

Utilizing Composites of Environmental Noxious Waste Materials for Decontamination of Heavy Metal Ions in Solution

Cyprian Y. Abasi^{1,a,*}, Oyatemen Ebiyegbagha^{1,b}, Jackson Godwin^{1,c}

¹Department of Chemical Sciences, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria

^aabasicy@yahoo.com, ^boyatemen@gmail.com, ^cgodwinj2012@gmail.com

*Corresponding author

Keywords: Composite, PET, waste plastic bottles, sawdust, heavy metals, kinetics, isotherm

Abstract: Heavy metals, sawdust and waste plastic bottles are pollutants which are threats to the environment and by extension to humans, animals and plants. Composites of waste plastic bottles and sawdust in different ratios (3:1, 6:1 and 12:1) were used to adsorb iron (III) and lead (II) from aqueous solution. Batch adsorption was used to determine the kinetics and equilibrium of the adsorption. Atomic absorption spectrometry (AAS) was used to determine the concentrations of the metals in pre and post adsorption. FTIR was used to characterize the composite adsorbents; the results showed peaks for OH (3291.2, 3336.0, 3406.8 and 3652.8cm⁻¹) and CO (1714.6cm⁻¹) which influence adsorption. Pseudo second order (PSO) and Weber-Morris intraparticle diffusion models were studied and experimental data largely favoured pseudo second order kinetic model; while intraparticle diffusion was dominant for the 12:1 ratio for Pb as shown by the higher R² value (0.921). For equilibrium studies, experimental data fitted Langmuir more than the Freundlich. Percentage adsorption of more than 90% was achieved for both metals at initial concentrations as high as 50ppm for iron and 100ppm for lead. It was also observed that the percentage adsorption of lead was more than that of iron. The results of the equilibrium and kinetic studies showed that the different ratios of waste PET plastic bottles to sawdust are potential adsorbents for iron and lead from aqueous phase.

1. Introduction

Heavy metal poisoning in drinking water is currently a concern to humans and is frequently the source of serious health problems such as cancer, organ damage, and other serious illnesses. Heavy metals are elements that occur in nature with a large density and a weight that is at least five (5) times that of water. Their numerous industrial, residential, agricultural, medical, and technical uses have resulted in their pervasiveness in the environment [1]. [2], listed different methods by which water contaminated with heavy metals can be treated. Some examples are biological methods, chemical precipitation, coagulation, etc. However, (it is a well-known fact that some of) these

conventional methods are often economically expensive [3]. Composite of sawdust and PET has been prepared in different ratios, at different temperatures, different pressures and other operating parameters and used in some construction fields [4]. The focus of this study is on the use of Polyethylene terephthalate (PET) waste bottle/sawdust composite as an adsorbent for lead (II) and iron (III) from aqueous solution.

The presence of lead in water and the food chain can result to lead poisoning which is a high health risk to growing fetuses and living victims. According to the [5], two hundred and forty (240) million people are at the risk of lead poisoning and ninety nine percent (99%) of those with above 20 µg/dL lead in their blood are in the developing world. The main source of vulnerability of African children to lead is leaded gasoline [6]. In Nigeria up to seventy percent(70%) of young children have been reported to have blood lead concentration of equal to or above 10 µg/dL[7]. [8] advised that though the amount of lead found in four comestible snail specimen in Bayelsa State were low, these snails should be consumed in moderation because of the bioaccumulative nature of lead. [9] reported that the concentration of lead in Swali, Amassoma, Tombia and Otuokpoti rivers in Bayelsa State of Nigeria exceeded the acceptable limits (10 ug/L).

Iron, though considered essential nutrient, can also be a contaminant in water. Elevated threshold levels of iron found in Epie creek (Yenagoa, Bayelsa State) was attributed to anthropogenic inputs such as soil and dumpsite leachates, which lowered the clarity and increased turbidity of the aquatic environment, making the water unsafe for human consumption [10]. [11], in their research work titled ‘the potability of groundwater in Bayelsa State, central Niger Delta, Nigeria: a review’ concluded that the physicochemical parameters of some acclaimed potable water (including heavy metals like iron) were above the Standards Organization of Nigeria (SON) and the World Health Organization (WHO) recommended limits. In drinking water iron (II) salts are capricious, and are precipitated as insoluble Fe(OH)₃, which settles as a rust-like silt, causing turbidity issues, staining of laundry and plumbing[12]. Another concern about the presence of iron in drinking water is its highly objectionable metallic taste, even at low concentrations (1.8 mg/L)[13]. Depression, fast and shallow breathing, coma, convulsions, respiratory failure and cardiac arrest are among some of the effects of toxic iron concentration in the human body [12]. An excess of iron in the body can induce hemochromatosis, diabetes, gastrointestinal issues, vomiting and nausea. It also has the potential to harm the liver, pancreas, and heart. Water with iron has a metallic taste that is (very) unpleasant. Iron tends to create reddish orange stains and residue on bathroom fixtures such as bathtubs, showers, and faucets, as well as fading the colour and lowering the quality of clothing.

In 2015, over 350 million tonnes of plastic was produced [14]. For plastic waste generation, it has been reported that China produces an estimated 59.8 million tonnes of plastic waste every year, the United states generate 37.83 million tonnes, followed by Germany which generate 14.48 million tonnes of plastic waste per year [15]. In Africa, Egypt, Nigeria, South Africa, Algeria and Morocco are among the top generators of plastic waste [15]. The problem of plastic waste stems from over production to the almost non-biodegradability of plastic waste and outright waste mismanagement.

Wood exploitation waste (sawdust) stored in an uncontrolled condition (which is the case most of the time especially in developing countries) may be an important factor of environmental pollution. The most popular way of discarding sawdust is by burning. The burning of sawdust has been known to produce nitrogen oxides (NO_x) and sulfur oxides (SO_x), which are known to damage human respiratory system (most especially NO_x) [16].

Sawdust has also been found to be associated with increase in blood pressure [17]. Sawdust and the burning of sawdust also contribute to the emission of particulate matter into the environment [18]. Sawdust when dumped into inland water (whether treated or untreated) has negative impact on fish distribution and their communities [19]. Nigeria turns out about 1.8 million tonnes of sawdust yearly [20]. In this work, composite of plastic waste bottles and sawdust in different ratios was

applied to remove heavy metals from aqueous solution, thus seeking alternative use of otherwise problematic waste materials and is an attempt to solve environmental pollution issues.

2. Materials and Methods

2.1 Preparation of Adsorbent

The plastic materials (waste PET plastic bottles) were collected from trenches, drainages, streets, dump sites and eateries around Yenagoa and Amassoma in Bayelsa State of Nigeria.

The waste PET plastic bottles were washed with detergent and tap water. Washing was done to get rid of surface impurities and remove the commercial labels attached to the plastic bottles. Distilled water was used to rinse the waste plastic bottles and then sun - dried.

The shredding process was done manually using a pair of scissors.

2.2 Collection, Drying and Sieving of Sawdust

Sawdust was collected from a local sawmill in Yenagoa, in the Yenagoa Local Government Area of Bayelsa state, Nigeria. The sawdust has a lot of contaminants from the environment in which they were stored like dust, mud, stones, and colour. The colour in sawdust is known to be an issue in the calibration of spectroscopic instruments used in determining heavy metal ion concentration after adsorption [21]. The sawdust was washed using tap water several times and after that, using distilled water as a rinse to remove the earthly impurities. The sawdust was then sun-dried for one (1) day and oven-dried at 110 °C for 48 h to constant weight; it was ground and sieved to 150 µm maximum particle size, labeled and kept in an air tight container for further processing.

2.3 Preparation of Pet Waste Bottles/Sawdust Composite

An aluminum pot was placed on an electric hot plate for close to one minute and 120g of the waste PET plastic bottles shreds were put inside the pot to melt. At melting, 40g of 150µm sawdust was added. The mixture was whisked together to allow uniformity of the blended mixture. This was then poured onto a flat cardboard for curing for 20 minutes in air. This whole process was repeated using 120g waste PET plastic bottles shreds and 20g of 150µm sawdust and 120g waste PET plastic bottles shreds and 10g of 150µm sawdust to produce 3:1, 6:1 and 12:1 PET waste bottle/sawdust composite respectively.

2.4 Grinding and Sieving of the Formed Composite

The 3:1, 6:1 and 12:1 waste PET bottle/sawdust composite thus formed were then crushed separately into smaller particle size with the help of a hammer, mortar and a manual grinding machine and sieved to obtain a particle size of 300µm. They were kept in air tight containers to be employed as the adsorbent.

2.5 Characterization of Pet Waste Bottle/Sawdust Composite

Fourier transform infrared spectroscopy (FTIR) was used to determine the functional groups in the adsorbents after preparation.

2.6 Preparation of Adsorbates

1000ppm stock solution of Fe(III) and Pb(II) were prepared by measuring 7.38g of

Fe(NO₃)₃·9H₂O and 1.615g of Pb(NO₃)₂ respectively, which were dissolved inside one(1) liter flask with a volumetric scale and made up with distilled water. Working concentrations (50, 100, 150, 200 and 250 ppm) were obtained using the dilution method.

2.7 Batch Adsorption Studies

0.08g of the various composite adsorbents, 10 mL each of different standards (50, 100, 150, 200 and 250 ppm) of adsorbates were used in a batch adsorption experiment to determine the adsorption kinetics and capacity of the adsorbents.

2.8 pH Monitoring of Adsorbate Before and After Adsorption

The pH of the adsorbate before and after the adsorption was monitored using a pH meter.

3. Results and Discussion

3.1 Characterization of Adsorbents

FTIR was used to characterize the different ratios of adsorbents prepared and the spectra are presented in figure 1 A, B and C.

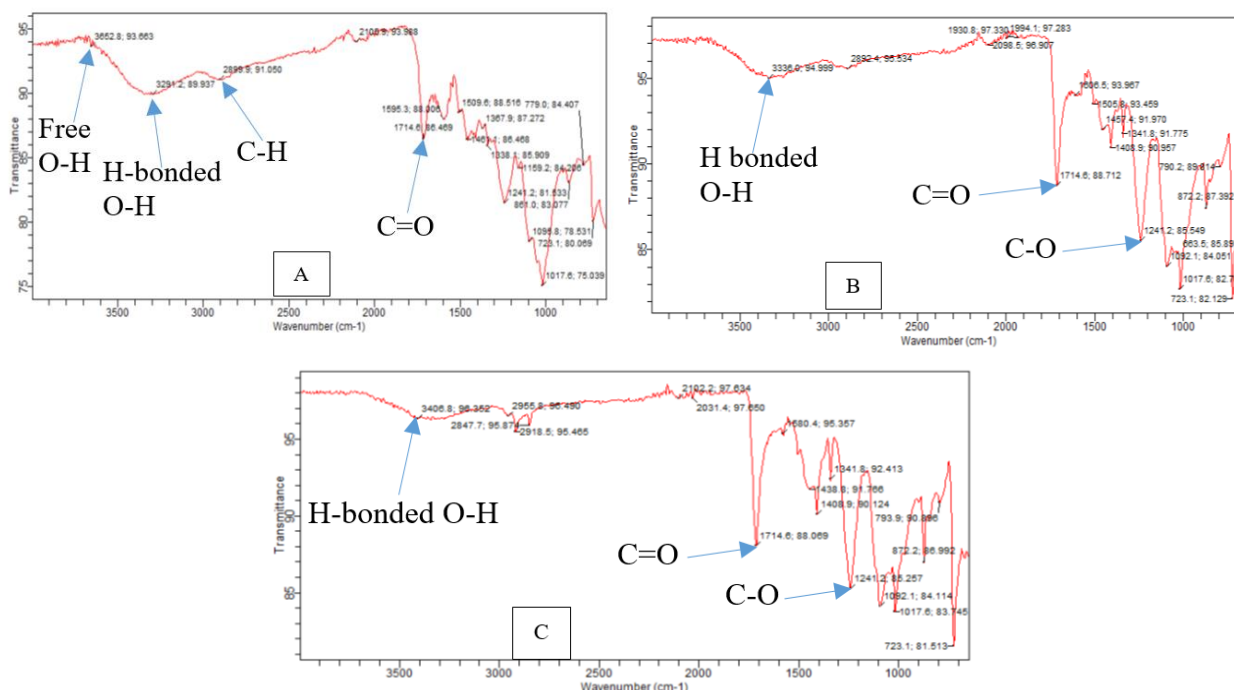


Figure 1: FTIR for PET waste bottle/sawdust composite; (A) 3:1, (B) 6:1 and (C) 12:1

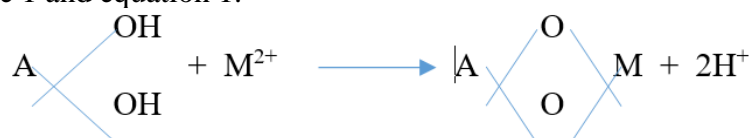
The results of the FTIR spectra showed bands and peaks consistent with organic material containing alkenes, alkanes, haloalkanes, alkanols, carbonyls and aromatic functional groups [3] [22], [4] [23] [24]. The spectra contain adsorption influencing groups such as C-OH and C=O [25]. The groups and their bands values are shown in Table 1.

Table1: FTIR Bands of functional groups on adsorbents used for adsorption

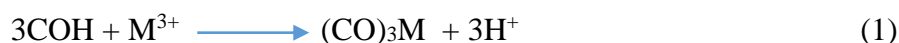
Functional Groups	$\bar{\nu}$ (cm ⁻¹) for 3:1	$\bar{\nu}$ (cm ⁻¹) for 6:1	$\bar{\nu}$ (cm ⁻¹) for 12:1
Free O-H	3652.8	-	-
H bonded O-H	3291.2	3336.0	3406.8
C=O	1714.6	1714.6	1714.6
C-O	1241.2	1241.2	1241.2

3.1.1 Possible Adsorption Mechanism

The principal mechanism for metal adsorption by biosorbents in which the major hydroxo groups are COH and CO is ion exchange ([26], [27], [28],[39],[30], [31]. The probable mechanism is as shown in the scheme 1 and equation 1.



Scheme 1: Possible ion exchange mechanism



Where A is the bulk of the adsorbent

The above mechanism is as a result of the acidic nature of the solution.

3.2 Kinetic Studies

The effect of time on the quantity of heavy metal ions, adsorbed by the composites are shown in figures 2 and 3, and the kinetic parameters are shown in tables 2 and 3.

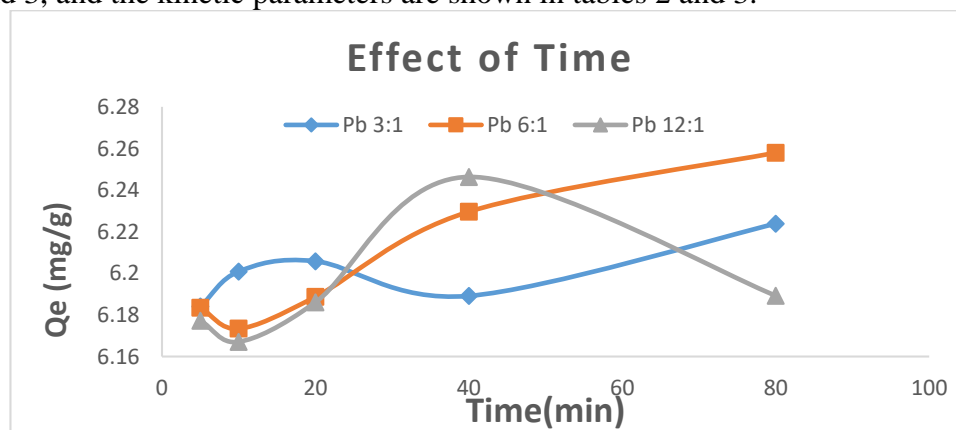


Figure 2: Effect of time on Pb(II) ions adsorption on PET waste bottle/sawdust composite

From the results, the quantity adsorbed increased nonlinearly with time for the adsorption of lead (Pb) as shown in figure 2. The nonlinear nature of the plots are as a result of the probable reversibility of the adsorption action [32]. However, the overall adsorption occurred in the forward direction for the removal of the adsorbate by the adsorbent. For the iron adsorption, the trend shows a general decrease in adsorption as time increased. Figure 3 shows that the adsorption was very fast and high adsorption occurred at short time intervals. This implies that the adsorption occurred at the surface of the adsorbent [33].

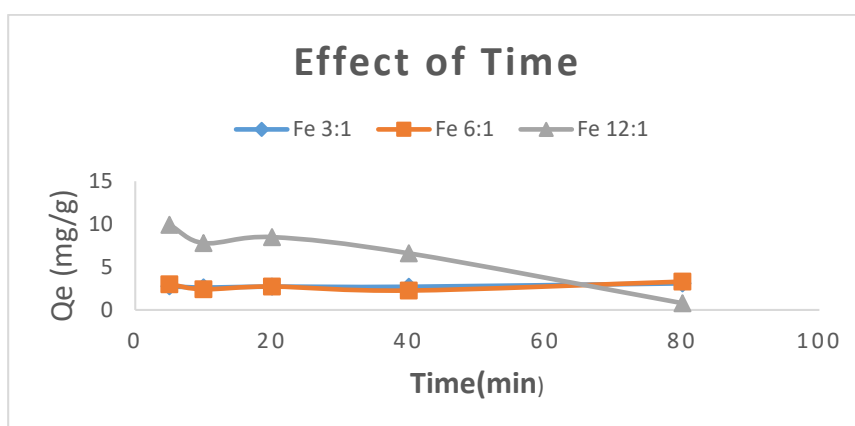


Figure 3: Effect of time on Fe(III) ions adsorption on PET waste bottle/sawdust composite

The pseudo second order (PSO) kinetic equation is given in (2)

$$t/q_t = 1/k_2 q_e^2 + t/q_e \quad (2)$$

Where; q_t = amount of adsorbate adsorbed at time t .

k_2 = adsorption rate constant.

q_e = amount of adsorbate adsorbed at equilibrium.

Pseudo second order (PSO) plots for iron and lead are given in figures 4 and 5 while the parameters values are as shown in tables 2 and 3.

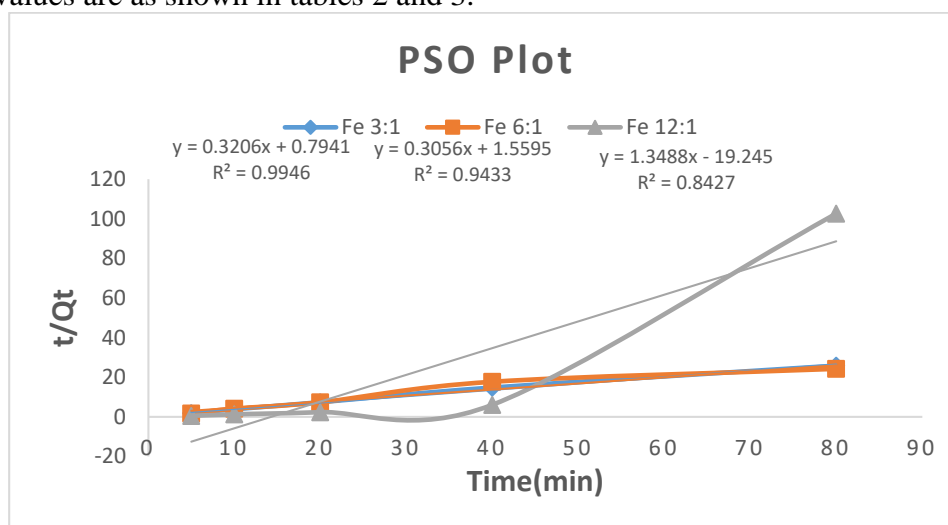


Figure 4: Pseudo second order plot for Fe(III) ions adsorption on PET waste bottle/sawdust composite

The high R^2 values for both Fe(III) and Pb(II) suggest that the adsorption best fit the Pseudo second order (PSO) model. This confirms the fact that the adsorption was rapid, ion-exchange occurs first, followed by slower adsorption which is as a result of ion diffusion into the pores of the adsorbents for a longer period. In general, the pseudo second order (PSO) plots for both Fe^{3+} and Pb^{2+} for all the adsorbents show that the initial ion concentration is inversely proportional to the rate constants of the PSO [26]. Chemisorption occurs when heavy metals make a chemical (typically covalent) link with the adsorbent surface and seek out areas with the highest coordination number. Chemisorption is normally limited to just one sheet (monolayer) of particles on the adsorbent's surface, while additional layers of physically adsorbed molecules may be added afterwards [34]. PSO is based on the assumption that the rate determining step is chemisorption [35], [36], this

implies that the process here is chemisorption.

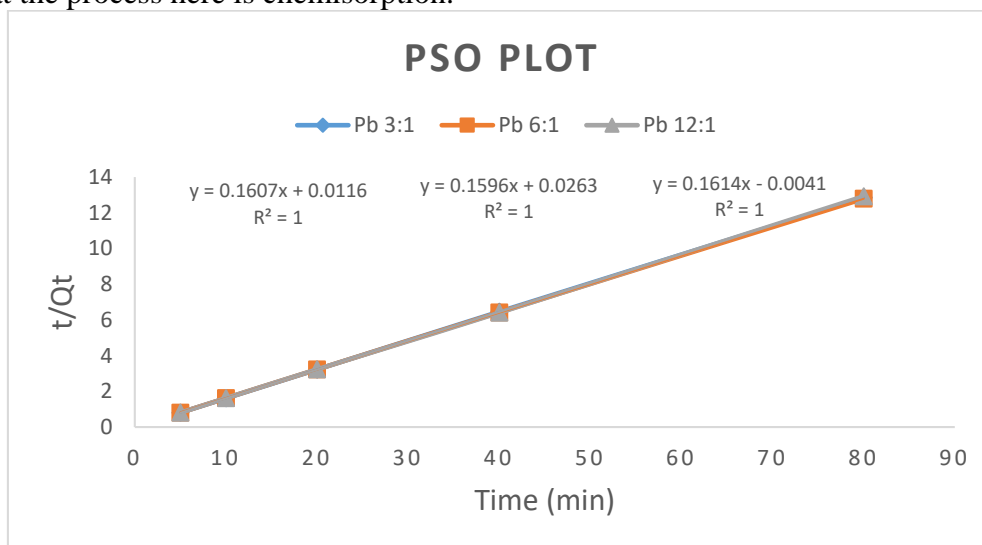


Figure 5: Pseudo second order plot for Pb (II) ions adsorption on PET waste bottle/sawdust composite

Table 2: Pseudo second order (PSO) parameters for Fe (III) ions adsorption on PET waste bottle/sawdust composite

Metal ion	Composite Sample	Parameter	Value
Fe(III)	3:1	q_e (mg/g)	3.119 (EXPT = 3.091)
		k_2 (g/mg.min)	0.129
		R^2	0.9946
	6:1	q_e (mg/g)	3.272 (EXPT= 3.297)
		k_2 (g/mg.min)	0.056
		R^2	0.9433
	12:1	q_e (mg/g)	0.741 (EXPT = 0.780)
		k_2 (g/mg.min)	-10.578
		R^2	0.8427

Table 3: Pseudo second order (PSO) parameters for Pb (II) ions adsorption on PET waste bottle/sawdust composite

Metal ion	Composite Sample	Parameter	Value
Pb	3:1	q_e (mg/g)	6.223 (EXPT = 6.224)
		k_2 (g/mg.min)	2.226
		R^2	0.9999
	6:1	q_e (mg/g)	6.266 (EXPT = 6.246)
		k_2 (g/mg.min)	0.969
		R^2	0.9999
	12:1	q_e (mg/g)	6.196 (EXPT = 6.189)
		k_2 (g/mg.min)	-6.354
		R^2	0.9999

Weber-Morris intraparticle diffusion plots for Fe(III) and Pb(II) ions are as instantiated in figures 6 and 7 while table 4 shows the variables for Pb(II) ions adsorption using 12:1 PET waste bottle/sawdust composite (adsorbent). The Weber-Morris intraparticle diffusion plots for Pb(II) ions

shows multilinearity which implies that Weber-Morris intraparticle diffusion was not the sole rate determining step, other processes like boundary layer diffusion and mass transfer may also be involved in controlling the rate ([26], [33], [29]). For iron, the correlation coefficients (R^2) were poor. The linear form of Weber-Morris intraparticle diffusion model is given in equation 3

$$q_t = K_{ID}t^{1/2} + C \quad (3)$$

Where; K_{ID} = intraparticle diffusion rate constant ($\text{mg/gmin}^{1/2}$)
 C = constant related to the thickness or boundary layer

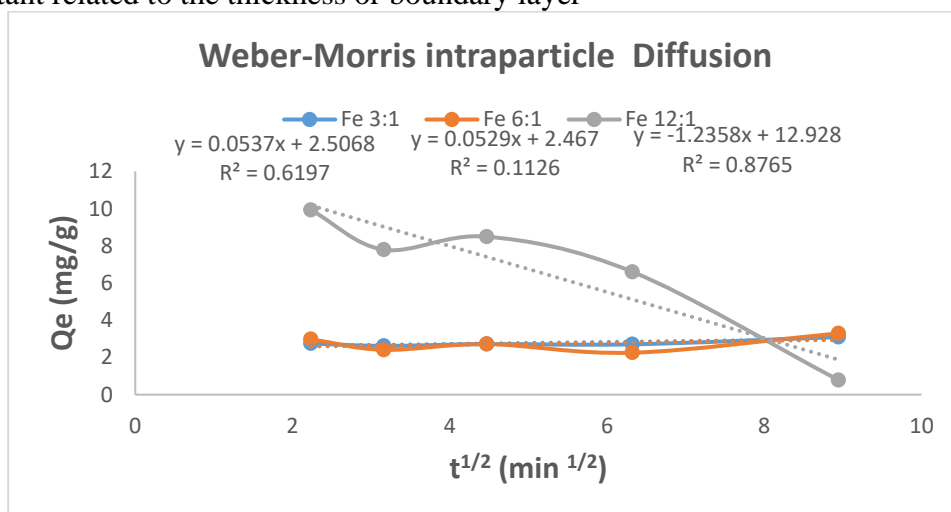


Figure 6: Weber-Morris intraparticle diffusion plot for Fe(III) ions adsorption on PET waste bottle/sawdust composite

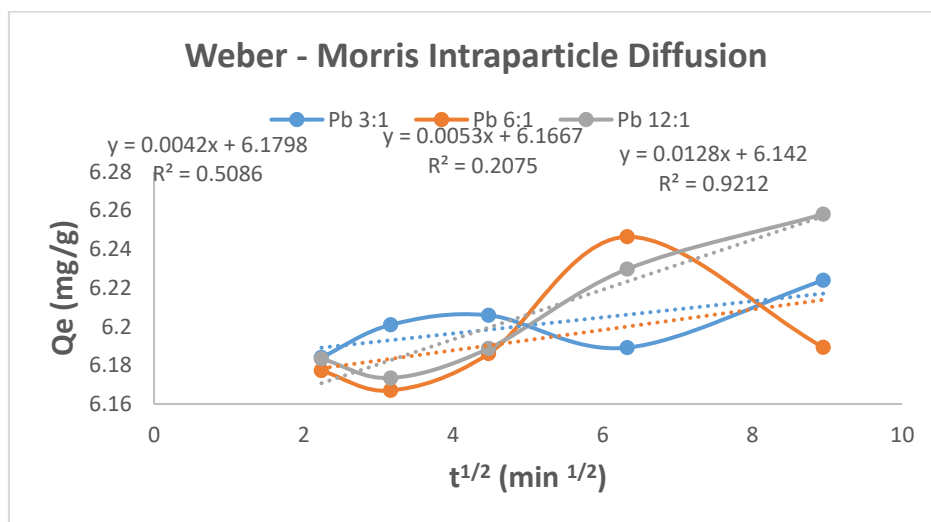


Figure 7: Weber-Morris intraparticle diffusion plot for Pb adsorption on PET waste bottle/sawdust composite

Table 4: Weber-Morris parameters for Pb(II) adsorption on PET waste bottle/sawdust composite (12:1)

Metal ion	Sample	Parameter	Value
Pb	12:1	K_{ID} ($\text{mg/gmin}^{1/2}$)	0.013
		C	6.142
		R^2	0.921

3.3 Adsorption Isotherms Determination

Langmuir and Freundlich isotherms were used to analyze the results as shown in figures 8 to 19 and the parameters are as shown in tables 5 and 6. From the R^2 values of the graphs, experimental outcome better fits the Langmuir model for all except Pb (12:1 in figure 16), more than Freundlich model. The Langmuir isotherm describes a saturated monolayer (chemisorption) adsorption of an adsorbate on a homogeneous leveled plane of an adsorbent; in addition individual adsorptive location can just be occupied once in a one-on-one manner [34], [37],[38], [29]. The linear form of the Langmuir equation is as in equation 4

$$C_e/Q_e = 1/K_L Q_m + C_e/q_m \quad (4)$$

Where, K_L is Langmuir constant for adsorption balance and energy (L/mg) and Q_m is maximum adsorption capacity (mg/g). Adsorption isotherm correlation values from figures 8 to 19 shows generally, the Freundlich to be far less than or poorer than those of the Langmuir. The highest correlation value of the Langmuir plot is 0.995 for Fe in figure 10. Figure 15 gives the highest Langmuir R^2 value for Pb at 0.993. The highest Freundlich R^2 for Fe is in figure 11 at 0.890 and highest for Pb is in figure 19 at 0.726.

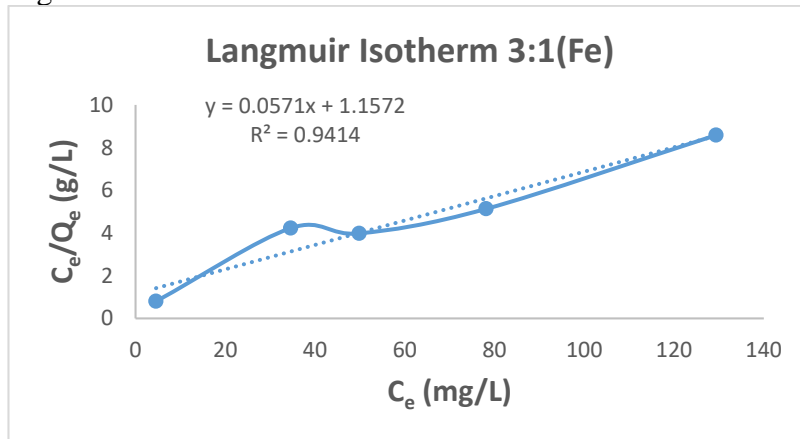


Figure 8: Langmuir isotherm for adsorption of Fe(III) ions on PET waste bottle/sawdust composite (3:1)

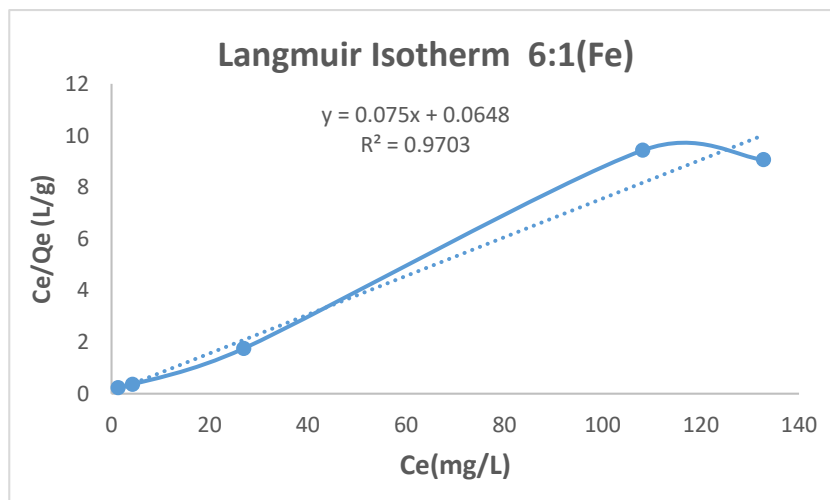


Figure 9: Langmuir isotherm for adsorption of Fe(III) ions on PET waste bottle/sawdust composite (6:1)

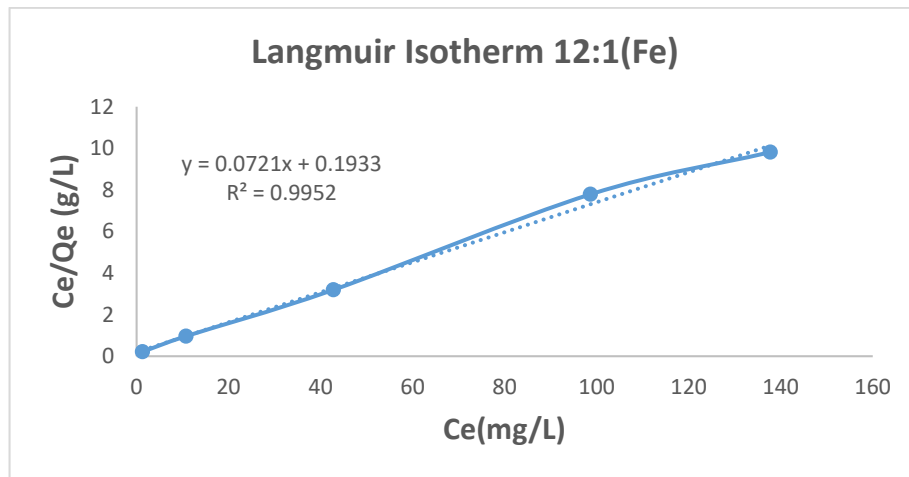


Figure 10: Langmuir isotherm for adsorption of Fe(III) ions on PET waste bottle/sawdust composite (12:1)

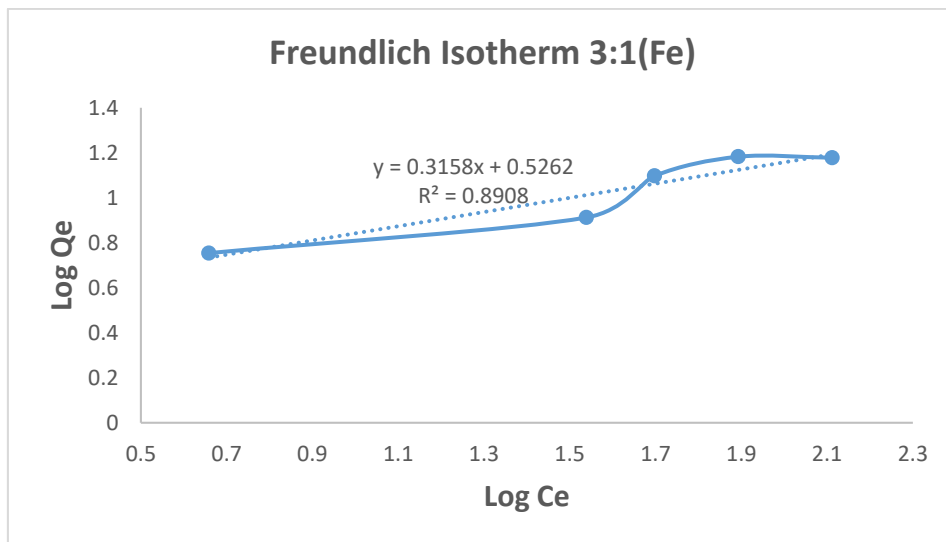


Figure 11: Freundlich isotherm for adsorption of Fe (III) ions on PET waste bottle/sawdust composite (3:1)

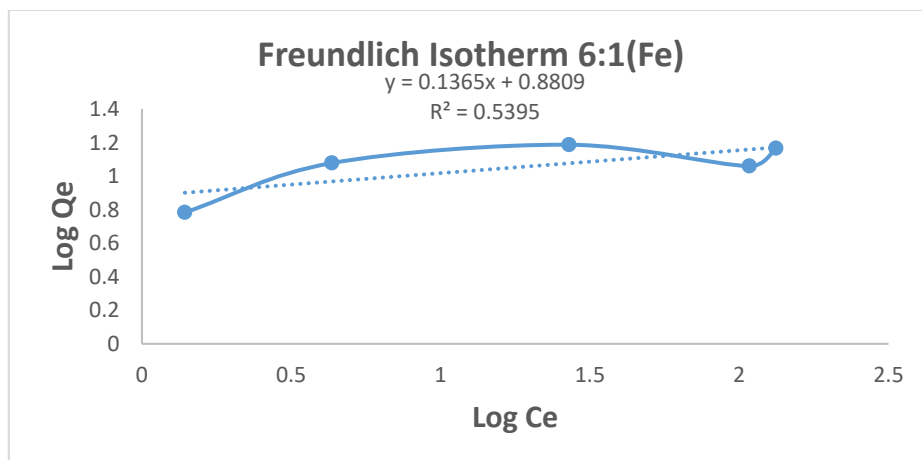


Figure 12: Freundlich isotherm for Fe(III) ions adsorption on PET waste bottle/sawdust composite (6:1)

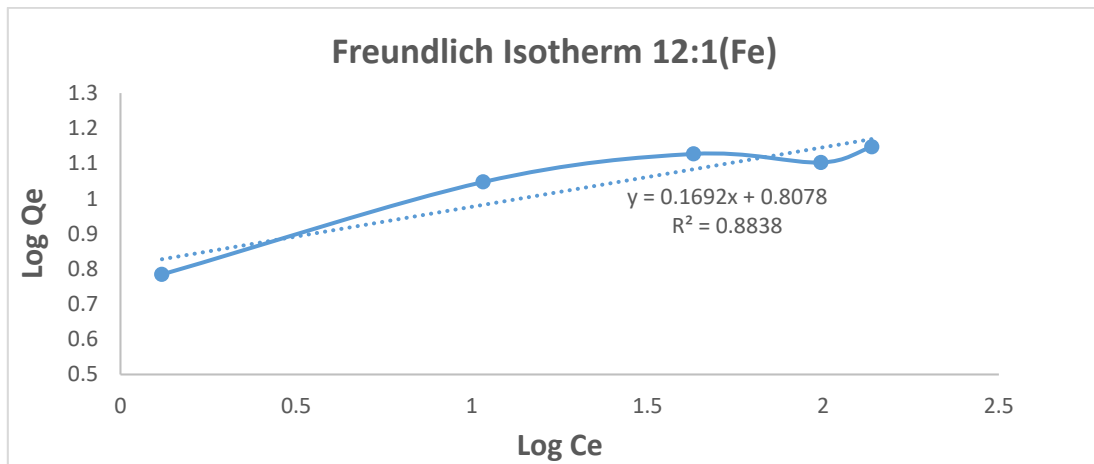


Figure 13: Freundlich isotherm for Fe(III) ions adsorption on PET waste bottle/sawdust composite (12:1)

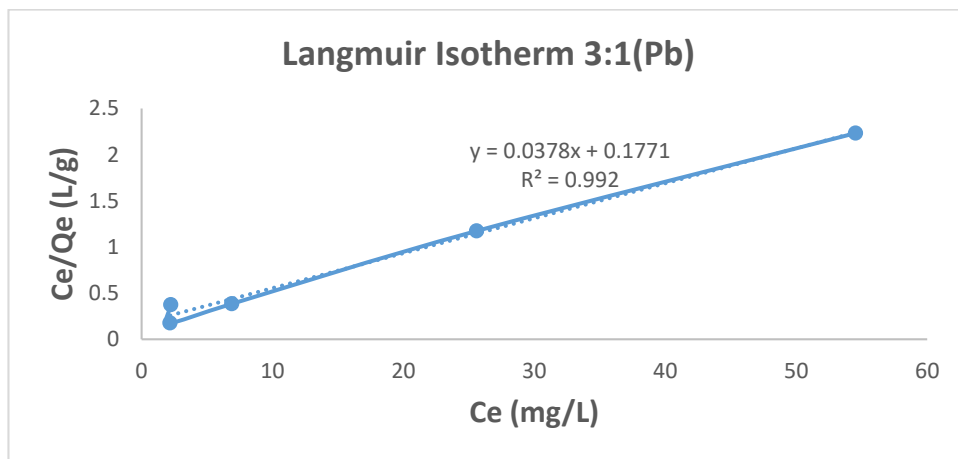


Figure 14: Langmuir isotherm for adsorption of Pb(II) ions on PET waste bottle/sawdust composite (3:1)

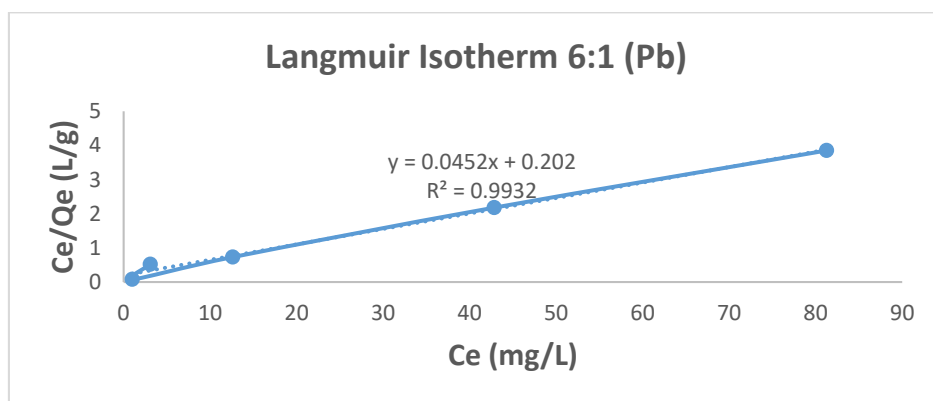


Figure 15: Langmuir isotherm for Pb(II) ions adsorption on PET waste bottle/sawdust composite

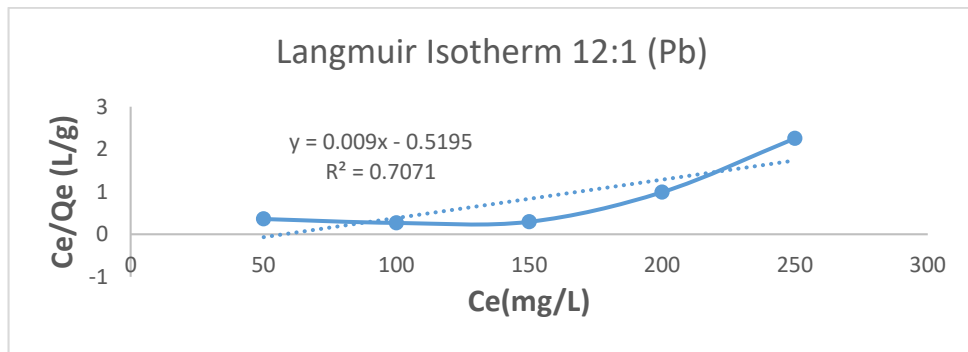


Figure 16: Langmuir isotherm for Pb(II) ions adsorption on PET waste bottle/sawdust composite (12:1)

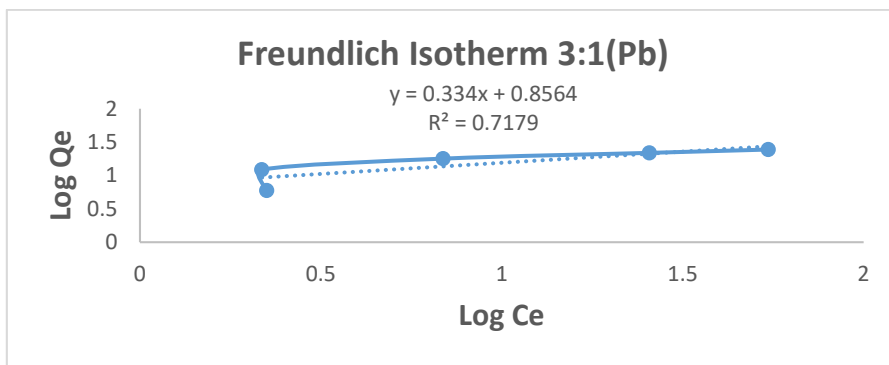


Figure 17: The Freundlich isotherm for Pb(II) ions adsorption on PET waste bottle/sawdust composite (3:1)

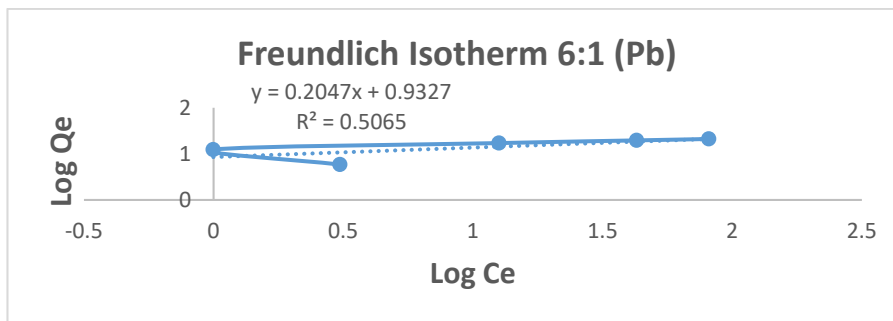


Figure 18: Freundlich Isotherm for adsorption of Pb(II) ions on PET waste bottle/sawdust composite (6:1)

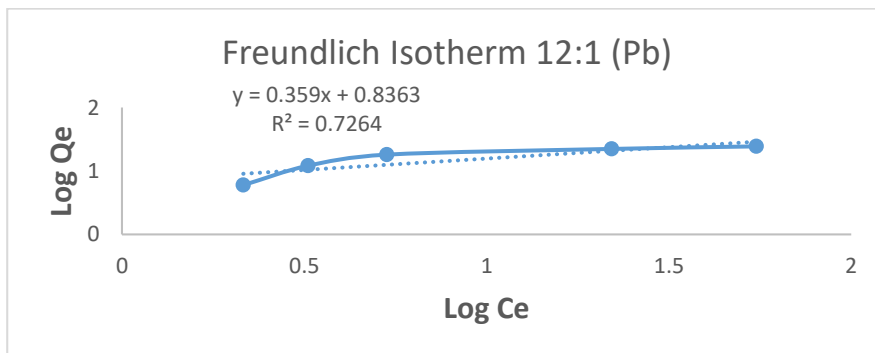


Figure 19: Pb Freundlich isotherm for adsorption of Pb(II) ions on PET waste bottle/sawdust composite

The linear Freundlich equation is given as in equation 5

$$\log Q_e = \log K_f + 1/n \log C_e \quad (5)$$

Where, K_f and n are Freundlich constant associated with adsorption capacity (mg/g) and adsorption intensity individually. Table 4.6 below shows the Freundlich parameters for Pb(II) adsorption 12:1

Table 5: Langmuir isotherm parameters for adsorption of Fe³⁺ (3:1, 6:1 and 12:1) and Pb²⁺ (3:1 and 6:1) on PET waste bottle/sawdust composite

Metal ion	Composite Sample	Parameter	Value
Fe	3:1	Q_m (mg/g)	17.513 (EX = 15.231)
		K_L (L/mg)	0.049
		R^2	0.9414
	6:1	Q_m (mg/g)	13.333 (EX = 14.651)
		K_L (L/mg)	1.157
		R^2	0.9702
	12:1	Q_m (mg/g)	13.870 (EX = 14.035)
		K_L (L/mg)	0.373
		R^2	0.9952
Pb	3:1	Q_m (mg/g)	26.455 (EX = 24.433)
		K_L (L/mg)	0.213
		R^2	0.9920
	6:1	Q_m (mg/g)	22.124 (EX = 21.093)
		K_L (L/mg)	0.224
		R^2	0.9932

Table 6: Freundlich isotherm parameters for Pb(II) adsorption on PET waste bottle/sawdust composite (12:1)

Freundlich isotherm	Sample	Parameters	Values
Pb	12:1	K_f (mg/g)	6.860 (EX = 5.981)
		n	2.786
		R^2	0.726

3.3.1 Initial Ion Concentration Effect

The plots for the effect of initial ion concentration are shown in figures 20 to 25. At 50ppm, percentage adsorption was highest for Fe(III) in the following trend 12:1 > 6:1 > 3:1. At 100ppm, percentage adsorption was highest for Pb in the following trend 6:1 > 12:1 > 3:1. The results showed composites with higher PET waste bottle content (12:1 and 6:1) were better adsorbents for Pb²⁺ and Fe³⁺ as compared to the ratios with low PET waste bottle content (3:1). As shown in figures 1 (Fourier transform infrared spectra) and in table 1 (Fourier transform infrared bands of functional groups in the adsorbents), the amount of OH containing groups decreased (and even disappeared) as the amount of the PET waste bottle increased in the composite. The presence of OH containing group is associated with strong hydrogen bonding which make the adsorbent more compact. This makes the active adsorptive sites in the adsorbent difficult to access which results in decreased adsorption capacity [39]. From the results, the composites of waste plastic bottles and sawdust adsorbed lead more than iron [33], [27]. The electronegativity of Pb is 2.33 while that of Fe is 1.83; the ionic radius of Pb²⁺ is 119 pm while that of Fe³⁺ is 60 pm, hence the greater adsorption of Pb(II) in comparison to Fe(III). The higher adsorption of Pb²⁺ as compared to Fe³⁺ can also be related to it higher initial ion concentration (which is 100 ppm for lead(II) and 50 ppm for iron(III) respectively). This means there are more particles (ions) in the 100 ppm lead (II) than the 50 ppm iron(III). More particles of lead(II) means the collision probability between the metal ions and the

adsorbent's active adsorptive surfaces is higher in lead(II) than iron(III) hence the more adsorption of lead(II) compared to iron (III) [40]. The hydration of metal ions is also important in adsorption process [41]. Lead(II) has an hydrated radius of 4.01Å while iron(III) has an hydrated radius of 4.57Å, hence lead(II) experiences less viscous drag and is highly mobilized and attracted to the adsorption site compared to iron(III).

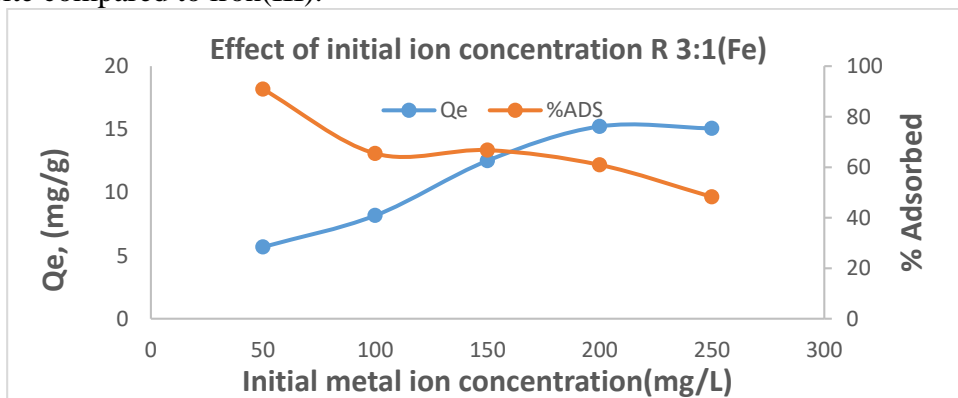


Figure 20: The effect of the initial ion concentration on Fe(III) adsorption on PET waste bottle/sawdust composite (3:1)

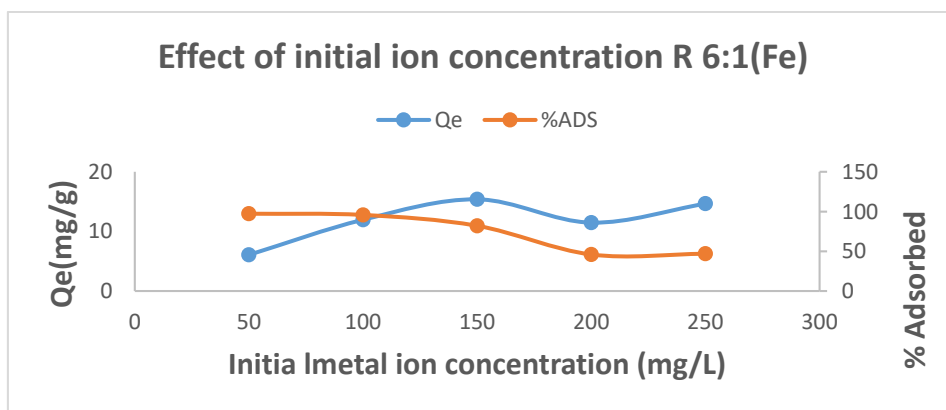


Figure 21: The effect of the initial ion concentration on Fe(III) adsorption on PET waste bottle/sawdust composite (6:1)

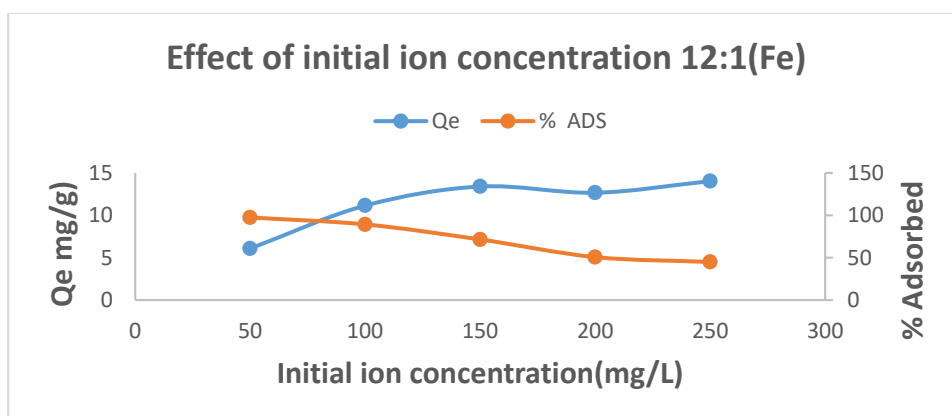


Figure 22: The effect of the initial ion concentration on Fe(III) adsorption on PET/sawdust composite (12:1)

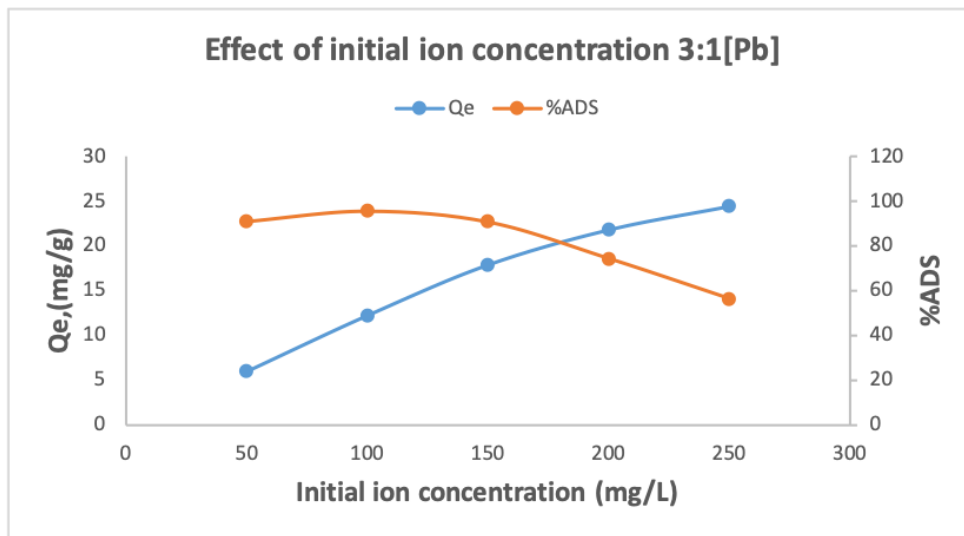


Figure 23: The effect of the initial ion concentration on Pb(II) adsorption on PET waste bottle/sawdust composite (3:1)

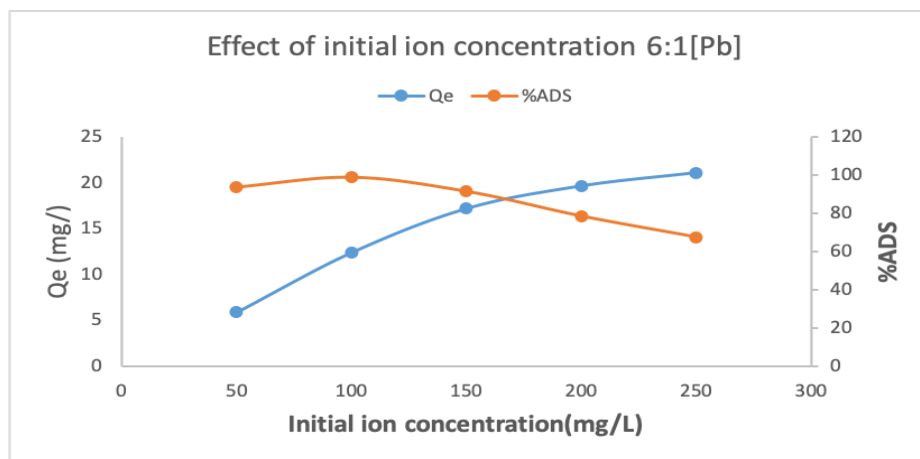


Figure 24: The effect of the initial ion concentration on Pb(II) adsorption on PET waste bottle/sawdust composite (6:1)

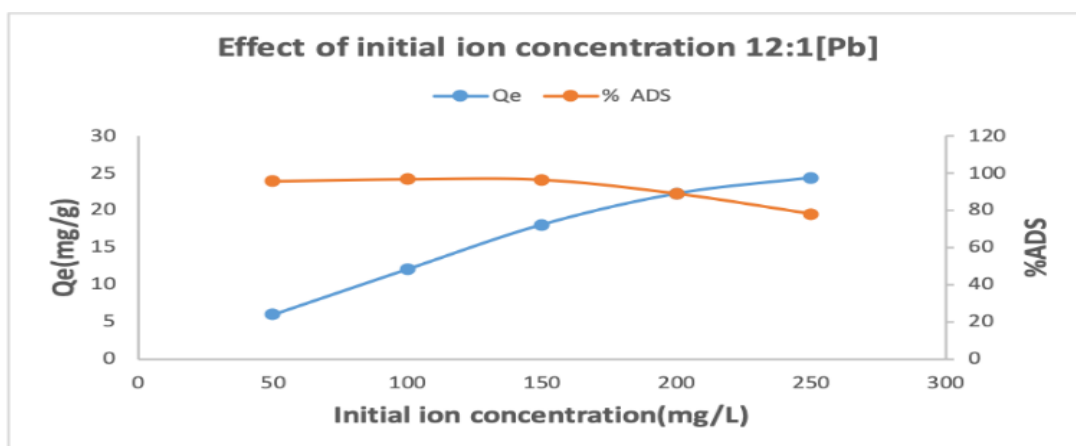


Figure 25: The effect of the initial ion concentration on Pb(II) adsorption on PET waste bottle/sawdust composite (12:1)

3.4 pH Change of Adsorbate Before and After Adsorption

Table 7 shows the pH changes of the adsorbate in pre and post adsorption. The results showed that for both metals, the pH increased after adsorption, meaning the adsorption was caused by an ion exchange process, that H^+ were competitively adsorbed along with the metals [42], [34] [43] [27],[28]. Increase in pH will therefore favour the adsorption of these metals on the adsorbent.

Table 7 Pre and post adsorption pH for Fe and Pb

Kinetic studies	Pre adsorption	Post adsorption
Fe (50ppm)	2.71	3.43
Pb (50ppm)	5.23	5.84
Equilibrium studies		
Fe (250ppm)	2.18	2.31
Pb (50ppm)	3.89	5.59

4. Conclusion

PET waste bottle/sawdust composite was successfully prepared, in the matrix-filler ratios of 3:1, 6:1 and 12:1. The composite proved to be a good adsorbent for the metals applied. The Fourier transform infrared (FTIR) spectroscopy of all the adsorbents showed the existence of the functional groups (C-OH and C-O) that influence heavy metal adsorption. The adsorption kinetics of PET waste bottle/sawdust composite is largely pseudo second order and the adsorption capacity is high as shown by the percentage adsorption which is more than 90% for both lead(II) and iron(III) at the studied concentrations. The adsorption was also pH-dependent and ion exchange in mechanism with a pseudo second order controlling kinetics. The adsorption was also favoured by decreasing filler content, implying that, the chemical groups in the matrix may have had more interaction with the metal ions that were removed from solution. The use of otherwise problematic waste materials (like used plastic bottles and sawdust) for the purpose of adsorption of lead(II) and iron(III) is promising and further study needs to be carried out.

Acknowledgement

The authors are grateful to the Niger Delta University for the work space and power supply.

Disclosure Statement

The authors have no conflict of interest.

References

- [1] Rashmi, V and Pratima, D. (2013). Heavy metal pollution-A case study. *Recent Research in Science and Technology*. 5 (5), 98-99.
- [2] Gunatilake, S. K. (2015). Methods of removing heavy metals from industrial wastewater. *Journal of Multidisciplinary Engineering Science Studies (JMESS)*, 1, (1), 12-18.
- [3] Ghadah, M. A. and Foziah F. A. (2018). Study on adsorption of Cu and Ba from aqueous solutions using nanoparticles of *origanum* (OR) and *lavandula* (LV). *Hindawi*, (11), 1-8
- [4] AL-Ajaj, I. A. and AL-Obaidi, M. F. (2015). Effect of sawdust wood on some mechanical properties of recycled polyethylene terephthalate (RPET). *International Journal of Current Engineering and Technology*, 1, 2347-5161.
- [5] WHO. (2019). "Lead poisoning and Health." Retrieved January 2020 from <https://www.who.int>
- [6] Gernard, N. and Ruth, N. (2013). Blood lead concentrations in sub-Saharan African children below 6 years: systematic review. *Tropical medicine & international health*, 18, (10): 1283-1291.

- [7] Wright, N. J., Thacher, T. D., Fischer, P. R. and Pettifor, J. M. (2014). Causes of lead toxicity in a Nigerian city. Retrieved January 2020 from [www. archdischild. com](http://www.archdischild.com)
- [8] Douye, P. and Donbebe, S. (2017). Health risk of lead poisoning in four edible snail samples obtained from Bayelsa state Nigeria. Joint event on 3rd international conference and expo on drug discovery & designing and 9th annual pharmaceutical chemical analysis congress, Vienna Austria.
- [9] Ezomoh, O. O., Azikiwe, S. Sunday, B. E. and Okemmadu, A. C. (2019). Determination of heavy metal, cadmium, iron, lead, mercury, tin, nickel and vanadium in four different water samples in bayelsa metropolis. *Journal of research in environmental and earth science*. 5 (1): 16-19
- [10] Timi, T, Young, E and Ayobami, A. (2019). Assessment of heavy metals contamination of water and cupscale grass (*sacciolepis aficana*) along the epie creek in Bayelsa Nigeria. *Journal of plant and animal ecology*, 1, (4)
- [11] Tariwari, C. N. A., Elijah, I. O. and Cosboy, E. M. (2015). The portability of groundwater in Bayelsa state, central niger delta Nigeria: a review. *Journal of environmental treatment techniques*, 3(2): 127-135
- [12] WHO. (2003). Iron in Drinking-water. WHO Guidelines for Drinking-water Quality. WHO/SDE/WSH/03. 04/08
- [13] Ujile, A. A. and Joel, O. F. (2013). Adsorption process of Iron(III) from Borehole water on activated carbon from Nigerian Bamboo. *ResearchGate*, 5 (06), 1321-1325.
- [14] Hannah, R. and Max, R., (2018). "Our world in data, plastic pollution." Retrieved January 2020 from <https://ourworldindata.org>
- [15] Samanda, D. (2019). "These countries produce the most plastic waste." Retrieved January 2020 from <https://www.thestreet.com>
- [16] Teodora, D., Lucian, F. and Ferenc G. (2016). Environmental impact of sawdust briquettes use – experimental approach. *Energy procedia*. 85, 178-183.
- [17] Ezeja, G. U., Umahi-ottah, G. and Ifeanyi, E. (2021). Occupational exposure to sawdust and blood pressure status of timber workers in south east Nigeria. *Asian Journal of Cardiology research*. 4 (4), 33-40.
- [18] Okedere, O. B., Fakinle, B. S., Sonibare, J. A., Elehinafe, F. B. and Adesina, O. A. (2017). Particulate matter pollution from open burning of sawdust in southwestern Nigeria. *Cogent Environmental Science*, 3, (1), 1-11
- [19] Francis, O. A., Robert, B. I. and Efe, C. O. (2006). The impact of sawmill wood wastes on the water quality and fish communities of Benin River, Niger Delta, Nigeria. *World Journal of Zoology*, 1 (2): 94-102.
- [20] Jacob, M. O., Habeeb, O. Z. and Isa, O. E., (2016). Sustainable wood waste management in Nigeria. *Environmental & socio-economic studies*, 4, (3), 1-9.
- [21] Soumen, P. (2017). Removal of Cu (II) heavy metal from aqueous solution using natural adsorbent – sawdust. *International journal of advance research in science and engineering*, 6, (11), 1630-1640.
- [22] Ostovar, F., Ansari, R. and Moafi, H. F. (2017). Preparation and application of silver oxide/sawdust nano composite for chromium (VI) ion removal from aqueous solutions using column system. *Global NEST journal*. 19 (3), 412-422.
- [23] Gad, H. M. H., Omar, H. A., Khalil, M. H. and Hassan, M. R. (2013). Factors affecting sorption of Pb(II) from aqueous solutions using sawdust based activated carbon. *Journal of American science*, 9(10): 95-106.
- [24] Juu-En, C., Yi-Kuo, C., Min-Her, I., Ying-Liang, C. and Jing-Hong, H. (2013). Heavy metal removal by ambient-temperature argon plasma modified polyethylene terephthalate (PET) fibers with surface acrylic acid grafting. *International journal of the physical sciences*, 8, (6), 244-253.
- [25] Zdenka, K., Stefan, D. and Magdalena, B. (2019). Removal of copper, zinc and iron from water solutions by spruce sawdust adsorption. *Ekonomia I srodowisk*. 3 (70), 64-74.
- [26] Tanjun, M. B. K., Alhaji, N., Ayeshamariam, A., Vidhya, V. and Jayachandran, M. (2016). Removal of Ni(II) ions on to polymer loaded sawdust (PLSD) – Batch adsorption studies. *Fluid mechanics: open access journal* 3, (2).
- [27] Adouby, K., Koffi, A. L. C., Eboua, W. N. and Yao, B. (2007). Removal of heavy metal ions (Pb²⁺, Cu²⁺) in aqueous solutions by pterygota macrocarpa sawdust. *Journal of applied sciences*, 7, (14), 1864-1872.
- [28] Marina, S., Mile, K. and Biljana, S. (2007). The adsorption of Cd(II) ions from water by unmodified and modified wood sawdust. PSU-UNS. International conference on engineering and environment. ICEE2007010-23 - ICEE2007010-26. Prince of songkia university, faculty of engineering, Thailand.
- [29] Bulut, Y. and Tez, Z. (2006), Removal of heavy metals from aqueous solution by sawdust adsorption. *Journal of environmental sciences*, 19, (2), 160-166.
- [30] Marina, S. and Mile, K. (2003). Optimization of usage of wood sawdust as adsorbent of heavy metal ions from water. ISIRR section III. Hunedoara, Romania.
- [31] Raji, C., Manju, G. N. and Anirudhan, T. S. (1997). Removal of heavy metal ions from water using sawdust-based activated carbon. *Indian journal of engineering & materials sciences*, 4, 254-260.
- [32] Sadegh, G., Mehdi, Y., Hadis, D. and Seyed, H. M. (2016). Efficiency of date palm sawdust as a low cost and available adsorbent for the removal of heavy metals. *International journal of life science & pharma research*, 1, 82-92.
- [33] Jihyun, L., Hee-Man, k., Lee-Hyung, K. and Seok-Oh, K. (2008). Removal of heavy metals by sawdust adsorption: equilibrium and kinetic studies. *Korean society of environmental engineers. Environ. Eng. Res.*, 13, (2), 79-84.

- [34] Fathy, E. A., Saeyda, A. A. and Fathia, E. H. (2017). Removal of lead and copper ions from polluted aqueous solutions using nano-sawdust particles. *International journal of water resources*, 7 (4).
- [35] Dariush, R. (2013). Pseudo-second order kinetic equations for modeling adsorption systems for removal of lead ions using multi-walled carbon nanotube. *Journal of nano structure in chemistry*
- [36] Augustus, N. E., Nimibofa, A. and Donbebe, W. (2020). Interpretation of adsorption thermodynamics and kinetics. *Journal of physical chemistry*, (10), 166-182.
- [37] Orodu, V. E. and Abasi, C. Y. (2015). Equilibrium and kinetics of adsorption of Ni(II) and Pb(II) ions on cow bone ash. *International journal of science and research (IJSR)*, 6, (5), 782-786.
- [38] Inengite, A. K., Abasi, C. Y. and Johnny, D. B. (2014). Equilibrium studies of methylene blue dye sorption by dried water hyacinth shoot. *Environmental and natural resources research*, 4, (4), 120-129.
- [39] Nazia, R., Nobuhiro, S., Satoru, Y., Masaaki, S., Hirotaka, O., and Kazuhiro, H. (2013). Selective Cu(II) adsorption from aqueous solutions including Cu(II), Co(II) and Ni(II) by modified acrylic acid grafted PET film. Retrieved August 2020 from <https://www.hindawi.com>
- [40] Mohammad, N., Snahasish, B., Sirajur, R., Tasrina, R. C., Andrew, J. P. and Scott, D. Y. (2020). Modification and application of albizzia lebbeck sawdust for the sorption of lead(II) and copper (II) from aqueous solutions. *Oriental journal of chemistry*, 36, (4).
- [41] Ashok, V. B., Tushar, A. K., Arun, G. D. and Jyoti, A. A. (2015). Removal of heavy metals Cd²⁺, Pb²⁺ and Ni²⁺ from aqueous solution using synthesized azide cancrinite, Na₈[AlSiO₄]₆(N₃)₂·4(H₂O)₄·6. *Journal of chemical & engineering data*. A – H.
- [42] Demcak, S., Balintova, M. and Demcakova, M. (2017). Study of heavy metals removal from model solutions by wooden materials. Paper presented in the 1st international conference on advances in environmental engineering 1-5. *Earth and environmental science*. IOP publishing.
- [43] Velizar, S., Dragana, B., Milan, G and Bogdanovic, G. (2009). Heavy metal ions adsorption from mine waters by sawdust. *Association of the chemical engineers (AChE) – chemical industry & chemical engineering quarterly*. 15 (4), 237-249.