Journal of Engineering Research Innovation and Scientific Development 3 (3), (2025), 9-13 https://doi.org/10.61448/jerisd33253

Journal of Engineering Research Innovation and Scientific Development
journal homepage: www.jerisddelsu.com
Print ISSN 2971-6594 Online ISSN 2971-6608

Adsorptive Treatment of Abattoir Wastewater using Biosorbent Prepared from *Raphia hookeri* Seed

Pereware Famous Tarbuka[1], Ndubuisi Matthew Onumba[2], Bamidele Honesty Akpeji[3], Ovonomo Deborah Pereware-Tarbuka[4], Joshua Omomuetho Sunday[5]

[1&4]*Department of Chemical Engineering, Federal University of Petroleum Resources, PMB 1221, Effurun, Delta State, Nigeria.*
[3]*Department of Science Laboratory Technology, Federal University of Petroleum Resources, P.M.B. 1221, Effurun, Nigeria*
[5]*Department, Tecnimont Nigeria Limited, Port Harcourt Refinery Rehabilitation Project, Alesa Eleme, Rivers State*

Corresponding author: tarbuka.f.pereware@gmail.com (Tarbuka P.F)
https://orcid.org/0000-0002-6989-2962

Article history: Received: 20-05-25, Revised: 21-06-25, Accepted: 10-07-25, Published: 13-07-25

Abstract

Industrial activities and urbanisation in Nigeria have gradually increased the problem of wastewater disposal. Breweries, textile factories, abattoirs, and other industries that discharge effluents into nearby water bodies cause pollution that renders these waters unusable unless treatment is carried out. In this research, a local waste material (Raphia Hookeri Seed) was prepared through carbonisation (at 600°C), chemical impregnation (using sodium hydroxide), and thermal activation (at 700ºC) to serve as a biosorbent for removing pollutants from abattoir wastewater, measured as Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Dissolved Solids (TDS), and Salinity. Batch experiments were conducted under different conditions, including biosorbent dosage, pH, and contact time. The results show maximum pollutant adsorption from the abattoir wastewater with BOD5 of 1448 mg/l, COD of 4018 mg/l, and TDS of 1640 mg/l, achieved at an optimum biosorbent dosage of 1 g/100 ml of wastewater. This dosage was used consistently in other experimental conditions. The findings indicate that the optimal contact time is 60 minutes, with removal efficiency increasing as contact time extends. Additionally, the results reveal that the removal efficiency of BOD decreases when the amount of adsorbent increases. In conclusion, the Raphia Hookeri seed biosorbent demonstrates a high affinity and capacity for adsorbing particulate pollutants, which can contribute to elevating BOD/COD levels in abattoir wastewater.

Keywords: *Raphia hookeri*; Biosorption; Abattoir wastewater treatment; Activated carbon; Chemical Oxygen Demand (COD)

1. Introduction

Water pollution is a major global problem which requires evaluation and revision of water resource policy at all levels (international, down to individual aquifers and wells). It is suggested to be the leading cause of deaths and disease worldwide (Robina *et al.,* 2017; Sasakova *et al.,* 2018). Water pollution contributes to the increased chemical oxygen demand (COD) and biochemical oxygen demand (BOD) by increasing the amount of particulate matter present in water bodies, with organic waste containing nitrates and phosphates (additional nutrients), leading to death of plants (excess plants fight for space to grow), which will in turn affect aquatic life (Sivashanmugam, 2007; Tammin *et al.,* 2014). Water pollution causes bio-magnification through the improvement in concentration of various toxic substances along the biological food chain.

Industrial activities and urbanisation in Nigeria have gradually led to the increased problem of waste disposal (Ogbu et al., 2016). Previous literature reviews have identified various causes and sources of water pollution in the global environment. These include the indiscriminate disposal of waste into water bodies, industrial effluent discharges into rivers, human activities near water sources, metal deposits in rivers and lakes, domestic waste and effluents, agricultural runoff into ponds, and the release of unwanted chemicals into waterways (Omoleke, 2004; Ademiluyi *et al.,* 2009). Reports showed that all these activities harm humans, aquatic animals, wildlife, agricultural products, processing equipment, and the general environment by making the water unsuitable for beneficial use and purposes.

To mitigate these effects, abattoir wastewaters must undergo significant treatment before discharge (Bustillo-Lecompte *et al.,* 2017). Past reports have shown that there are three general phases of wastewater treatment, which are primary, secondary, and tertiary. During primary treatment, a large percentage of the suspended solids and inorganic material is removed from the sewage. The focus of secondary treatment is reducing organic material by accelerating natural biological processes. Tertiary treatment is necessary when water is to be reused; 99 percent of solids are removed, and various chemical processes are employed to ensure the water is as free from impurities as possible. (Ademiluyi *et al.,* 2009). Primary treatment involves physical separation of floatable and settleable solids. Secondary treatment involves biological removal of dissolved solids. Tertiary treatment involves physical, chemical, and biological treatment (Robina Farooq & Zaki Ahmad, 2017).

Secondary treatment usually involves a biological process where microorganisms transform non-settleable solids into settleable solids. It includes methods such as activated sludge, tertiary filters, and lagoons. The tertiary treatment includes physical and chemical methods. Physical processes involve electro-dialysis, reverse osmosis, carbon adsorption, and centrifugation. The chemical process includes hydrolysis, ozonation, precipitation, coagulation, and flocculation.

The treatment methodology employed in this study involves the utilisation of a biosorbent to address wastewater issues. The research focuses on using a biosorbent derived from Raphia hookeri to evaluate its adsorptive capacity in the treatment of abattoir wastewater, employing activated carbon prepared from the biosorbent of Raphia hookeri seed. Given the challenge of maintaining water purity in both local and large communities, this research is anticipated to provide a viable solution to the human concerns associated with wastewater treatment.

2. Materials and Methods

2.1 Equipment and Instruments Used

In this investigation, a comprehensive range of laboratory equipment and materials was systematically used to ensure accurate sample preparation and analysis. Solid samples were first dried after pretreatment in a laboratory oven to eliminate moisture content before further processing. Following oven-drying, the samples underwent high-temperature treatment in a Carbolite furnace, which allowed complete volatilisation of organic matter for ashing procedures. Sample homogenisation and thorough mixing were achieved with the Stuart SSL2 reciprocating shaker, ensuring uniformity before and after processing. Particle size distribution was assessed using Fisherbrand test sieves, while water quality parameters such as pH, electrical conductivity, and total dissolved solids were quantitatively measured with the Hanna HI991300 pH/EC/TDS meter. Laboratory safety and control of volatile emissions were maintained using the ESCO laboratory fume hood during sample digestion and chemical reactions. For tests needing temperature stability, like BOD incubation, the Lovibond thermostat Schrank served as the controlled-temperature chamber.

Biochemical Oxygen Demand (BOD) analyses were conducted using the Hach BODTrak II system along with BOD Trak II bottles, and Chemical Oxygen Demand (COD) digestion was performed using the Hach DRB200 COD reactor. Absorbance readings for these analyses were taken on the Hach LANGE DR 2800 and DR/2 Spectrophotometers, ensuring precise quantification of analytes. Thermometers were used to confirm appropriate temperatures during various procedures, and a high-precision weighing balance provided accurate mass determination for both reagents and samples. Volumetric measurements were carried out using graduated cylinders, volumetric pipettes with fillers, burettes, and volumetric flasks (100, 200, and 250 mL). Mixing, reactions, and heating steps involved beakers (100, 200, and 500 mL) and borosilicate test tubes with covers, supported by racks for organisation during processing. Separation of solids from liquids was efficiently achieved using funnels and 110 mm filter paper. Other laboratory essentials included foil paper for handling hot samples, gloves and nose masks for personal protection, spatulas for sample transfer, plastic containers for storage, stirrers for mixing, and wash bottles for cleaning equipment. Litmus paper provided quick qualitative checks for acidity or alkalinity during analysis, complementing the suite of analytical procedures carried out in this study.

2.2 Chemical Reagents

All chemical reagents used in this study were of analytical grade to ensure accurate and reliable results. Sodium hydroxide (NaOH) was utilised for chemical impregnation and pH control during sample preparation and analysis. Concentrated sulphuric acid (H_2SO_4) played a critical role in digestion procedures and COD (Chemical Oxygen Demand) analysis. The primary sample analysed was abattoir wastewater, collected and treated alongside distilled water for dilutions and reagent preparation. Specific reagents used for BOD (Biochemical Oxygen Demand) and COD determination included Hach glucose/glutamic acid (GGA) solution as a standard, one nutrient buffer pillow, and pH buffer solutions for calibration. Potassium dichromate, mercuric sulphate, and silver sulphate served as oxidising and catalytic agents in COD tests, while Hach COD reagents facilitated rapid and accurate determination. Potassium chromate indicator solution and standard silver nitrate titrant were employed in chloride titration. Additional reagents such as aluminum oxide and phenolphthalein indicator solution aided in further water quality analyses, and hydrogen peroxide was used as an oxidising agent where required.

2.3 Preparation of the Biosorbent

Raphia hookeri seed, the precursor, was collected from a commercial dealer near Miller Waterside, Warri, Delta State. The Raphia palm seeds were washed, air-dried for 24 hours, and then oven-dried at 105º C for 3 hours to remove moisture. After cooling, the oven-dried precursor was weighed and carbonised at 600 ºC in a furnace for 90 minutes. Following carbonisation, the red-hot carbons were allowed to cool. The cooled, carbonised precursors were then crushed into pellets and smaller particles to increase surface area. The chemical activation involved soaking the crushed carbon in 0.3M NaOH and covering it with foil for 24 hours. The chemical agents used for impregnation served as dehydrating agents and aimed to inhibit the formation of tar and other undesired products during carbonisation. The activated carbons were removed from the solution and washed adequately with distilled water several times. The pH was monitored with litmus paper until it indicated neutrality. The samples were then oven-dried for one hour. Upon completion of drying, they were immediately subjected to thermal activation at 700º C for 90 minutes using the furnace. The activated carbons were then weighed and ground into finer particles. These particles were sieved through a 250 µm Fisherbrand test sieve and collected in an appropriately labelled plastic container, indicating the carbonisation/activation temperatures, time, and particle size. This method of preparing the precursor was followed by the procedure of Tarbuka (2018), with some modifications.

2.3 Adsorptive Treatment of Abattoir Wastewater using Biosorbent

In this treatment procedure, a batch adsorption experiment was conducted. 100 ml of the wastewater sample and the required mass of the biosorbent *Raphia Hookeri* seed were weighed into a 250 ml conical flask and placed on a Stuart SSL2 reciprocating shaker with a stirring speed set at a constant 200 rpm at ambient temperature. The effects of adsorbent dose, contact time, and pH were studied following standard procedures. The wastewater sample was filtered and analysed for BOD, COD, TDS, EC, Cl-, and pH analysis using the standard method of Bustillo-Lecompte *et al.* (2017) and Okafor *et al.* (2006).

3. Results and Discussion

3.1 Characterisation of *Raphia Hookeri* Biosorbent

This FTIR spectrum of the unused biosorbent presented in Figure 1 shows a broad peak around 3400 cm^{-1}, indicating hydroxyl (O–H) groups from alcohols or water; distinct peaks near 2900 cm^{-1} suggest C–H stretching in aliphatic chains; a strong signal at 1774 cm^{-1} points to carbonyl (C=O) groups; and additional features at 1650–1420 cm^{-1} and near 1036 cm^{-1} correspond to aromatic C=C bonds, amide groups, and C–O stretching in polysaccharides. Altogether, these indicate the surface is rich in hydrophilic and aromatic groups.

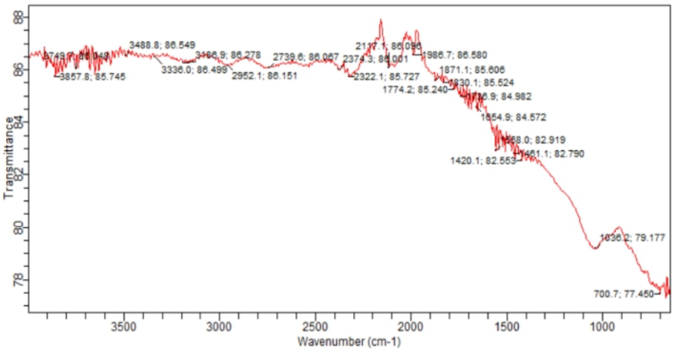

Figure 1: FTIR spectrum of unused Raphia hookeri seed showing key functional groups for adsorption

Table 1 presents the characterisation results of the activated carbon or biosorbent. The properties examined include ash content, moisture content, pH, and bulk density. The ash content is 6.01%, indicating that the activated carbon has low inorganic content and high fixed carbon. Since porous materials tend to adsorb moisture, the moisture content of the biosorbent is approximately 8.5%, reflecting its moisture level. This suggests resistance to microbial growth. The percentages for carbon yield, pH, particle size, and bulk density are 52.4%, 7.4, 250 µm, and 0.72, respectively.

Table 1 - Physical properties of Raphia hookeri seed

Sample	*Raphia Hookeri* (Biosorbent)
Carbon yield (%)	52.4
Ash content (%)	6.01
Particle sizes (µm)	<250
Moisture content (%)	8.5
pH	7.4
Bulk density (g/cm^3)	0.72

3.2 Physicochemical Properties of the Abattoir Wastewater

Table 2 shows the in situ and initial physicochemical properties of the very turbid abattoir wastewater sample, with the parameters cutting across: pH, Temperature, conductivity, total dissolved solids, salinity, chemical oxygen demand, and biological oxygen demand, all of which result in values that fall within the acceptable World Health Organisation standard. Similar parameters were checked for wastewater by Inyang et al. (2012) and Hatam-Nahavandi et al. (2015) in their past experiment.

Table 2 - The initial physicochemical properties of the abattoir wastewater sample.

Parameters	Test Method	Result	WHO Limit
pH *(in situ)*	ASTM-D1293-84	6.33	6.50-9.20
Temperature (ºC), *(in situ)*	Thermometer	26.8	_
Conductivity(µs/cm)	ASTM-D1125	3270	N/A
Total Dissolved Solids (TDS), (mg/l)	SM-1030-E	1701	500-1500
Salinity (Cl^-), mg/l	SM-4500-CL-B	89.3	200-600
Chemical Oxygen Demand (COD), mg/l	SM-5220	4118	N/A
Biological Oxygen Demand (BOD_5), mg/l	ASTM-D5210-B	1520	_

3.3 The Process Parameters

The process parameters of dosage, pH, and contact time were investigated for abattoir wastewater treatment, with the optimum adsorbent dosage used to evaluate the effects of the other parameters.

3.3.1 Effects of Adsorbent Dosage

The effect of dosage on adsorptive removal of pollutants in wastewater presented in Table 3 show that increasing the activated dosage from 1 g/100 ml to 4 g/100 ml had minimal effect on pH (7.61–7.75), keeping it within the WHO's permissible range (6.50–9.20). Temperature remained largely unchanged

Table 3 - Effect of activated dosage on the removal of pollutants in wastewater

Parameters	Test Method	1 g/100ml	2g/100ml	3g/100ml	4g/100ml	WHO Limit
pH	ASTM-D1293-84	7.61	7.61	7.68	7.75	6.50-9.20
Temperature(ºC)	Thermometer	25.4	26.3	25.3	25.4	_
Conductivity(µs/cm)	ASTM-D1125	3133	3360	3483	3521	N/A
Total Dissolve Solids(TDS), (mg/l)	SM-1030-E	1640	1743	1811	1836	500-1500
Salinity(Cl^-), mg/l	SM-4500-CL-B	645	566	596	605	200-600
Chemical Oxygen Demand(COD), mg/l	SM-5220	4018	4270	4152	4308	N/A
Biological Oxygen Demand(COD), mg/l	ASTM-D5210-B	1448	1630	1556	1715	_

(25.3–26.3°C). However, there was a steady increase in conductivity (3133–3521 µs/cm), total dissolved solids (TDS) (1640–1836 mg/l), and salinity (645–705 mg/l) with higher dosages, with both TDS and salinity exceeding WHO recommended limits (TDS: 500–1500 mg/l, salinity: 200–600 mg/l). Additionally, chemical oxygen demand (COD) and biological oxygen demand (BOD) remained high or increased with higher dosage, indicating persistent organic pollution. Overall, while the process kept pH stable, it was ineffective at reducing salinity, TDS, COD, and BOD to safe levels.

3.3.2 Effect of Adsorption Dose on Total Dissolved Solids

Figure 2 shows the effect of adsorption dosage on total dissolved solids. It shows that as the concentration of the adsorbent dosage increases; more dissolved solids are being added to the sample. From this, the adsorbent dosage that was able to adsorb some of the dissolved solids in the wastewater sample was the dosage of 1g/100 ml because it shows a decline in the number of dissolved solids on comparison with the raw total dissolved solid of 1701 mg/l. So, a lower amount of adsorbent dosage yields higher adsorption of dissolved solids in the wastewater sample (Mohan *et al.,* 2002).

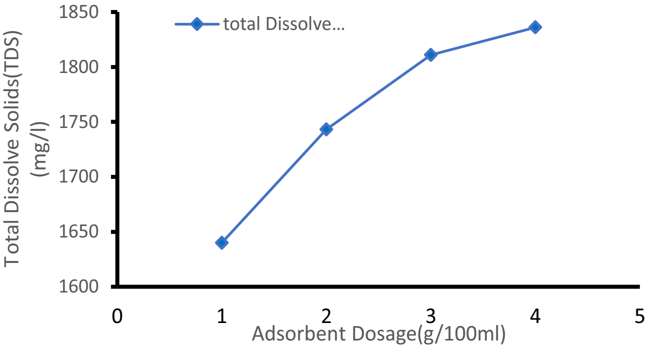

Figure 2 - Effect of dosage size on Total Dissolved Solids

3.3.3 Effect of Adsorption Dosage on Salinity

Figure 3 shows the effect of dosage on the Salinity. The concentration of chloride ions across the various doses of adsorbent does not follow any gradual trend. Still, on comparison with the initial salinity value of the raw sample, it shows a steep increment in concentration of chloride ion from a raw value of 89.3 mg/l to a range value of 645 mg/l upon treatment of the raw sample with various doses of the adsorbent.

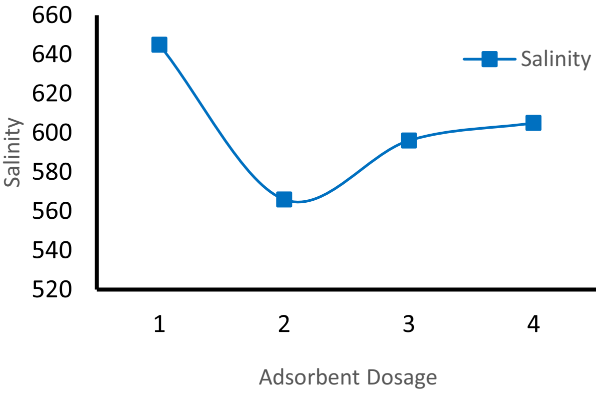

Figure 3: Effect of dosage size on Salinity

3.3.4 Effect of Adsorbent Dosage on Chemical Oxygen Demand (COD)

Figure 4 illustrates how changing the adsorbent dosage affects the Chemical Oxygen Demand (COD) of abattoir wastewater after biosorbent treatment. Initially, COD increases from 4020 mg/L to 4280 mg/L as the biosorbent dose rises from 1 g/100 ml to 2 g/100 ml, likely due to poor dispersion or more organic substances being released at lower doses. When the dosage reaches 3 g/100 ml, COD decreases to approximately 4160 mg/L, reflecting improved adsorption as more active sites become available. At 4 g/100 ml, COD increases again to 4300 mg/L, possibly because of particle agglomeration or desorption, which reduces adsorption efficiency. This non-linear trend reveals an optimal dose around 3 g/100 ml for effective COD removal, underscoring the importance of precise dosing in biosorbent-based wastewater treatment. Ibaraj *et al. (2012)* also showed a similar report on the effect of dosage, which agrees with these results in this study.

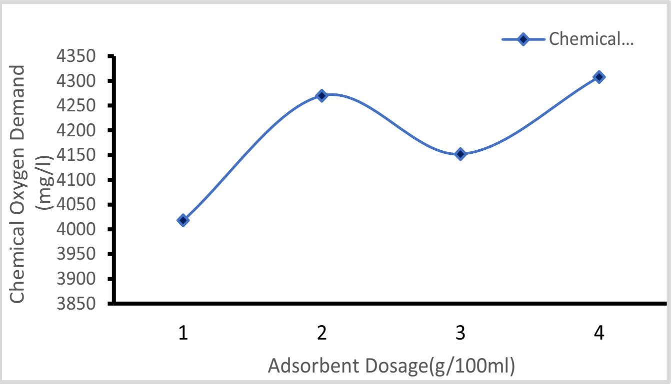

Figure 4: Effect of dosage size on Chemical Oxygen Demand

3.3.5 Effect of Adsorbent Dosage on Biological Oxygen Demand (BOD)

Figure 5 illustrates a clear non-linear relationship between adsorbent dosage and BOD_5 in abattoir wastewater, with BOD_5 rising from about 1450 mg/L at 1 g/100 ml to roughly 1620 mg/L at 2 g/100 ml, then decreasing to around 1550 mg/L at 3 g/100 ml, and sharply increasing again to approximately 1720 mg/L at 4 g/100 ml. Recent studies, such as Ogundolie et al (2024) and (Shan et al. (2022), similarly indicate that optimal biosorbent dosages maximise the removal of organic pollutants, while under- or over-dosing can diminish efficiency due to the addition of extra organic matter or particle aggregation limiting active site availability. This highlights that precise optimisation of biosorbent dosage is crucial for effective BOD_5 reduction in complex wastewaters and supports trends observed both within this research and in broader recent studies literature.

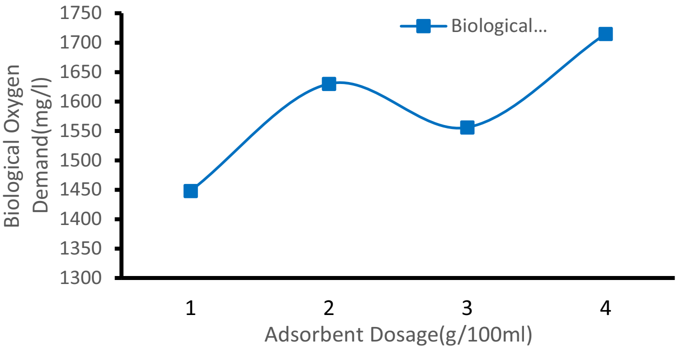

Figure 5: Effect of dosage size on Biological Oxygen Demand

3.4. Effect of pH Adjustment

The effect of pH adjustment studied in this work is about COD, BOD and salinity.

3.4.1 The effect of pH on Chemical Oxygen Demand (COD)

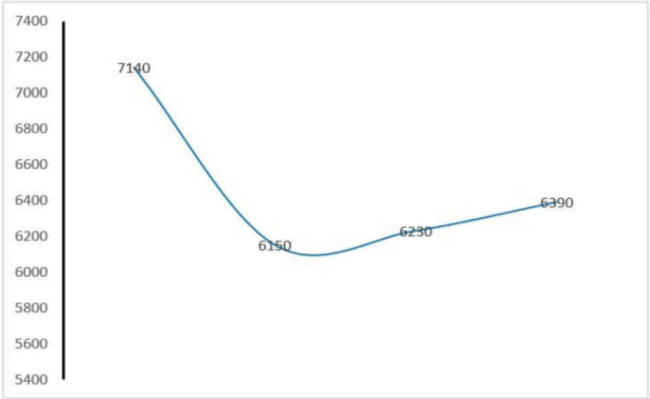

Figure 6 - Effect of pH on Chemical Oxygen Demand

Figure 6 illustrates that the adsorption performance of *Raphia hookeri* biosorbent for COD removal from abattoir wastewater is strongly pH-dependent (Inyinbor et al., 2024). COD levels were highest (~7140 mg/L) at acidic pH (~4), indicating low adsorption efficiency, likely due to excessive competition between hydrogen ions and COD-causing organics for active sites (Sun et al., 2024). Optimal removal occurred at pH 5–6, where a higher concentration of H^+ ions helps neutralise the negatively charged adsorbent surface, reducing electrostatic repulsion and enhancing diffusion of organics. Beyond pH 6, COD levels gradually increased, with reduced adsorption capacity at higher pH values- possibly due to the abundance of OH^- ions, which introduce repulsive forces and hinder the diffusion of organics, leading to less effective adsorption (Aluyor & Badmus, 2008).

3.4.2 Effect of pH on Biological Oxygen Demand

Figure 7 shows that as pH increases, Biological Oxygen Demand (BOD) in abattoir wastewater rises steadily from 1,450 mg/L to 1,580 mg/L. This pattern indicates that higher pH levels decrease the effectiveness of Raphia hookeri seed biosorbent in removing biodegradable organics, likely due to unfavourable changes in surface charge and reduced interaction between the biosorbent and wastewater pollutants. Recent research by Inyinbor et al. (2024) confirms that Raphia hookeri-based adsorbents perform better at mildly acidic pH, with significant drops in efficiency as pH becomes more alkaline, due to hindered adsorption caused by less favourable electrostatic conditions and lower access to active sites. This emphasises the importance of optimising pH for maximum BOD reduction when using Raphia hookeri biosorbents in wastewater treatment.

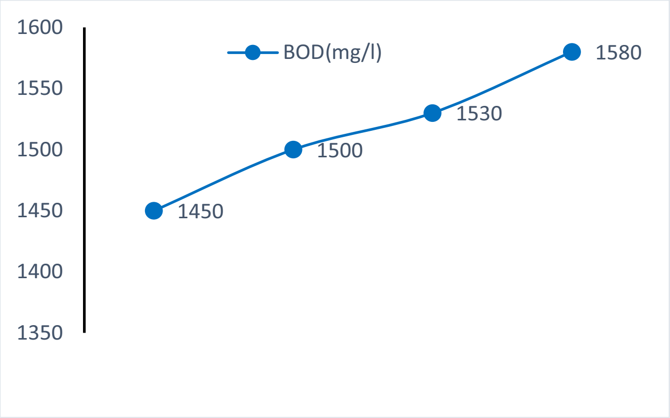

Figure 7: Effect of pH on Biological Oxygen Demand

3.5 Effect of Contact Time

The effect of time studied in this work is centred on BOD and COD, respectively.

3.5.1 Effect of Contact Time on Biological Oxygen Demand

From Figure 8, the time intervals show a gradual reduction of the biological oxygen demand as the period of adsorption increases. At 60 minutes, the adsorption records a low biological oxygen demand, which shows that some pollutants have been adsorbed during the batch equilibration period and at 15 minutes, many changes were not observed when compared to the sample. This could be a result of excess pollutants which have not been adsorbed during this period. From the graph, there is a continuous reduction in the BOD values as the batch adsorption period increases without reaching an optimum within the range of periods used in these batch experiments.

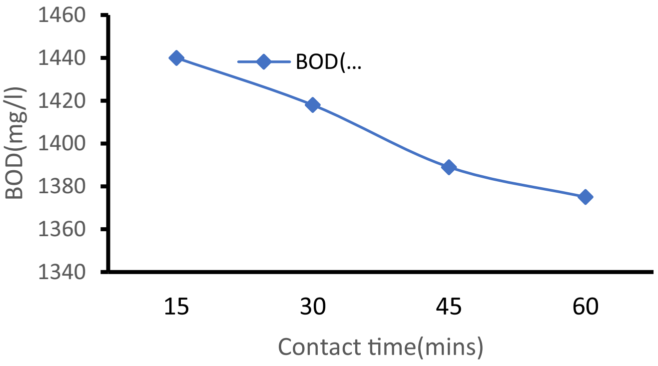

Figure 8: Plot of the Effect of Contact Time on BOD

3.5.2 Effect of Contact Time on Chemical Oxygen Demand

Figure 9 illustrates the effect of contact time on COD. The impact of contact time on the COD of abattoir wastewater does not follow a smooth trend; at a batch experiment period of 30 minutes, there was a sharp decrease from the raw abattoir wastewater values, followed by a gradual reduction in COD levels as the experiment proceeded, without reaching an optimal period within the range of 15 to 60 minutes used for the study. Wartelle *et al.* (2001) and Toles *et al.* (2000) observed a similar outcome in their previous research.

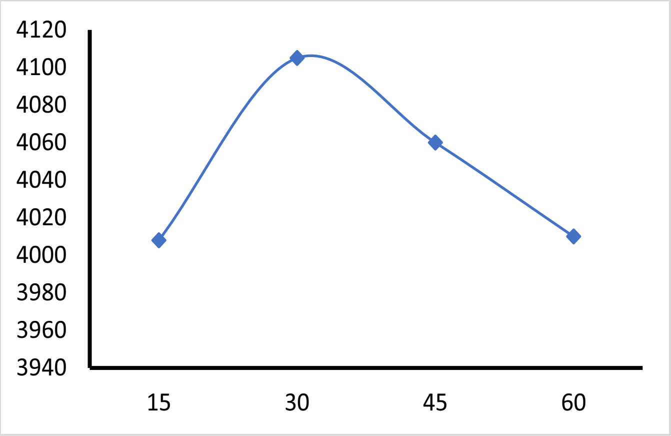

Figure 9: Effect of contact time on COD removal

4. Conclusion

This study demonstrates that activated carbon produced with Raphia hookeri precursors is an effective and sustainable biosorbent for abattoir wastewater treatment. The adsorptive performance was evaluated using key water quality parameters such as Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Dissolved Solids (TDS), salinity, electrical conductivity, and pH. Experiments show that the biosorbent performs optimally at lower dosages (1 g/100 mL), achieving significant pollutant reduction with minimal input. The adsorbent exhibits a strong affinity for contaminants, both organic and inorganic, so that after treatment, if the process parameters are correctly set, it effectively reduces pollutant levels. However, the study also observed a rise in BOD and COD values under certain conditions, possibly due to the release or desorption of biodegradable components from the adsorbent surface. This highlights the importance of further optimisation, especially in stabilising the biosorbent post-treatment. Overall, the findings underscore the potential of *Raphia hookeri*-based activated carbon as a cost-effective and environmentally friendly solution for treating organic-rich wastewater, particularly in decentralised or resource-limited settings.

References

Ademiluyi, F. T., Amadi, S. A., & Amakama, N. J. (2009). Adsorption and treatment of organic contaminants using activated carbon from waste Nigerian bamboo. *Journal of Applied Sciences and Environmental Management, 13*(3), 39–47.

Aluyor, E. O., & Badmus, O. A. M. (2008). COD removal from industrial wastewater using activated carbon prepared from animal horns. *African Journal of Biotechnology, 7*(21), 3887–3891.

Ardejani, F. D., Badii, K. H., Limaee, N. Y., Shafaei, S. Z., & Mirhabibi, A. R. (2007). Numerical modelling and laboratory studies on the removal of Direct Red 23 and Direct Red 80 dyes from textile effluents using oraange peel, a low-cost adsorbent. *Dyes and Pigments, 73*, 178–185.

Bansode, R. R. (2002). *Treatment of organic and inorganic pollutants in municipal wastewater by agricultural by-product based granular activated carbons (GAC)* (Master's thesis, Louisiana State University). LSU Master's Theses, 2950. https://digitalcommons.lsu.edu/gradschool_theses/2950

Bustillo-Lecompte, C., & Mehrvar, M. (2017). Slaughterhouse wastewater: Treatment, management and resource recovery. In *Physico-Chemical Wastewater Treatment and Resource Recovery*. IntechOpen. https://doi.org/10.5772/65499

Chima, G. N., Ogbonna, C. E., & Nwankwo, I. U. (2009). Effects of urban wastes on the quality of Asata River in Enugu, South Eastern Nigeria. *Journal of Environmental Studies, 8*(1), 31–39.

Collivignarelli, M. C., Abbà, A., Benigna, I., Sorlini, S., & Torretta, V. (2018). Overview of the main disinfection processes for wastewater and drinking water treatment plants. *Sustainability, 10*, 2086.

Dastgheib, S. A., & Rockstraw, D. A. (2001). Pecan shell activated carbon: Synthesis, characterization, and application for the removal of carbon from aqueous solution. *Carbon, 39*(12), 1849–1855.

Farooq, R., & Ahmad, Z. (2017). *Biological wastewater treatment and resource recovery*. IntechOpen. https://www.intechopen.com/chapters/53454

Fakayode, S. O. (2005). Impact assessment of industrial effluent on water quality of the receiving Alaro River in Ibadan. *Ajeam-Ragee, 10*, 1–3.

Gerbens-Leenes, P. W., Mekonnen, M. M., & Hoekstra, A. Y. (2013). The water footprint of poultry, pork and beef: A comparative study in different countries and production systems. *Water Resources and Industry, 1–2*, 25–36.

Hameed, B. H., Din, A. T. M., & Ahmad, A. L. (2007). Adsorption of methylene blue onto bamboo-based activated carbon: Kinetics and equilibrium studies. *Journal of Hazardous Materials, 141*(3), 819–825.

Hatam-Nahavandi, K., Mahvi, A. H., Mohebali, M., Keshavarz, H., Mobedi, I., & Rezaeian, M. (2015). Detection of parasitic particles in domestic and urban wastewaters and assessment of removal efficiency of treatment plants in Tehran, Iran. *Journal of Environmental Health Science and Engineering, 13*, 4.

Ibaraj, S., & Sulochana, N. (2002). Effects of agitation time and adsorbent dosage on the adsorption of dyes. *Indian Journal of Chemical Technology, 9*, 201–208.

Inyang, U. E., Bassey, E. N., & Inyang, J. D. (2012). Characterization of brewery effluent fluid. *Journal of Engineering and Applied Sciences, 4*, 65.

Inyinbor, A. A., Ayeni, T. S., Bankole, D. T., Lukman, A. F., & Solomon, P. (2024). The efficiency of *Raphia hookeri* adsorbent in indigo carmine dye removal: Economy depth via chemometrics. *Heliyon, 10*(4), e32121. https://doi.org/10.1016/j.heliyon.2024.e32121

Kleisiaris, C. F., Sfakianakis, C., & Papathanasiou, I. V. (2014). Health care practices in ancient Greece: The Hippocratic ideal. *Journal of Medical Ethics and History of Medicine, 7*, 6.

Lee, T., Ooi, C.-H., Othman, R., & Yeoh, F.-Y. (n.d.). Activated carbon fiber – The hybrid of carbon fiber and activated carbon. *School of Materials & Mineral Resources Engineering, Universiti Sains Malaysia*.

Mara, D. (2004). *Domestic wastewater treatment in developing countries*. Earthscan.

Menkiti, M. C., & Onukwuli, O. D. (2010). Coag-flocculation studies of *Moringa oleifera* coagulant (MOC) in brewery effluent: Nephelometric approach. *Journal of American Science, 6*(12), 788–806.

Menkiti, M. C., Onyechi, C. A., & Onukwuli, O. D. (2011). Evaluation of perikinetics compliance for the coag-flocculation of brewery effluent by *Brachystegia eurycoma* seed extract. *International Journal of Multidisciplinary Sciences and Engineering, 2*(6), 77–83.

Mohan, S. V., Rao, N. C., & Karthikeyan, J. (2002). Adsorptive removal using apple pomace and wheat straw. *Water Research, 36*, 2824–2830.

Mohan, S. V., Ramaniah, S. V., & Sarmar, P. N. (2007). Biosorption of direct azo dye from aqueous phase onto *Spirogyra spp.*: Evaluation of kinetics and mechanistic aspects. *Biochemical Engineering Journal, 38*, 61–69.

Ogundolie, F. A., Babalola, O. O., Adetunji, C. O., Aruwa, C. E., Manjia, J. N., & Muftaudeen, T. K. (2024). A review on bioremediation by microbial immobilization—An effective alternative for wastewater treatment. *AIMS Environmental Science, 11*(6), 918–939. https://doi.org/10.3934/environsci.2024046

Ogbu, K. C., Ebenebe, C. I., & Abajue, M. C. (2016). Physico-chemical characteristics of Ama brewery effluent and its receiving Ajali River in Udi, Enugu State, Nigeria. *Animal Research International, 13*(2), 2392–2399.

Okafor, J. O., & Aneke, N. A. G. (2006). Characterization of adsorbents for the purification of Coca-Cola effluent. *Proceedings of the Nigerian Society of Chemical Engineers, 31st Annual Conference*, 22–24.

Omoleke, I. I. (2004). Management on environmental pollution in Ibadan, an African city: The challenges of health hazard facing government and the people. *Journal of Human Ecology, 15*(4), 265–275.

Sasakova, N., Gregova, G., Takacova, D., Mojzisova, J., Papajova, I., Venglovsky, J., Szaboova, T., & Kovacova, S. (2018). Pollution of surface and ground water by sources related to agricultural activities. *Frontiers in Sustainable Food Systems, 2*, 42. https://doi.org/10.3389/fsufs.2018.00042

Shan, J., Li, C., Zhang, Z., Zhang, J., Wang, X., & Huang, X. (2022). Application of biomass adsorbents in the treatment of heavy metals in wastewater: A review. *Desalination and Water Treatment, 267*, 108–120. https://doi.org/10.5004/dwt.2022.28691

Sivashanmugam, P. (2007). *Basics of environmental science and engineering* (pp. 100–120).

Sun, B., Li, Z., Xiao, D., Liu, H., Song, K., Wang, Z., Liu, Y., Zheng, Z., Wang, P., Dai, Y., Huang, B., Thomas, A., & Cheng, H. (2024). Unveiling pH-dependent adsorption strength of CO_2 intermediate over high-density Sn single-atom catalyst for acidic CO_2-to-HCOOH electroreduction. *Angewandte Chemie International Edition, 63*(24), e202318874. https://doi.org/10.1002/anie.202318874

Tarbuka, P. F. (2018). *Adsorptive removal of ion (II) and methylene blue onto biosorbent prepared from Raphia hookeri seed* (Master's thesis, Niger Delta University).

Toles, C. A., Marshall, W. E., Johns, M. M., Wartelle, L. H., & McAloon, A. (2000). Acid activated carbons from almond shells: Physical, chemical and adsorptive properties and estimated cost of production. *Bioresource Technology, 71*(1), 87–92.

Wartelle, L. H., & Marshall, W. E. (2001). Nutshells as granular activated carbons: Physical, chemical and adsorptive properties. *Journal of Chemical Technology and Biotechnology, 76*, 451–455.

Yakubu, M. K., Gumel, M. S., & Abdullahi, A. M. (2008). Use of activated carbon from date seeds to treat textile and tannery effluents. *African Journal of Science and Technology, Science and Engineering Series, 9*(1), 39–49.

Younos, T., & Parece, T. E. (2016). Sustainable water management in urban environments. In T. Younos & T. E. Parece (Eds.), *The handbook of environmental chemistry* (Vol. 47, pp. 270–276).