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ANALYSIS OF BATCH ADSORPTION OF ABATTOIR WASTEWATER USING ACTIVATED CARBON FROM PALM KERNEL SHELL AS ADSORBENT

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Abstract. Abattoir wastewater was collected from three different points (S1, S2 and S3) along the drainage channel of Trans Amadi Slaughterhouse in Port Harcourt and treated with activated carbon prepared from palm kernel shells (PKS). Characterization of the wastewater showed severe pollution across all sampling points as most parameters exceeded Federal Environmental Protection Agency (FEPA) permissible discharge limits. Sampling point S1 located closest to the slaughtering floor had the highest pollutant loads with BOD, COD and TSS concentrations of 487.00, 1386.13 and 3165.00 mg/L respectively, and chromium concentration of 33.53 mg/L. Palm kernel shells were impregnated with 30% (w/v) $ZnCl_2$ at a ratio of 1:1 before carbonization at 600 ± 10°C. Washing of the activated carbon with 0.1 M HCl was done to remove residual zinc compounds. Batch adsorption experiments were carried out using adsorbent dosages of 5, 10 and 15 g/100 mL under constant agitation speed of 150 rpm for 120 minutes. Removal efficiency improved with increasing dosage for all samples. At 15 g/100 mL, removal efficiencies of 95.38 to 96.63%, 72.95 to 75.69%, 97.18 to 98.47% and 97.57 to 98.66% were recorded for BOD, COD, TSS and TDS respectively, while heavy metal removals of 86.04 to 99.62%, 95.70 to 97.51% and 91.42 to 96.79% were obtained for Pb, Cd and Cr respectively. Analysis of treated wastewater samples showed that BOD, TDS and Cd met FEPA discharge limits across all samples while chromium and TSS remained above permissible limits in more polluted wastewater samples. $ZnCl_2$ activated PKS carbon was found to be an efficient and low-cost adsorbent for abattoir wastewater treatment and its performance is dependent on influent strength and operating conditions.

Keywords: Palm kernel shell, activated carbon, abattoir wastewater, heavy metals, batch adsorption.

1. Introduction

Industrialization and urbanization have continued to increase the volume of wastewater generated in many parts of the world, and much of this wastewater carries both organic and inorganic pollutants at levels that are harmful to the environment. Slaughterhouses are among the most problematic sources of industrial wastewater. Their effluents contain blood, fats, proteins, suspended solids, and pathogenic microorganisms, all of which contribute to significantly elevated BOD and COD values [1,2]. Given that this wastewater also carries biodegradable materials such

as blood, oil, grease, and undigested animal matter, discharging it without treatment poses a serious threat to the environment [2]. When abattoir effluent enters water bodies untreated, it depletes dissolved oxygen, encourages eutrophication and creates conditions that cause the spread of waterborne diseases [1,2].

Adsorption is one treatment method that has been widely adopted, largely because it is easy to set up, relatively affordable, and effective against many types of pollutants at once [3]. Activated carbon is the most commonly used adsorbent for this purpose, though its high production cost has been a persistent challenge, more so in developing countries. This is why researchers have been turning to agricultural waste materials as a cheaper alternative [3]. One such material is palm kernel shell (PKS), which is a by-product of palm oil processing and is available in large quantities in Nigeria and other palm-producing countries.

PKS has been found to be a good raw material for activated carbon production because of its high carbon content and porous nature [4]. Several researchers have worked with activated carbon from palm kernel shells and their findings have been promising. Jun et al. [5] used PKS activated carbon to treat oil refinery effluent and got good results in terms of turbidity and organic pollutant reduction. They linked the good performance to the pore structure and surface functional groups of the carbon. Baby et al. [6] looked at how well PKS adsorbents could remove heavy metals from water and reported that the longer the contact time and the more adsorbent used, the better the removal. They also noted that pH played a role in how well the metals were taken up. Baby et al. [7] went further and showed that when PKS activated carbon is functionalized, its ability to adsorb pollutants improves because the surface chemistry changes. Dechapanya and Khamwichit [8] and Flafel et al. [9] both worked with chemically modified PKS adsorbents and reported high removal efficiencies for heavy metals and organic contaminants in batch tests. In their findings, contact time, adsorbent dosage and pH were the factors that had the most influence on performance.

Studies on the use of PKS activated carbon for abattoir wastewater treatment are still very few. Most of the existing works focused on other types of industrial wastewater and did not examine how the adsorbent performs when the same effluent has different contamination levels, or whether it can remove physicochemical pollutants and heavy metals simultaneously. This study was therefore carried out to address that gap. This study examined the treatment of abattoir wastewater collected from the Trans-Amadi Slaughterhouse in Port Harcourt using activated carbon produced from palm kernel shells (PKS) and chemically activated with $ZnCl_2$. Batch adsorption experiments were carried out to evaluate how effective the prepared adsorbent was in reducing physicochemical pollutants and removing heavy metals from the wastewater.

2. Materials and Method

2.1. Materials and Reagents

The materials used in this study were palm kernel shells (PKS) that were bought from Choba Market in Rivers State, Nigeria. The abattoir wastewater samples were collected from Trans-Amadi Slaughterhouse in Port Harcourt, Rivers State, Nigeria.

Zinc chloride ($ZnCl_2$) was used as the chemical activating agent, hydrochloric acid (HCl) was used for post-activation washing to remove residual zinc compounds, and silver nitrate ($AgNO_3$) solution was used for chloride detection. Nitric acid (HNO_3) was used to acidify heavy metal samples to pH < 2 and for digestion, while sulfuric acid (H_2SO_4) was used to preserve BOD and COD samples to pH < 2. Potassium dichromate ($K_2Cr_2O_7$) was used as the oxidant and silver sulfate (Ag_2SO_4) as the catalyst for COD determination. Manganous sulfate ($MnSO_4$), alkali-iodide-azide reagent, sodium azide (NaN_3), sodium thiosulfate ($Na_2S_2O_3$) as titrant, and starch indicator solution were used for BOD analysis. Distilled water was used for all solution preparations and rinsing.

2.2. Instrumentation

Sample collection and preparation: 1 L high-density polyethylene (HDPE) bottles, 500 mL glass bottles, cooler box with ice packs.

General laboratory equipment: Analytical weighing balance, hot air oven, muffle furnace, desiccator, stainless steel sieves (1–2 mm and 710 µm/No. 25 mesh), mortar and pestle, Whatman No. 1 filter paper, Whatman GF/C glass fiber filters, membrane filters, 250 mL conical flasks, parafilm, orbital shaker, evaporating dish and airtight container.

Analytical instruments: Digital thermometer, digital pH meter, nephelometric turbidity meter, conductivity/TDS meter, 5-day BOD incubator set at 20 ± 1°C, COD reflux digestion block at 150°C, and Atomic Absorption Spectrophotometer (AAS).

2.3. Preparation of the Activated Carbon

2.3. Pretreatment of Palm Kernel Shells

The palm kernel shells were thoroughly rinsed with distilled water to remove dirt and impurities. The cleaned shells were then oven-dried at 105 ± 5°C for 6 hours to reduce moisture content. Dried shells were crushed and sieved to 1–2 mm particle size to ensure uniform impregnation.

2.3.2. Chemical Impregnation

A 30% (w/v) $ZnCl_2$ solution was prepared. The dried palm kernel shells were impregnated with $ZnCl_2$ solution at a 1:1 (w/w) impregnation ratio under constant agitation at 120 rpm for 24 hours at room temperature. The impregnated sample was then oven-dried at 105 ± 5°C for 12 hours to remove excess moisture prior to carbonization.

2.3.3. Carbonization and Thermal Activation

The $ZnCl_2$-impregnated shells were carbonized/activated in a muffle furnace at 600 ± 10°C for 2 hours under limited oxygen conditions. The material was allowed to cool to room temperature in the muffle furnace.

2.3.4. Post-Activation Treatment

The activated carbon was washed with 0.1 M hydrochloric acid (HCl), for 2 hours under agitation to remove residual zinc compounds, specifically zinc oxide (ZnO), and basic zinc chlorides ($Zn_5(OH)_8Cl_2 \cdot H_2O$) formed during carbonization. The acid-washed sample was then rinsed repeatedly with hot distilled water until the filtrate attained neutral pH ~6–7 and tested negative for chloride ions (Cl^-), using silver nitrate solution ($AgNO_3$). The washed sample was oven-dried at 105 ± 5°C for 6 hours, cooled in a desiccator, and subsequently ground using a mortar and pestle. The material was sieved to obtain a particle size of ≤710 µm and stored in an airtight container for further use.

2.4. Collection and Characterization of Abattoir Wastewater

Wastewater samples were collected from Trans-Amadi Slaughterhouse in Port Harcourt, Rivers State, Nigeria. Three points were marked along the slaughterhouse drainage channel for sampling and their descriptions are shown in Table 1.

Table 1: Description of the three sampling points along the abattoir drainage channel.

Designation	Description
S1	Effluent outlet near the slaughtering floor, 50 m downstream from main discharge point.
S2	Drainage channel downstream, 100 m from main discharge point.
S3	Sedimentation pit overflow, 200 m downstream from main discharge point.

Sample collection was done using pre-cleaned 1 L high density polyethylene (HDPE) bottles for physicochemical parameters and 500 mL glass bottles for BOD, COD and heavy metal samples. Glass bottles were chosen for the latter to prevent analyte adsorption onto plastic walls. All bottles were rinsed three times with the sample water before use. Samples were collected at 10:00 am while slaughtering was still ongoing so that the wastewater would reflect pollution at its peak. After collection, samples were kept on ice at 4°C and taken to the laboratory within one hour. BOD and COD samples were acidified with H_2SO_4 to pH below 2 and stored at 4°C. Heavy metal samples were preserved with HNO_3 to the same pH level. For the adsorption experiments, each sample was left to settle for 30 minutes and then filtered through Whatman No. 1 filter paper to remove coarse suspended solids that could interfere with the adsorbent in the batch tests. The unfiltered samples were kept separately for TSS and TS determination.

2.5. Sample Analysis

Prior to adsorption experiments, physicochemical parameters and heavy metal concentrations of the abattoir wastewater samples were determined according to Standard Methods for the Examination of Water and Wastewater (APHA, 2017) [10]. All analytical procedures were conducted in strict accordance with the methods specified by the American Public Health Association (APHA), the American Water Works Association (AWWA), and the Water Environment Federation (WEF) as outlined in the 23rd Edition of Standard Methods (APHA, 2017). The specific standard codes applied to each parameter are detailed below:

1. Temperature: Measured on-site using a calibrated digital thermometer, APHA Standard Method 2550 B.
2. pH: Determined using a calibrated digital pH meter, APHA Standard Method 4500-H^+ B.
3. Turbidity: Measured using a nephelometric turbidimeter, APHA Standard Method 2130 B, expressed as Nephelometric Turbidity Units (NTU).
4. Total Dissolved Solids (TDS): Determined using a calibrated conductivity/TDS meter, APHA Standard Method 2510 B, after filtration through 0.45 µm membrane filters.
5. Total Suspended Solids (TSS): Determined gravimetrically, APHA Standard Method 2540 D. A well- mixed sample was filtered through pre-weighed glass fiber filters (Whatman GF/C), and the residue retained on the filter was dried at 103°C to constant weight. It was calculated using Equation 1:

$$TSS(mg/L) = (W_2 - W_1) \times 1000/V \quad (1)$$

where: W_1 = weight of empty filter (mg); W_2 = weight of filter + dried residue (mg); V = volume of sample filtered (mL).

6. Total Solids (TS): Determined gravimetrically, APHA Standard Method 2540 B. A 100 mL well-mixed sample was evaporated in a pre-weighed dish and dried at 103°C to constant weight. It was calculated using Equation 2:

$$TS(mg/L) = (W_2 - W_1) \times 1000/V \quad (2)$$

where: W_1 = weight of empty evaporating dish (mg); W_2 = weight of dish + dried residue (mg); V = volume of sample evaporated (mL).

7. Biochemical Oxygen Demand (BOD_5): Determined by the 5-day BOD test, APHA Standard Method 5210 B. Dissolved oxygen was measured before and after 5 days incubation at 20 ± 1°C using the azide modification of the Winkler method, APHA Standard Method 4500-O C. It was calculated using Equation 3:

$$BOD_5\ (mg/L) = (Di - Df) \times dilution\ factor \quad (3)$$

where: D_i = initial dissolved oxygen (mg/L); D_f = final dissolved oxygen after 5 days (mg/L); Dilution factor = total volume / volume of sample used.

8. Chemical Oxygen Demand (COD): Determined by closed reflux method, APHA Standard Method 5220 D. Samples were digested with potassium dichromate and sulfuric acid reagent at 150°C for 2 hours.
9. Heavy Metals (Pb, Cd, Cr): Samples were digested with concentrated HNO_3 following APHA Standard Method 3030 E. Pb, Cd, and Cr concentrations were determined using Atomic Absorption Spectrophotometry (AAS), APHA Standard Method 3111 B. Instrument calibration was verified using certified standards, and blank samples were analyzed for quality control.

2.6. Batch Adsorption Study

For each wastewater sample (S1, S2 and S3), 100 mL was measured into 250 mL conical flasks. Activated carbon was added at three dosages: 5 g, 10 g and 15 g per 100 mL of wastewater. A different flask was used for each dosage. The flasks were covered with Parafilm and put on an orbital shaker at 150 rpm for 120 minutes at 28 ± 2°C. The choice of 120 minutes was informed by literature, where contact times of 60 to 180 minutes have been reported to be sufficient for most activated carbon systems to reach equilibrium [11-13].

The pH was not touched at any stage because the idea was to treat the wastewater as it was collected. After shaking, the flasks sat for 10 minutes and the contents were then filtered through Whatman No. 1 filter paper. The filtered water was analysed for residual pollutant concentrations as detailed in Section 2.5. Glassware was washed with distilled water between runs. Removal efficiency for each parameter was calculated using Equation 4.

$$Removal\ efficiency = (Ci - Cf)/Ci \times 100 \quad (4)$$

where Ci and Cf are the initial and final concentrations of the parameter.

3. Results and Discussion

3.1. Results

3.1.1. Initial Characterization of Abattoir Wastewater

The three wastewater samples were analysed before the adsorption experiments were carried out and the results are presented in Tables 2 and 3. Each parameter was compared against the FEPA [14] discharge limits to establish how contaminated the samples were.

Table 2: Physicochemical Parameters of Abattoir Wastewater Samples before Adsorption and FEPA Discharge Limits.

Sample	pH	Temp (°C)	BOD (mg/L)	COD (mg/L)	TDS (mg/L)	TSS (mg/L)	TS (mg/L)	Turbidity (NTU)
S1	5.91	35	487.00	1386.13	3502.00	3165.00	6667.00	43.70
S2	6.01	32	308.70	1265.64	2364.00	2023.00	4387.00	38.54
S3	6.08	30	240.00	845.03	1698.00	1513.00	3211.00	36.24
FEPA	6.00-9.00	<40	50.00	N/A	2000.00	30.00	N/A	N/A

Table 3: Heavy Metal Concentrations in Abattoir Wastewater Samples before Adsorption and FEPA Discharge Limits.

Sample	Pb (mg/L)	Cd (mg/L)	Cr (mg/L)
S1	10.46	2.07	33.53
S2	17.23	1.86	29.25
S3	13.18	1.61	25.22
FEPA	<1.0	<1.0	<1.0

3.1.2. Post-Adsorption Characterization of Abattoir Wastewater

The analysis of the abattoir wastewater samples after adsorption treatment was carried out to evaluate the performance of the prepared activated carbon in removing physicochemical and heavy metals contaminants. Table 4 presents the post-adsorption physicochemical parameters and heavy metal concentrations of the abattoir wastewater samples at varying adsorbent dosages (5 g, 10 g, and 15 g), while Table 5 presents the corresponding removal efficiencies.

Table 4: Post-Adsorption Physicochemical Parameters and Heavy Metal Concentrations of Abattoir Wastewater Samples at Varying Adsorbent Dosages.

Sample	Carbon Dosage (g)	pH	Tep (℃)	Turbidity (NTU)	TSS (mg/L)	TDS (mg/L)	TS (mg/L)	BOD (mg/L)	COD (mg/L)	Pb (mg/L)	Cd (mg/L)	Cr (mg/L)
S1	5	6.15	34	14.29	72.10	67.20	139.30	28.76	610.32	4.92	0.37	14.26
	10	6.33	34	6.58	58.90	54.30	113.20	22.13	460.44	2.92	0.18	6.42
	15	6.51	33	3.39	48.40	47.00	95.40	16.42	350.21	1.46	0.06	1.53
S2	5	6.22	32	9.31	45.80	52.20	98.00	20.60	430.18	3.85	0.31	11.42
	10	6.37	32	5.12	37.40	42.30	79.70	16.90	368.77	2.18	0.14	5.28
	15	6.56	31	4.04	34.20	41.30	75.50	12.34	307.56	0.48	0.08	2.51
S3	5	6.24	31	5.25	43.40	48.60	92.00	18.26	312.48	2.87	0.19	8.10
	10	6.42	31	3.06	46.70	37.80	84.50	14.82	270.80	1.14	0.06	3.28
	15	6.58	30	1.02	42.60	41.30	83.90	11.08	228.59	0.05	0.04	0.81

Table 5: Removal Efficiencies of Physicochemical Parameters and Heavy Metals at Varying Adsorbent Dosages

Sample	Carbon Dosage (g)	BOD (%)	COD (%)	TDS (%)	TSS (%)	TS (%)	Pb (%)	Cd (%)	Cr (%)
S1	5	94.09	55.96	98.08	97.72	97.91	52.96	82.13	57.49
	10	95.46	66.78	98.45	98.14	98.30	72.08	91.30	80.86
	15	96.63	74.73	98.66	98.47	98.57	86.04	97.10	95.44
S2	5	93.33	65.99	97.79	97.74	97.77	63.20	83.33	60.97
	10	94.52	70.87	98.21	98.15	98.18	87.34	92.47	81.95
	15	96.00	75.69	98.25	98.31	98.28	97.21	95.70	91.42
S3	5	92.39	63.02	97.14	97.13	97.13	78.23	88.20	67.88
	10	93.83	67.96	97.77	96.91	97.37	91.35	96.27	86.99
	15	95.38	72.95	97.57	97.18	97.39	99.62	97.51	96.79

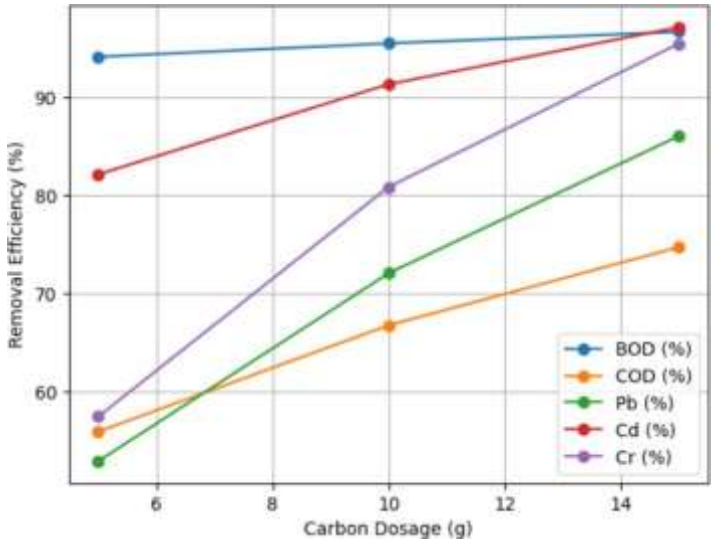

Fig. 1: Effect of adsorbent dosage on removal efficiency (sample S1).

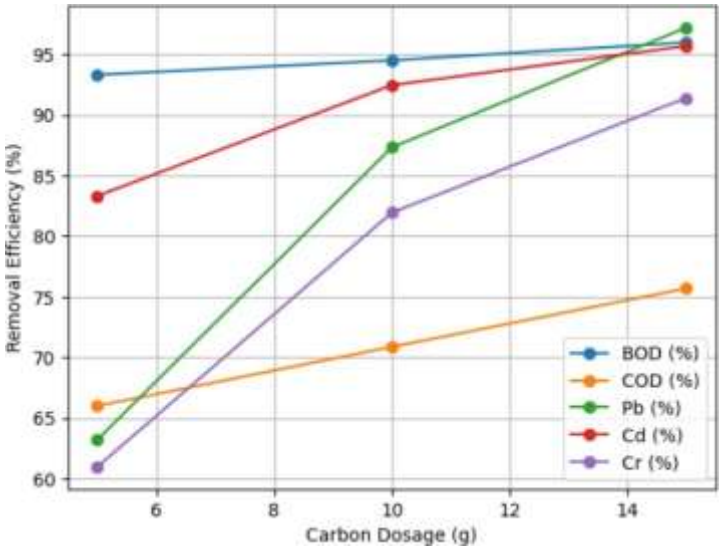

Fig. 2: Effect of adsorbent dosage on removal efficiency (sample S2).

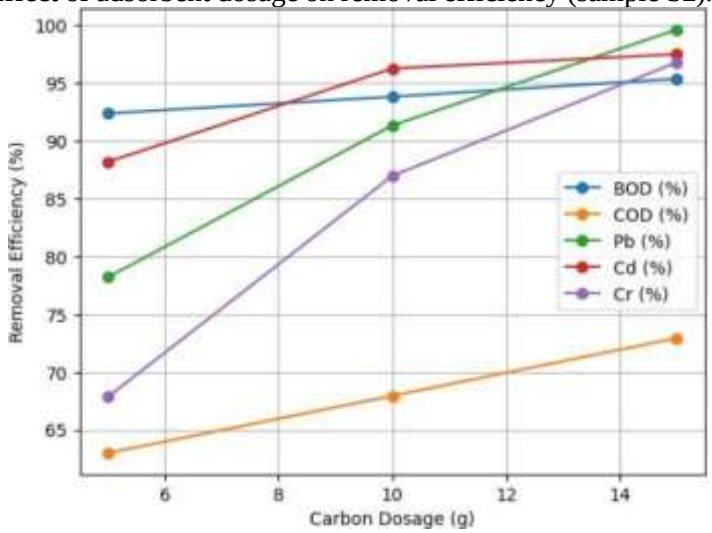

Fig. 3: Effect of adsorbent dosage on removal efficiency (sample S3).

3.2. Discussion

3.2.1. Influence of Discharge Location on Wastewater Contamination Levels

The results in Tables 2 and 3 show that the quality of the wastewater varied across the three sampling points. Sample S1 which was collected closest to the slaughtering floor had the highest concentrations for most of the parameters measured. The BOD, COD, TSS and TDS values recorded at S1 were 487.00 mg/L, 1386.13 mg/L, 3165.00 mg/L and 3502.00 mg/L respectively. However, lead concentrations were actually higher at S2 and S3, recording 17.23 mg/L and 13.18 mg/L respectively, compared to 10.46 mg/L at S1. The higher lead concentration at S2 could be due to inputs from blood, offal and other metal containing materials deposited along the drainage channel, as well as movement of contaminated particles from one point to another. This suggests that the distribution of contaminants in the drainage channel is not only determined by how close a point is to the slaughter floor but also by what happens along the channel itself.

Moving downstream, pollutant concentrations generally reduced. At S3 which was 200 m from the main discharge point, BOD dropped to 240.00 mg/L, COD to 845.03 mg/L and TSS to 1513.00 mg/L. This reduction was likely due to dilution and settling of solids along the drainage channel. All three sampling points exceeded FEPA discharge limits for BOD, TSS, Pb, Cd and Cr. TDS was above the permissible limit only at S1 and S2. The BOD recorded at S1 was about 9.7 times the FEPA limit of 50 mg/L, while TSS was about 105.5 times the 30 mg/L limit. Lead at S2 was 17.23 mg/L which is far above the FEPA limit of less than 1.0 mg/L. The pH of the wastewater ranged from 5.91 to 6.08 and temperatures ranged from 30 to 35°C, which are conditions that point to fresh organic loading and active decomposition of organic matter. These results show that abattoir wastewater from Trans-Amadi Slaughterhouse poses a serious pollution risk and the situation is worst near the slaughtering floor.

3.2.2 Adsorption Performance

From the results in Tables 4 and 5, it can be seen that the activated carbon prepared from palm kernel shells was able to reduce all the contaminants that were measured, and the removal efficiency got better as the dosage increased from 5 g to 15 g across all three samples.

For organic pollutants, BOD removal ranged from 92.39% to 96.63% and COD removal ranged from 55.96% to 75.69% at the 15 g dosage. TSS, TDS and TS removals were mostly above 97% at the higher dosages. These results show that the activated carbon was very effective in removing both suspended and dissolved matter from the wastewater. The good performance can be linked to the porous structure that was created during $ZnCl_2$ activation and the fact that the acid washing step removed materials that would have blocked the pores of the carbon.

Turbidity also reduced greatly, dropping from 43.70 NTU in the raw S3 sample to 1.02 NTU after treatment at 15 g dosage, which is consistent with the high TSS removal recorded. The pH of the wastewater went up from a range of 5.91 to 6.08 before treatment to 6.51 to 6.58 after treatment. This increase in pH suggests that some of the acidic organic compounds in the wastewater were removed during adsorption, and the negative AgNO3 test confirmed that there was no residual acid left in the treated samples. Temperature dropped slightly by 1 to 2°C, which was probably due to heat loss during the shaking process. At the 15 g dosage, BOD and Cd met FEPA discharge limits in all three samples. TSS however remained above the permissible limit in all samples even at the highest dosage. Chromium met the FEPA limit only in S3, while S1 and S2 still had chromium levels above the limit even though a lot of it had been removed. This shows that while the activated carbon performed well overall, TSS and chromium were the most difficult contaminants to bring down to acceptable levels and further work is needed to achieve full compliance for these parameters.

3.2.2. Carbon Dosage and Heavy Metal Removal

As seen in Figures 1 to 3 and Table 5, increasing the adsorbent dosage from 5 g to 15 g led to better heavy metal removal across all three samples. This trend was observed for Pb, Cd and Cr and it suggests that the availability of active sites on the carbon surface played a big role in how much of the metals were removed. At the highest dosage of 15 g/100 mL, removal efficiencies were above 90% for most of the metals. Cd recorded the highest removal across all three samples, followed by Pb and then Cr.

Even though the initial Pb concentration in S2 was quite high at 17.23 mg/L, the activated carbon was still able to bring it down to within FEPA limits, which shows that the adsorbent had enough capacity to handle that level of contamination. Chromium was however the most difficult metal to remove and it only met the FEPA limit in S3.

The fact that Cd was removed first, followed by Pb and then Cr, suggests that the three metals were competing for adsorption sites. Cd and Pb appeared to bind more strongly to the activated carbon surface, which is consistent with the role of oxygen-containing functional groups in promoting electrostatic attraction and surface complexation of divalent metal ions at the pH range of 6.15 to 6.58.

Overall, the 15 g/100 mL dosage gave the best results and achieved FEPA compliance for Cd in all samples and for Pb in S2 and S3. The fact that Cr did not fully comply in S1 and S2, and that Pb did not comply in S1, shows that for highly polluted wastewater like S1, further adjustment of operating conditions such as contact time and pH may be needed to achieve full compliance.

4. Conclusion

This study showed that activated carbon prepared from palm kernel shells using $ZnCl_2$ chemical activation can be used to treat abattoir wastewater effectively. The initial characterization of wastewater from Trans-Amadi Slaughterhouse showed that the wastewater was severely polluted, with BOD, TDS, TSS, Pb, Cd and Cr all exceeding FEPA discharge limits at most of the sampling points, which confirms the environmental risk that comes with discharging such wastewater without treatment. The activated carbon performed well in removing pollutants from the wastewater and removal efficiency increased as the dosage increased. At a dosage of 15 g/100 mL, the adsorbent reduced organic load, suspended solids and heavy metal concentrations considerably. Removal efficiencies exceeded 95% for most physicochemical parameters. Pb and Cd were also substantially reduced, although chromium compliance was only achieved in S3, making Cr the most stubborn contaminant especially in the more polluted samples. TSS did not meet FEPA limits in any of the samples even at the highest dosage. From the results of this study, it can be concluded that $ZnCl_2$ activated palm kernel shell carbon is an effective and low cost adsorbent for the treatment of abattoir wastewater. However, its performance depends on how strong the wastewater is and the operating conditions used. More work is still needed to optimize the operating parameters so that full compliance can be achieved for all pollutants across wastewater of varying strengths.

5. Recommendation

The following recommendations are made based on the results of this study:

1. The dosage of 15 g/100 mL that worked best in this study should be tested in a continuous flow column setup to find out how long the adsorbent lasts before it stops working and whether it can be reused after regeneration.

2. More work needs to be done to figure out the best contact time, pH and particle size that will help remove chromium and suspended solids more effectively, especially from wastewater with very high pollutant levels like S1.
3. It is recommended that the activated carbon prepared in this study be characterized using FTIR, SEM and BET analysis so that more information can be gotten about its surface functional groups, structure and pore size, and how these properties relate to its adsorption behaviour.
4. The production of activated carbon from palm kernel shells should be encouraged in Nigeria because it is a cheap and readily available agricultural waste material that can be put to good use in wastewater treatment instead of being discarded.

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