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Research paper

Effect of hydrogen ion concentration and adsorbent dosage on the removal of heavy metals from metal scrap effluents using activated carbon from African palm fruit

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Abstract

This study details the production of activated carbon from African palm fruit and subsequent treatment of heavy metals; Cadmium, Copper, Nickel, and Lead in wastewater effluent with the produced activated carbon from a metal scrap market in the heart of Kaduna state, Nigeria, which constitutes high level of pollution in the environment. Hydrogen ion concentration and adsorbent dosage were determined on water treatment quality using Atomic Absorption Spectrophotometer (AAS). The produced activated carbon showed a significant ability in removing heavy metals; Cadmium, Copper, Nickel, and Lead from samples of the wastewater. Higher efficiencies were observed with increase in adsorbent dosage (99.73 ± 0.265, 95.96 ± 0.053, 99.91 ± 0.085, and 95.12 ± 0.035 % at 2.5 g for Cadmium, Copper, Nickel, and Lead, respectively) and at a pH of 6 (99.61 ± 0.182 and 80.31 ± 0.015 % for Cadmium and Lead, respectively) and at a pH of 8 (99.79 ± 0.201 and 99.73 ± 0.252 for copper and nickel respectively). This findings show that African palm fruit can be utilized to produce activated carbon used in removal heavy metals from effluent water, representing an effective means of utilizing agricultural residues and also an alternative to the expensive commercial activated carbon.

Keywords: *African Palm Fruit; Adsorbent Dosage; pH; Activated Carbon; Wastewater Effluent.*

1. Introduction

Borassus aethiopum has a fan-like palm with a trunk of about 50 cm diameter and growing up to 30 m high. The trunk is considered as a good material for house construction as it appears to be very resistant to termites and fungi, and it is a very hard wood (Ouattara et al. 2015). Its shells are considered as agricultural waste in Northern Nigeria. Activated Carbon is a class of microporous materials that serve as adsorbents for the removal of gaseous and liquid pollutants as well as many other applications. They are amorphous and have an extensively developed internal pore structure. They are produced from a material rich in carbon, such as wood, coal, lignin and coconut shell (Gamby et al 2001; Gupta et al. 2004; El-said et al. 2010; Verla et al. 2012).

Recent study by Abdulrazak et al. 2016 showed higher percentage removal of heavy metals from wastewater effluent using activated carbon at a temperature of 80°C and at an optimum contact time of 60 minutes, after which the percentage removal decreases. Also, Khan et al.2001 reported that at an adsorbent dose of 0.8g /50ml is sufficient to remove 80–100% Cr (VI) from aqueous solution having an initial metal concentration of 20mg/L at a pH value of 1 but the efficiency reduced sharply to 15% at pH 3. (Halim et al. 2008) studied the removal of lead ions from industrial waste water by different types of natural materials. They reported that at lead concentration of 4mg/L and pH 6 the adsorption capacity was higher for Nile-rose plant powder at 80% removal and at the same Concentration and pH it was also reported that bone powder removed 98.8% of lead. (Abdulrazak et al. 2015) also studied the removal efficiency of chromium by produced activated carbon from moringa oleifera pods from tannery wastewater and reported higher removal efficiency at higher temperature. Iyagba and Opete (2009) reported that the removal of chromium and lead from drill cuttings using palm kernel shell and husk as adsorbents is possible. The removal and rapid decontamination of heavy metals becomes very important for the environmental remediation. The primary parameter for choice of adsorbent materials is cost. The most effective method for heavy metal removal from water is adsorption through the use of activated carbon for heavy metal removal from waste water (Nwabanne et al. 2012). This is due to its good capacity for adsorption of heavy metals. However, high cost of activated carbon and 10-15% loss during the regeneration has limits its use in the utilization of activated carbon in the developing countries (Ho et al. 2005). Therefore, there is increasing research interest in using alternative low-cost adsorbents especially from low cost agricultural wastes in water treatment (Khan et al. 2003; Abdulrazak et al. 2015).

2. Materials and method

2.1. Activated carbon preparation

African palm fruits were collected and sun-dried for six days. The seeds were then removed and the sample was pulverized using mortar and pestle. This was used for the analysis.
Activated carbon used as sorbent was prepared according to the method described by (Abdulrazak et al. 2015). Six grams (6g) of ground African palm fruits were soaked in 50 ml of 50% w/v phosphoric acid solution at 30°C for 48h. After filtration, the impregnated raw material was then carbonized in a muffle furnace at 300°C for 2 hours in nitrogen atmosphere. After cooling, each of the carbonized materials was washed with 200 ml hot distilled water, and then dried for 2 hours at 120°C. The dried activated carbon was then weighed to determine percentage yield, which is mathematically expressed as;

$$Percentage\ yield\ (\%) = \frac{yield\ (g)}{mass\ of\ raw\ material\ (g)} \times 100 \quad (1)$$

2.2. Physiochemical properties

2.2.1. Bulk density

The method described by Abdulrazak et al. 2016. A 25cm^3 cylinder was filled to the mark with the produced activated carbon. The cylinder was tapped for at least one to two minutes to compress the carbon to a steady volume. The compressed sample was poured out of the cylinder and weighed and the mass (m) was divided by the final volume occupied in the cylinder.

$$Bulk\ density = \frac{mass\ (g)}{final\ volume\ (cm3)} \quad (2)$$

2.2.2. Conductivity

This was done as described by Abdulrazak et al. 2016. Exactly 0.5g of the activated carbon was placed into 100 cm^3 beaker containing 50 cm^3 distilled water. It was macerated using a glass rod and then allowed to stay for about 1 hour. The conductivity was determined using conductivity meter.

2.3. Effect of hydrogen ion concentration

The effect of Hydrogen ion concentration on the adsorption of heavy metals by the activated carbon from African palm fruit was studied over a pH range of 2, 4, 6, 8 and 10 respectively. Exactly 50ml of effluent was measured into five different 250ml conical flask. The pH of the flask was adjusted to 2, 4, 6, 8 and 10 for the 1st, 2nd, 3rd, 4th, and 5th flask respectively using 0.1M HCl or 0.1M NaOH solutions. A weight of 0.5g of the activated carbon was then added into the effluent in each flask and the mixtures were stirred for a period of 60 min. It was then filtered using filter paper,

2.4. Effect of adsorbent dosage

50ml of the digested effluents was added into five different 250ml conical flask. 0.5g, 1.0g, 1.5g, 2.0g, and 2.5g of the adsorbent was added into the 1st, 2nd, 3rd, 4th, and 5th flask respectively, and the mixtures were corked and stirred for 60 minutes. The content of each flask was filtered using filter paper.

2.5. Data analysis

Each procedure in the study was repeated five times and data was expressed as mean percentage ± Standard deviation.

3. Results and discussion

Table 1 shows the result of physiochemical properties of the produced activated carbon is represented below.

Table 1: Result of the Physicochemical Properties of the Adsorbent.

Parameters	Values
Bulky density (g/cm^3)	0.66
Electrical conductivity (μScm)	1.2×10^2

Tables 2 and 3 shows the Effect of Hydrogen ion concentration on removal of Heavy metals; Cadmuim, Nickel, Lead and Copper. From the table below, there are higher treatment efficiencies at pH 6, except for Copper and Nickel, which shows higher treatment efficiency at pH 8. This is in agreement with similar work carried out by Mustaqeem et al. (2014a).

Table 2: Effect of Ph on Removal of Heavy Metals (Cadmium and Copper)

pH	Percentage removal of Heavy metals (%)									
	Cadmium					Copper				
	Minimum Level	Maximum level	Mean	Standard Deviation	Variance	Minimum Level	Maximum Level	Mean	Standard Deviation	Variance
2	89.17	89.29	89.22	0.061	0.004	86.00	86.20	86.12	0.108	0.012
4	92.84	93.00	92.92	0.080	0.006	90.40	90.50	90.44	0.055	0.003
6	99.40	99.73	99.61	0.182	0.033	96.50	96.58	96.53	0.044	0.002

8	95.50	95.78	95.64	0.140	0.020	99.60	100.0	99.79	0.201	0.041
10	92.80	92.90	92.85	0.050	0.003	95.50	95.61	95.55	0.057	0.003

Table 3: Effect of pH on Removal of Heavy Metals (Nickel and Lead)

pH	Percentage removal of Heavy metals (%) Nickel					Lead				
	Minimum Level	Maximum Level	Mean	Standard Deviation	Variance	Minimum Level	Maximum Level	Mean	Standard Deviation	Variance
2	99.00	100	99.65	0.566	0.321	74.00	74.20	74.07	0.113	0.013
4	99.79	100	99.86	0.118	0.014	77.50	77.60	77.55	0.050	0.003
6	99.00	100	99.66	0.572	0.327	80.30	80.33	80.31	0.015	0.0002
8	99.50	100	99.73	0.252	0.063	80.25	80.30	79.34	0.055	0.033
10	99.70	100	99.87	0.153	0.023	79.30	79.40	79.34	0.04	0.002

Hydrogen ion concentration is an important parameter for adsorption of metal ions from aqueous solution because it affects the solubility of metal ions. For this, the role of hydrogen ion concentration was examined at different pH. (Mustaqeem et al. 2014b) Hydrogen ion concentration affects protonation of functional groups on the adsorbents, as well as its solubility. The metal uptake was low at low pH, this is due to more Hydrogen ions that are in solution which compete with the metal ion for active site of the adsorbent. As the pH increases, there is increase in the percentage removal due to reduction of the H^+ ion in solution. Highest removal of Copper and Nickel, Cadmium and Lead were highest at pH of 6. Apart from Nickel and Copper, the percentage removal for all metals decreases at pH of above 6. The decrease in removal may be due to the formation of metal hydroxide complex at higher pH and also due to weakening of electrostatic force of attraction between the oppositely charged adsorbate and adsorbent which ultimately leads to the reduction in adsorption capacity (Baral et al. 2006). This is similar to what was reported by (Mulu 2013).
Tables 4 and 5 show the Effect of Adsorbent Dosage on removal of Heavy metals; Cadmuim, Nickel, Lead and Copper. The table below shows higher treatment efficiencies with increased dosage. That is, highest percentage removal of the heavy metals analyzed occurred at adsorbent dosage of 2.5g.

Table 4: Effect of Adsorbent Dosage on Removal of Heavy Metals (Cadmium and Copper)

Adsorbent Dosage (g)	Percentage removal of Heavy metals (%) Cadmium					Copper				
	Minimum Level	Maximum Level	Mean	Standard Deviation	Variance	Minimum Level	Maximum Level	Mean	Standard Deviation	Variance
0.5	91.73	99.76	91.75	0.015	0.0002	85.60	85.85	85.75	0.132	0.0175
1.0	99.70	99.77	99.73	0.036	0.0013	87.65	87.73	87.69	0.040	0.0016
1.5	99.12	99.20	99.16	0.040	0.0016	90.30	90.50	90.37	0.1102	0.0121
2.0	99.30	100.0	99.73	0.379	0.1433	91.40	91.50	91.45	0.050	0.0025
2.5	99.50	100.0	99.70	0.265	0.0700	95.90	96.00	95.96	0.053	0.0028

Table 5: Effect of Adsorbent Dosage on Removal of Heavy Metals (Nickel and Lead)

Adsorbent Dosage (g)	Percentage removal of Heavy metals (%) Nickel					Lead				
	Minimum Level	Maximum Level	Mean	Standard Deviation	Variance	Minimum Level	Maximum Level	Mean	Standard Deviation	Variance
0.5	91.70	91.73	91.73	0.025	0.0006	89.01	89.17	89.11	0.090	0.008
1.0	99.60	99.75	99.68	0.074	0.0058	92.30	92.40	92.35	0.050	0.003
1.5	99.08	99.12	99.10	0.020	0.0004	93.30	93.40	93.36	0.053	0.003
2.0	99.60	100	99.83	0.2053	0.0421	95.10	95.15	95.12	0.026	0.001
2.5	99.83	100	99.91	0.085	0.0073	95.10	95.16	95.12	0.035	0.001

The availability and accessibility of adsorption site is controlled by adsorbent dosage (Rafeah., et al 2009). It can be seen that, as the dose of the adsorbent increased, there is increase in percentage removal. Highest removal of Cadmuim, Nickel, Lead and Copper, were at adsorbent dosage of 2.5g. The increase in percentage removal as adsorbent dosage increase is due to the increase or availability of more adsorption site of the adsorbent at higher dose and also increase in functional groups available on the adsorbent on which metals could interact (Meikap, 2005).
Organic contents of wastewater and the presence of microorganisms stimulate adsorption and, therefore, show that the produced activated carbon can improve performance by developing different bacterial species (Jeong et al. 2016), which may also played a part in the whole study.

4. Conclusion

This results obtained shows that locally available materials such as low cost African palm fruit (Borassus aethiopum) could easily be sourced to produce activated carbon which can be used as efficient adsorbents for Heavy metal removal from effluent water, representing an environmentally effective means of utilizing these agricultural residue and also high cost of commercial activated carbon.

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