of the crucible and its content was recorded. Thereafter, the crucible containing the prepared activated carbon was placed in a laboratory oven (model E028–230V-T) at 150 °C for 3 hours. Afterward, the crucible was removed from the oven and cooled to room temperature in a desiccator, then reweighed and recorded. Hence, Equation (3) was used to calculate the moisture content. However, the carbon yield was gotten by weighing a known volume of the dried prepared activated carbon and recording it then, weighing and recording equal volume of the precursor (pulverized endocarp of *Irvingia gabonesis*). The carbon content was simply the ratio of the former to the later, expressed in percentage as shown in Equation (4).

$$Ash\ content\ (\%) = \left(\frac{C - A}{B - A}\right) \times 100 \quad (2)$$

$$Moisture\ content\ (\%) = \left(\frac{B - Z}{B}\right) 100 \quad (3)$$

$$Carbon\ yield\ (\%) = \left(\frac{W_a}{W_p}\right) \times 100 \quad (4)$$

Where: A is the weight of preheated cooled empty crucible in gram, B is the weight of crucible containing activated carbon in gram, C is the weight of crucible with ash in gram, Z is the oven dried weight of crucible containing prepared activated carbon in gram while W_a and W_p are the weights of known volume of prepared activated carbon in gram and weight of equal volume of precursor (pulverized endocarp of *Irvingia gabonesis*) in gram respectively.

The surface area was calculated using Brunauer-Emmett-Teller (BET) method while the pore size distribution was calculated using Density Functional Theory (DFT) technique. However, the surface morphology of the prepared activated carbon was determined using scanning electron microscopy (SEM), all in line with standard methods reported in ASTM (2010).

A fish farm in Yenagoa city, the Bayelsa state capital (Nigeria) was identified, and sampling of effluent was done at the drain through a 10 L container, filled to capacity and corked. It was then transported in an ice-parked cooler to the laboratory on same day. Batch experiment was conducted at room temperature (30 °C) by measuring 2.0 g of the prepared activated carbon via a weighing machine (model: FA 1604) into 1 L of the effluent in a beaker. The mixture in the beaker were thoroughly mixed with a magnetic stirrer (Model: SH-2) at 150rpm for different contact times (15, 30, 45,…….., 90 minutes). The selected physiochemical parameters (adsorbate) which include total suspended solids (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrate and phosphate were all analyzed before and after the adsorption using standard methods (APHA, 2012). The efficacy of the prepared activated carbon in removing or reducing the selected physiochemical parameters (adsorbates) was determined by employing Equation (5).

$$\%\, Adsorbate\ removed = \left(\frac{C_o - C_f}{C_o}\right) \times 100 \quad (5)$$

Where: C_o and C_f are the initial and final concentrations of the considered parameter (adsorbate) in mg/L.

RESULTS AND DISCUSSION

The basic characteristics of the activated carbon prepared from the endocarp of *Irvingia gabonensis* are presented in Table 1. The bulk density was found to be 0.32 g/cm^3 which agrees with the report of Asoiro *et al.* (2020) who recorded a range of 0.3 – 0.34 g/cm^3. The pH was 8.4, which is quite basic in nature and good for adsorption, since adsorption process increases with high pH especially within the range of 8.0 – 9.0 (Ogbozige and Nwobu, 2021).

The ash content of an activated carbon is a measure of the unusable part of the material that usually remains after burning. In other words, the lower the ash content, the better the activated carbon. The prepared activated carbon from *Irvingia gabonensis* endocarp was found to have an ash content of 4.51%, which is similar to the value (5%) recorded in a related studies that also uses phosphoric acid as activating agent (Kra *et al.,* 2019). The ash might have emanated from the inorganic constituent of the precursor as well as the activating agent used notwithstanding, the 4.51% ash content recorded is an indication that the prepared activated carbon from *Irvingia gabonensis* endocarp will be highly suitable for adsorption. This is because the ash content of a good activated carbon should be less than 20% (Aprilianda *et al.,* 2019).

Table 1: Properties of activated carbon from *Irvingia gabonensis* endocarp

Parameter	**Value**
Bulk density (g/cm^3)	0.32
pH	8.4
Ash content (%)	4.51
Moisture content (%)	3.39
Carbon yield (%)	56.01
Surface area (m^2/g)	776.05
Pore volume (cm^3/g)	0.38

A moisture content of 3.39% was recorded for the activated carbon made from the endocarp or (seed shell) of *Irvingia gabonensis*. This is within the recommended range of ≤6% for good activated carbon as reported by Sanni *et al.* (2017). Actually, there is no direct effect of moisture content on the adsorption capacity of an adsorbent. Nevertheless, high moisture content will certainly influence the mass of the required adsorbent which will consequently lead to low adsorption capacity for the given mass since greater percentage of it being water is not used for the adsorption. Besides, high moisture content which influences water activity will encourage fungi and other microbes to degrade the carbon by utilizing it in their metabolic processes thus, reducing the adsorption capacity. A high carbon yield during the activation stage is an indication of large quantity of adsorbent which consequently boost the adsorption process. A carbon yield of 56.01% was recorded for the activated carbon prepared. This recorded value is similar to those recorded by Neme *et al.* (2022) for activated carbon prepared from most seed shells (endocarps) using same activating agent (phosphoric acid).

Adsorbent with larger surface areas are known to perform better than those with smaller surface areas. The recorded surface area for this research was 776.05 m^2/g with a pore volume of 0.38 cm^3/g. This is quite good because even the wildly used commercial activated carbons have surface area ranging between 600 and 1200 m^2/g (Ahmadpour, 2022). The surface morphology of the prepared activated carbon prior to the adsorption process (Fig. 4) revealed that it has different openings. This could be attributed to the action of the activating agent (acid) used for treatment. Nevertheless, the observed openings were covered after the adsorption process as could be seen in Fig. 5 thus, suggesting that the openings served as transport pores for the adsorbate.

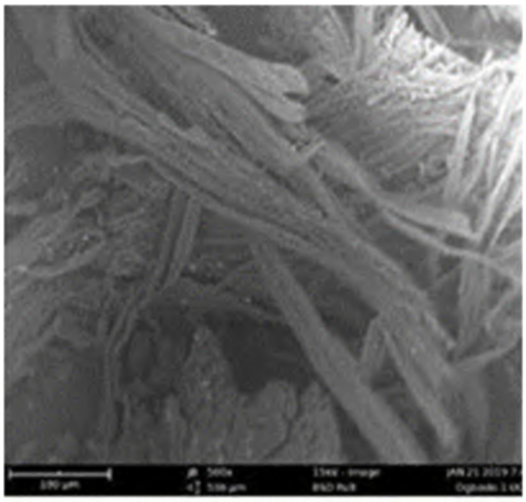

Fig. 4: SEM image of activated carbon at 150μm before adsorption

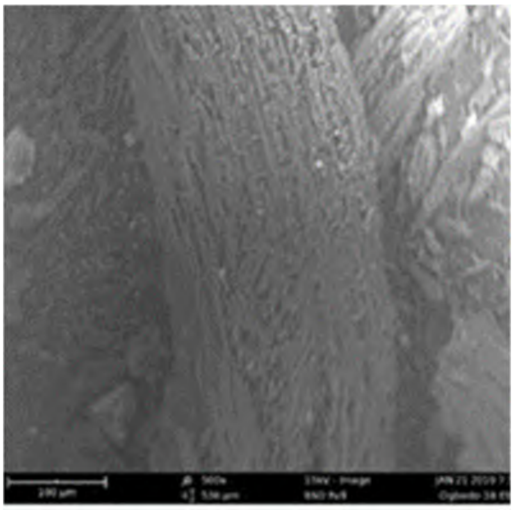

Fig. 5: SEM image of activated carbon at 150μm after adsorption

The results of the physiochemical parameters in treated aquaculture effluent are shown in Table 2. The results clearly showed that the concentrations of all the considered parameters in the untreated (raw) sample were above the permissible limits set by the US Environmental Protection Agency (EPA) for effluent discharge into surface waters. However, the use of the prepared activated carbon as adsorbent in treating the effluent drastically reduced the concentrations to conform with EPA standards with high percentage of reduction, which is quite commendable.

Table 2: Results of physiochemical parameters in treated aquaculture effluent

Parameter	Untreated	Treated	EPA limit	% Removal
TSS (mg/L)	112.01	19.86	50	82.27
BOD (mg/L)	122.52	31.08	50	74.63
COD (mg/L)	488.46	197.44	250	59.58
Nitrate (mg/L)	104.29	38.65	50	62.94
Phosphate (mg/L)	4.07	1.11	2	72.73

EPA limit = US Environmental Protection Agency limit for discharge into surface waters

CONCLUSION

The research has shown that aquaculture effluents contain certain pollutants that are beyond the permissible limit for discharge into surface waters with respect to effluent discharge limit of EPA. The characterization of activated carbon made from the endocarp of *Irvingia gabonensis* have clearly shown that the pore diameters (obtained through SEM) and the BET specific surface area are quite high while the pH, ash content and moisture content are within the recommended range for a good adsorbent.
Based on the conclusions drawn from this research, it is hereby recommended that aquaculture effluents should be thoroughly treated before discharging into water receiving bodies. Also, the use of activated carbons prepared from the endocarp of bush mango (*Irvingia gabonensis*) as adsorbent should be considered due to its effectiveness and relatively cheap cost as it is abundantly available in most West African communities. Furthermore, the use of activated carbon prepared from the endocarp of bush mango as adsorbent should be extended to the adsorption of metallic ions such as Pb^{2+}, Cd^{2+}, Ni^{2+}, Cr^{3+} among others since its characterisation has proven to be suitable.

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