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Biosorption of Heavy Metals from Electroplating Wastewater Effluent onto Acid Treated Banana Peels

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Abstract Heavy metal contamination has been an environmental concern over the decades due to the release of high concentration of heavy metals in effluents into the water bodies without pre-treatment, partly because of associated cost. In the present study, banana peels (BP) was activated by H_2SO_4 and used for the removal of Zn^{2+}, Pb^{2+}, Fe^{2+}, and Cd^{2+} ions from electroplating wastewater effluents. Electroplating effluent was considered in a batch adsorption experiments to evaluate the influence of contact time, pH, and adsorbent dosage at 30°C. The FTIR spectra of the adsorbents confirm the presence of −OH, C–H, $-CH_3$ and −COOH groups along with C–O stretching; a possibility that these functional groups are involved in the adsorption of heavy metal ions through ion exchange and complexation mechanisms. Adsorption data showed that the optimum removal of Zn^{2+}, Fe^{2+} and Cd^{2+} (98.03%, 81.80%, 80.59%, respectively) was obtained at pH 10.8, and at pH 4.6 for Pb^{2+} (91.44%). The equilibrium data fitted well to the Langmuir and Freundlich adsorption isotherms, indicating a homogeneous adsorption behaviour. Isotherm variables showed that the adsorption of heavy metal ions on the activated biomass is favourable and significant. Finally, activated BP has proven to be a promising cost-effective precursor for heavy metals remediation of electroplating wastewater effluents.

Keywords Adsorption, Banana peels, Contamination, Heavy metals, Wastewater effluents

1. Introduction

Heavy metals are a group of trace elements such as metals and metalloids that have a relatively high density and are toxic at low concentrations. Heavy metals have been reported to pollute the air, soil, and water and are known to be harmful to humans and the environment even at very low concentrations [1]. Its occurrence in the environment above the permissible limits specified by the World Health Organization (WHO) contaminates the surface water and may permeate soils to pollute the underground waters [2-4]. Pollution caused by heavy metals results from natural and anthropogenic activities. Natural causes of heavy metals pollution include weathering of metal-bearing rocks and volcanic eruption, whereas, mining, smelting, purification of metals, discharge of industrial effluents, agricultural activities and electroplating are examples of anthropogenic sources. The high toxic level of heavy metals corroborates the negative impact of heavy metals on human and the environment; heavy metals can find their way into the food chain and thus accumulate to an appreciable level over time to cause detrimental effects on the liver, lung, kidney and reproductive system in human [5, 6]. Therefore, stringent standards and guidelines regarding the application of suitable treatment methods and level of treatment must be followed before the discharge of wastewater containing heavy metals into the environment.

Several methods have been deployed for the removal of heavy metals from effluent, these method include but not limited to membrane filtration, ion exchange, electrochemical removal, chemical precipitation, solvent extraction, and adsorption [7, 8]. However, some of these methods are not only deleterious to the environment but are cost prohibitive. Hence, different approaches and technologies have been proposed, with the aim of developing a low-cost, environmental friendly, and more effective techniques for treating effluents for reuse or before disposal. Adsorption has demonstrated to be proficient in the decontamination of heavy metal containing effluents [9-11]. Of particular interest is that adsorption technique allows for process scale up, adsorbent recovery and reuse. In addition, for commercial viability, a good adsorbent material should possess thermal and chemical stability, mechanical strength, high selectivity in order to facilitate rapid separations, regeneration capacity, favourable transport and kinetic characteristics, low solubility and resistance to fouling. The applications of agro-wastes and/or agro-industrial by-products for heavy metals uptake from wastewater have been appreciated in recent times. Some of these wastes and by-products include maize bran, rice husk, neem bark, sawdust, bamboo, palm shell, wheat bran, grape stalks [12-14]. The application of agricultural waste as adsorbent for heavy metals removal from wastewater is advantageous in many ways. Besides easy availability, low-cost and regeneration, it requires an easy and modest processing technique, and possesses superior adsorption ability and selectivity [15, 16]. However, the modification vis-à-vis the treatment of plant wastes prior to use as adsorbent for heavy metals removal from wastewater effluent is essential in order to enhance their adsorption capacity.

Therefore, this study comprises the application of activated banana peels (AcBP) for the removal of heavy metals (Zn^{2+}, Pb^{2+}, Fe^{2+}, and Cd^{2+} ions) from electroplating effluent. Investigations involve the study of the influence of adsorbent dosage, contact time and the solution pH. Suitable adsorption isotherms were used to describe the adsorption of metal ions from the effluent.

2. **Materials and Methods**

2.1. Reagents

Sulphuric acid (purity 95-97%), used as activating agent, was obtained from Sigma Aldrich, USA. Hydrochloric acid and sodium hydroxide were also obtained from Sigma Aldrich. Deionised water was used for all analytical preparations.

2.2. Sample Collection

Banana peels (BP) were collected at Odogunyan Market, Ikorodu, Lagos State. The BP were cut into pieces and washed with tap water. Subsequently, the BP were washed with deionised water to remove impurities such as oil, dirt, and salts. The thoroughly washed BP were dried in a Gen Lab oven at 125^{o}C for 15 h, it was allowed to cool before being pulverized into 600 µm particle sizes.

2.3. Electroplating Effluents

Industrial wastewater was obtained from an electroplating industry in Ikorodu, Lagos, Nigeria, at the point of discharge into the stream. To start with, sample collection materials were washed with dilute HCl, they were rinsed with deionised water, dried in an oven at 120 ± 3°C for 2 h, and were allowed to cool to ambient temperature before use. During the collection of the effluent, the sample materials were rinsed three times with the samples to be collected before being filled. After collection, the sample bottles were immediately corked, and transferred to the laboratory for treatment and analysis [17].

2.4. Acid Activation of Banana Peels

A 10 g of dried BP was soaked in 100 mL of 0.1 M sulphuric acid solution for 6 h at 30°C. Thereafter, the AcBP was filtered, washed with distilled water and dried in an oven for 2 h before characterization. Fourier transform infrared spectroscopy (FTIR: BrukerAlpha II) was used to investigate the effect of acid activation on the BP. The bulk density, colour, pH and moisture content of the materials were also considered. The bulk density and pH were determined using standardized methods, whereas, colour was examined with the use of a colorimeter (Color-Tec-PCM TM, Stanford, USA).

2.5. Adsorption Experiment

For the adsorption experiment, a 50 mL electroplating effluent was contacted with AcBP in a 250 mL beaker. A mechanical shaker was used to stir the mixture for 60 min, and was filtered using Whatmann's filter paper. Atomic adsorption spectrophotometer (HACH DR- 500) was used to determine the concentration of heavy metal ions in the residual solution. The influence of adsorbent dosage (0.5 g - 2.0 g), contact time (10 - 60 min) and pH (2 - 8) on adsorption were studied at a temperature of 30°C. The adsorption capacity of AcBP was evaluated using Equation 1.

$$q_e = \frac{V(C_o - C_e)}{m} \quad (1)$$

where q_e (mg/g) is the amount of metal ions adsorbed per unit weight of AcBP, V (L) is the volume of solution, C_o (mg/L) is the initial concentration of heavy metal ions, C_e (mg/L) is the equilibrium concentration of heavy metal ions, and m (g) is the AcBP dosage.

2.6. Adsorption Isotherm

2.6.1. Langmuir Isotherm

Langmuir adsorption isotherm represents equilibrium distribution of adsorbate between the liquid and solid phases. It depicts a uniform dynamism of adsorption onto the surface and no migration of adsorbate on the plane of the surface. The model is applicable for the monolayer sorption onto a surface which contains a fixed number of equal sites. Moreover, the model views every adsorption site as thermodynamically equivalent and identical [18]. The Langmuir adsorption isotherm and the linearized form of the equation are given in Equation 2 and Equation 3, respectively.

$$q_e = \frac{q_{max} K_L C_e}{1 + K_L C_e} \quad (2)$$

$$1/q_e = 1/q_{max} + 1/q_{max} K_L C_e \quad (3)$$

where K_L (L/mg) is the adsorption equilibrium or Langmuir constant, q_{max} (mg/g) is the maximum adsorption capacity, q_e (mg/g) is the amount of heavy metal ions adsorbed per unit weight of AcBP, and C_e (mg/L) is the equilibrium concentration of heavy metal ions. A plot of $1/q_e$ against $1/C_e$ gave the values of K_L and q_{max} from the slope and the intercept of the plot. Quantitatively, K_L takes values from 0 to 1: $K_L = 1$, represents a linear relationship between q_e and C_e; whereas $K_L = 0$, denotes irreversible interactive effects.

Another important characteristic of the Langmuir isotherm is the separation factor, R_L, which is defined in terms of initial concentration of adsorbate, C_o, as illustrated in Equation 4.

$$R_L = \frac{1}{(1 + bC_O)} \quad (4)$$

where b is the Langmuir constant. The value of R_L suggests whether the adsorption is favourable or not: the range $0 < R_L < 1$ indicates favourable adsorption, while $R_L > 1$ depicts unfavourable adsorption [19].

2.5.2. Freundlich Isotherm

The Freundlich isotherm assumes an exponentially distributed adsorption sites with respect to the heat of adsorption. The model describes a multilayer adsorption by accounting for the interactive effects of adjacent adsorbate molecules on the adsorbent surface [20]. In addition, Freundlich isotherm (Equation 5) has established an empirical relationship between adsorbate molecules that are contiguous to the binding sites and the adjacent layers, and that the binding energy decreases away from the first layer as the adsorption process progresses [21]. The linearized form of Equation 5 is given as Equation 6.

$$q_e = K_f C_e^{1/n} \quad (5)$$

$$\log q_e = \log K_F + (1/n) \log C_e \quad (6)$$

where q_e is the adsorption capacity, a coefficient that describes the extent of adsorption is K_F, C_e is the equilibrium concentration of metal ion, and n is the Freundlich constant accounting for surface heterogeneity

[20]. The coefficient, K_F, is obtained from the intercept of the plot of log q_e against log C_e, while the intercept (1/n) measures the extent of surface heterogeneity.

3. Results and Discussion

3.1. Elemental composition of Electroplating Effluent

The heavy metal analysis of electroplating effluent is shown in Table 1. Also presented on the table are the environmental standards of effluent by the WHO and Federal Environmental Protection Agency (FEPA) of Nigeria. The results of the analysis indicated that the concentrations of heavy metal ions in the effluent are all above the WHO and FEPA permissible limit. Thus, these metal ions could bio-accumulate over time to cause deleterious effect on human and the environment [22].

Table 1: Heavy metal analysis of electroplating effluent

Heavy metals	Concentration (mg/l)	FEPA Permissible Limit (mg/l)	WHO Permissible Limit (mg/l)
Zn	12.60	< 1	< 1
Pb	1.63	< 1	< 1
Fe	24.60	< 20	< 15
Cd	10.40	< 0.003	< 0.003

Source of the permissible limits: FEPA, 2013.

3.2. Properties of the Banana Peels

The determination of adsorbent pH is important in adsorption studies of aqueous metal ions as it affects the surface characteristics of adsorbent. Depending on the pH, adsorbents active sites can either be protonated or deprotonated; likewise, the uptake of metal ions in solution depends on pH [23]. Values of 6.5 and 7.9 were obtained as the pH of the raw BP and AcBP, respectively.

A value of 11.7% was obtained as the moisture content of the BP. Moisture content are often considered in the evaluation of the relative capacity of materials for sorption, because it influences the storage quality of materials [24]. According to FAO [25], a moisture content below 12-13% was specified to be ideal for good storage quality, particularly for grains and cereal. This implies that the BP used in this research may be stored for a longer period.

The colour intensity of the BP is dark brown, the dark brown colouration could be ascribed to the effect of enzymatic reaction during the drying process [26]. The bulk density of AcBP was 0.48 g/cm^3. This important parameter provides information on the quantity of carbon as well as effluent that could be retained by the adsorbent [24]. Also, in determining filterability index, adsorbents with high densities are considered to be of better quality since they provide greater volume activity [26, 27].

3.3. FTIR Characterization of Banana Peels

The FTIR analysis of AcBP before and after the adsorption of heavy metal ions are presented in Tables 2a and 2b, respectively. The peak observed at 3332.47 cm^{-1} is associated with −OH and -NH_2 stretching vibrations of amides, lignin, pectin, absorbed water, and cellulose. The peak obtained at about 2920 cm^{-1} could be ascribed to C–H stretching vibrations of alkanes, methylene, and methyl groups. Protonated AcBP contributed to the absorbance bands at 1725.47 cm^{-1} (free C═O), 1709.86 cm^{-1} (C═O asymmetry), 1691.45 cm^{-1} (C═O stretching) showing amino acid and amide functionalities. Acid activated biomaterials often show strong absorbance peak around 1725 cm^{-1}, which represents carbon–oxygen functional group of carboxylic acid [28].

Table 2a: FTIR analysis of acid activated banana peels before adsorption

Wavelength	Intensity	Functional groups	Bond
3332.42	Medium	Amides, bonded NH	N-H stretching
2920.00	Medium	Alkanes (-CH-)	C-H stretching
2851.66	Medium	Alkanes (-CH2-)	C-H stretching
2363.68	Strong	Charged amines (C=NH+)	NH+ stretching
2323.53	Strong	Charged amines (C=NH+)	NH+ stretching

1725.47	Strong	Dicarboxylic amino acid	C=O stretching
1709.86	Strong	-CO-NH-CO- amide	C=O stretching
1691.45	Strong	6 ring ketones	C=O stretching
1665.17	Vibrating	Alkene (CHR1=CHR2)	C=C stretching
1538.85	Strong	Unsaturated nitro compound	NH3 + deformimg
1441.96	Medium	Aromatic multiple bond	C=C stretching
1409.99	Strong	Phenol, tertiary alcohol	O-H deformimg
1379.20	Strong	Aliphatic Nitro compounds	NO_2 stretching
1356.48	Strong	Aromatic tertiary amines	C-N vibrating
1325.02	Vibrating	Sulphur compound	S=O stretching

Table 2b: FTIR analysis of AcBP after the adsorption of heavy metal ions

Wavelength	Intensity	Functional groups	Bond
3330.71	Medium	Amides, bonded NH	N-H stretching primary Amide
2943.50	Medium	Alkanes (-CH-)	C-H stretching
2913.52	Weak	Alkanes (-CH-)	C-H stretching
1710.19	Strong	α, β unsaturated acid	C=O stretching
1624.75	Vibrating	Aliphatic nitro compound	NO_2 stretching
1372.20	Strong	Dicarboxylic amino acid	C=O stretching
1149.39	Vibrating	Aliphatic ethers	R-O-R stretching

Significant modifications were observed when comparing the spectra of AcBP before adsorption to those obtained for heavy metals adsorbed AcBP, which may have resulted from the protonation of biomass surface. For instance, no band was observed at 1709 cm^{-1} after adsorption, meanwhile absorbance peaks in the range 1725 – 1665 cm^{-1} were shown prior to adsorption experiment. The peak observed at 1441.96 cm^{-1} could be associated with alkenyl group and the absorption band at 1372.20 cm^{-1} could be credited to the stretching of –C=O in carboxylic acid group. The band shown between 1356 – 1149 cm^{-1} represents the stretching of C-N derivatives, S=O as a dative bond in sulfoxides and R-O-R group of ketone and aliphatic ether. Basically, BP is composed of hemicellulose, lignin, cellulose, pectin and functional groups of ketone, hydroxyl, amide and carboxyl, which might be attributed to the adsorption of heavy metal ions (Zn^{2+}, Pb^{2+}, Fe^{2+}, Cd^{2+} ions) from the electroplating effluent [29].

3.4. Adsorption Studies

3.4.1. Influence of Contact Time on Adsorption

The results obtained on the influence of contact time on the adsorption of heavy metal ions from electroplating effluent onto AcBP are presented in Figure 1.

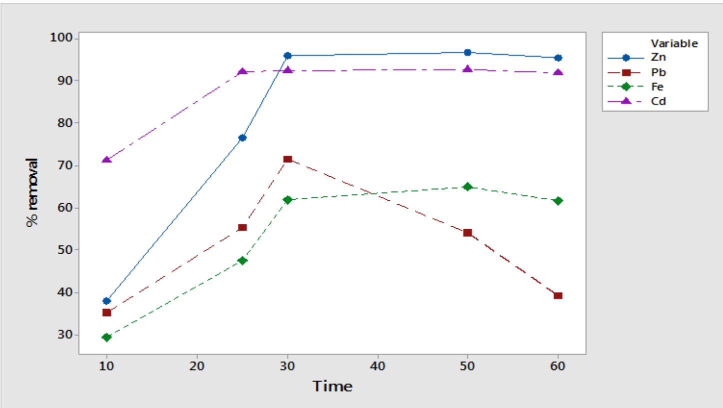

Figure 1: Influence of contact time on the adsorption of Zn^{2+}, Fe^{2+}, Pb^{2+} and Cd^{2+} ions onto activated banana peel

The result obtained shows an exponential increase in the uptake of metal ion with increased contact time for the first 25 – 30 min, particularly for Zn^{2+}. In a similar work by Mousavi-Qeydari et al. [30], whereby Ni^{2+} was absorbed from effluent by activated carbon synthesized from waste human hair, a rapid adsorption of the metal was observed within the first 15 min of contact time. The availability of virgin adsorbents active sites can create the concentration gradient that drive the fast adsorption observed at the initial stage of the experiment. Moreover, this rapid adsorption may be due to enhanced residence time and strong affinity of the adsorbents for the metal ions.

Furthermore, as observed in Figure 1, the uptake of Zn^{2+}, Fe^{2+}, and Cd^{2+} attained equilibrium adsorption within 30 min of the experiment, which could be triggered by decreased mass transfer coefficient as a result of active sites saturation. The drastic reduction in the adsorption of Pb^{2+} after 30 min may suggest the possibility of desorption of metal ions from the adsorbent surface. For Zn^{2+}, Fe^{2+}, and Cd^{2+} ions, the optimum adsorption was obtained at a contact time of 50 min, but at 30 min for Pb^{2+}. The concentration of Zn^{2+} decreased from 12.60 to 0.440 mg/l, Pb^{2+} from 1.63 to 0.465 mg/l, Cd^{2+} from 10.40 to 0.771, and Fe^{2+} from 24.60 to 8.651 mg/l, indicating 96.51%, 71.47% 92.58% and 64.83% removal, respectively. In descending order of adsorption: $Zn^{2+} > Cd^{2+} > Pb^{2+} > Fe^{2+}$. Zn^{2+} showed the highest percentage removal compared to Pb^{2+}, Fe^{2+} and Cd^{2+} ions. This might be attributed to a higher film and intra particle diffusion onto the interior active sites of AcBP. Similarly, Nurain et al. [31] observed that optimum adsorption of Pb^{2+} onto BP took place after 30 min.

3.4.2. Influence of pH on Adsorption

The influence of pH on the adsorption of Zn^{2+}, Pb^{2+}, Fe^{2+} and Cd^{2+} ions was investigated at pH values of 2.5, 4.6, 7.2, 10.8, and 12.2. The experiment was conducted at a temperature of 30°C, optimum contact time of 50 min, 2 g of AcBP and 50 mL volume of adsorbate was used.

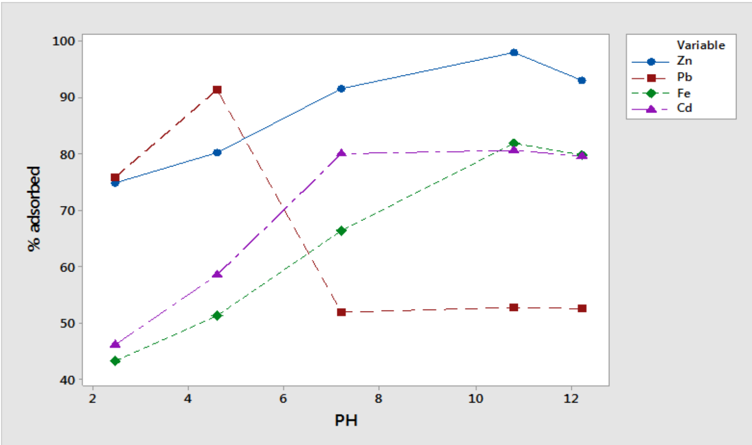

Figure 2: Influence of pH on the adsorption of Zn^{2+}, Fe^{2+}, Pb^{2+} and Cd^{2+} ions onto activated banana peel

Figure 2 shows that adsorption was low for Fe^{2+} and Cd^{2+} at pH 2.5, but considerably higher for Zn^{2+} and Pb^{2+} at the same pH. Metal ions uptake increased gradually with pH for Zn^{2+}, Fe^{2+} and Cd^{2+} and peaked at pH 10.8. However, the optimum adsorption for Pb^{2+} was obtained at a pH of 4.6, which thereafter dropped drastically. In similar studies, Memon et al. [32] investigated the influence of pH (1.0 – 9.0) on the biosorption of Cd^{2+} and Pb^{2+} from wastewater effluent onto BP extract. It was reported that optimum adsorption occurred at pH 8.0 and 5.0, for Pb^{2+} and Cd^{2+}, respectively. Likewise, Castro et al. [33] reported an optimum adsorption of Pb^{2+} by BP at pH of 5.0, while Šabanović et al. [34] obtained a maximum adsorption pH between 8.0 and 9.0, using the same biosorbent. Experimental results from this study indicated an optimum percentage removal of 98.03%, 81.80%, 80.59%, and 91.44% for Zn^{2+}, Fe^{2+}, Cd^{2+} and Pb^{2+}, respectively. In similar studies, Afolabi et al. [35] reported an optimum removal of 99.79% for Pb^{2+} using BP at pH 5, whereas a maximum adsorption of 87.5% was observed by Nurain et al. [31], for the same metal ions at pH 5. Since adsorbent surface becomes positively charged in acidic medium, it tends to repel approaching metal ions; this may be responsible for the observed low adsorption at pH of 2.5. The drastic drop in the adsorption of Pb^{2+} towards alkaline medium can be due to metal precipitation. The net positive charge on Zn^{2+}, Fe^{2+} and Cd^{2+} ions, existing as $ZnOH^+$, $FeOH^+$, and $CdOH^+$, can account for the increased adsorption at high pH values, as reported by Ibigbami et al. [17].

3.4.3. Influence of AcBP Dosage on Adsorption

The number of binding sites on adsorbents available for adsorption can be determined from biomass dosage. The results depicted in Figure 3 was obtained for the influence of AcBP dosage on the adsorption of Zn^{2+}, Fe^{2+}, Pb^{2+} and Cd^{2+} ions.

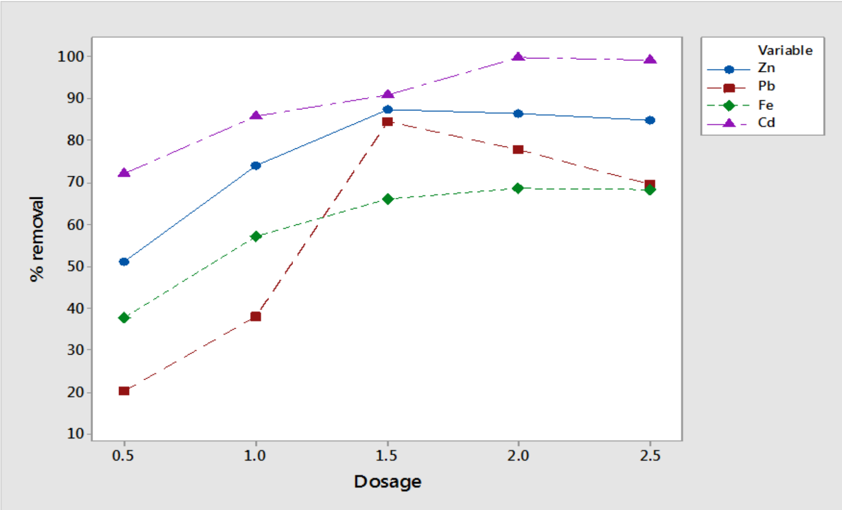

Figure 3: Influence of AcBP dosage on the adsorption of Zn^{2+}, Fe^{2+}, Pb^{2+}, and Cd^{2+} onto activated Banana peel

The results showed that the percentage removal of Zn^{2+}, Fe^{2+}, Pb^{2+}, and Cd^{2+} ions increased as the adsorbent dosage increased. A pH of 10.80 was kept constant for Zn^{2+}, Fe^{2+} and Cd^{2+}, and pH 4.6 for Pb^{2+}, all at 50 min contact time. The increase in the percentage of heavy metal ions removed might be due to a higher AcBP dose providing a more active functional group and surface areas. Therefore, a higher percentage of Fe^{2+} and Cd^{2+} ions were able to attach to AcBP particles than Zn^{2+} and Pb^{2+} ions, resulting in enhanced adsorption capacity. Moreover, it is expected that adsorption rate will decrease as the number of active sites decreases and the effluent becomes metal ions limiting.

For Fe^{2+} and Cd^{2+} ions, the initial increase was noted from 0.50 g – 2.00 g, whereas, 0.50 – 1.50g was recorded for Zn^{2+} and Pb^{2+} ions. Subsequently, as the adsorbent dosage increased from 2.00 – 2.50 g, the removal of Fe^{2+} and Cd^{2+} ions became constant, showing approximately 68.0% and 99.0% for Fe^{2+} and Cd^{2+} ions, respectively. On the other hand, the percentage removal of Zn^{2+} and Pb^{2+} ions slightly decreased as the AcBP dosage increased from 1.50 – 2.50. The optimum percentage removal was recorded at 2.0 g of AcBP for Fe^{2+} (68.54%) and Cd^{2+} (99.40%), likewise, an adsorbent dosage of 1.5 g AcBP gave the maximum heavy metal ions removal for Zn^{2+} (87.23%) and Pb^{2+} ions (84.42%). Generally, metal ions uptake increases with increase in adsorbent dosage, as revealed in this study and by previous researchers [30, 36]

3.5. Adsorption Models

The maximum adsorption capacity of AcBP was estimate by Langmuir model as shown in Table 3. Model parameters showed that Langmuir model was sufficient to analyse the adsorption of the metal ions studied.

Table 3: Equilibrium constants for the adsorption of Zn^{2+}, Fe^{2+}, Pb^{2+}, and Cd^{2+} onto activated Banana peel

Metals		**Langmuir constant**			**Freundlich constant**		
	q_{max} **(mg/g)**	***B*(L/mg)**	R_L	R^2	**1/n**	K_F	R^2
Zinc	909.09	275×10^{-5}	0.9996	0.9999	0.9772	0.2015	0.9999
Lead	0.0160	3.4500	0.2162	0.1249	0.4840	3.2520	0.7778
Iron	0.3533	0.1536	0.2092	0.7733	0.5690	0.3330	0.1577
Cadmium	104.167	239×10^{-5}	0.9997	0.9999	0.9753	0.2014	0.9999

The coefficient of determination of the extent of correlation (R^2) shows that the adsorption of Zn^{2+}, $Fe^{2+}$and Cd^{2+} could be described by the Langmuir model, although the uptake of Pb^{2+} is better modelled by the Freundlich isotherm. The Langmuir adsorption capacity (q_{max}) for Zn^{2+} and Cd^{2+} was found to be 909.09 mg/g and 104.167 with energy parameter of 275 x 10^{-5} L/mg and 239 x 10^{-5} L/mg, respectively. The value of q_{max} (mg/g) binding onto AcBP follows a descending order of $Zn^{2+} > Cd^{2+} > Fe^{2+} > Pb^{2+}$. This trend shows the entity multilayer of the adsorbent in the adsorption of the heavy metal ions. Furthermore, affinity binding parameter, *B*, indicated that metal ions have greater affinity for acid activated sites; thus the trend observed as $Pb^{2+} > Fe^{2+} > Zn^{2+} > Cd^{2+}$.

Furthermore, since metal adsorption is influenced by ion exchange, electronegativity of the metal ions (Pb > Fe > Cd > Zn) also explains their affinity to adsorbent surface. From Table 3, the values of R_L for Zn^{2+}, Fe^{2+}, Pb^{2+} and Cd^{2+} adsorption onto AcBP are less than 1; therefore, the adsorption process could be affirmed to be favourable. Similarly, the values of 1/n from Freundlich isotherm shown in Table 3 equally revealed that the adsorption of all the heavy metal ions onto AcBP was significant. Usually, the extent of adsorption can be described by the value of 1/n: a high value of 1/n (i.e. value approaching unity) shows that adsorption is predominantly controlled by concentration, particularly, at low concentration of metal ions in effluent solution. However, a value of 1/n approaching zero implies that adsorption is practically independent of adsorbate concentration [19]. The value of K_F shows high adsorption capacity as well as the propensity for metal ions to easily separate from effluent solution; hence, the higher the value of K_F, the greater the adsorption intensity.

4. Conclusion

The potential of acid activated banana peel (AcBP) to absorb Zn^{2+}, Pb^{2+}, Fe^{2+}, and Cd^{2+} from electroplating effluent was investigated. The presence of methyl and carboxyl (−COOH), −OH, C–H and C–O stretching of cellulose, polysaccharide, and hemicellulose were confirmed by the FTIR spectra, which could facilitate adsorption of these heavy metals. Adsorption of metal ions onto AcBP was found to depend on contact time, adsorbent dosage and pH of the effluent. Adsorption data fitted well to the Langmuir and Freundlich isotherms. The application of BP as a promising low-cost agro-waste for adsorption can concomitantly minimize the waste disposal challenge and enhance the treatment of heavy metal contaminated effluents.

Conflict of interest – The authors declare no conflict of interest.

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