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REMOVAL OF PB(II) AND ZN(II) FROM AQUEOUS MEDIA BY MESOPOROUS ADSORBENTS PREPARED FROM *TITHONIA DIVERSIFOLIA* STALK AND *THEOBROMA CACAO* POD

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Abstract: Cost-effective mesoporous adsorbents prepared from cocoa (*Theobroma cacao*) pod and sunflower (*Tithonia diversifolia*) stalk were evaluated for the sorption of Pb(II) and Fe(II) from wastewater. The different biomasses were acid activated by wet impregnation with phosphoric acid and carbonised at 500°C. Adsorbents studied were activated carbon from *Theobroma cacao* (TC-AC) and *Theobroma-Tithonia* blend (TT-AC) in a mass ratio of 75-25 wt%. The specific surface areas were 237.445 and 392.508 m^2/g for TC-AC and TT-AC respectively. Parametric studies revealed that adsorbate uptake reduced with increased initial concentration and increased with increasing dosage and contact time. The monolayer adsorption capacities for Pb(II) sorption onto TC-AC and TT-AC was 47.17 and 46.95 mg/g and for Fe(II) sorption onto TC-AC and TT-AC was 37.45 and 37.04 mg/g respectively. Langmuir isotherm and pseudo-second order kinetic models were the best fits for the adsorption process. From the study, it has been observed that high-quality mesoporous adsorbent can be obtained from the carbonisation of cocoa pod and sunflower stalk for water treatment applications.
Keywords: Cocoa; Tithonia diversifolia; Heavy metals; Environment; Pollution

1. INTRODUCTION

The remediation of industrial wastewater remains an area of concern among engineers and researchers because the water must be returned to receiving waters or to the land (Eletta and Ighalo 2019; Salam *et al.* 2011). They are adulterant and their toxicity is a major problem from several perspectives (Eletta *et al.* 2019a; Jaishankar *et al.* 2014). One of the major pollutants prevalent in these wastewaters is heavy metals which are non-biodegradable (Kano 2015; Pinho and Ladeiro 2012). Industrial wastewater could contain heavy metals like arsenic, cadmium, chromium, iron, copper, lead, nickel, and zinc depending on the source and these could harm human health (Adeniyi and Ighalo 2019; Jaishankar *et al.* 2014).

Lead is a highly toxic metal whose widespread use and disposal have caused extensive environmental contamination and health problems. Various sources of lead in the environment are metal plating, fertilizers and pesticides, battery waste from industries, smelting of ores, additives in gasoline and pigments, exhaust from automobiles (Jaishankar *et al.* 2014). Iron is the second most abundant metal on the earth's crust (Gutteridge 1992). Free iron can lead to lipid peroxidation, which results in severe damage to mitochondria and other cellular organelles (Jaishankar *et al.* 2014). Carcinogenesis, kidney damage, neurological disorder, blindness, damage to aquatic resources, and nervous disorder among others are some of the problems caused by these some of the heavy metal pollutants (Azimi *et al.* 2017; Balcıoğlu and Ötker 2003; Hegazi 2013).

Adsorption is a widely used technique for wastewater treatment because it is a clean easy to control, more efficient and cost-effective technology (Cherdchoo *et al.* 2019). Agricultural or lignocellulosic-based adsorbents have been gaining research interest due to their characteristics which includes; they are renewable, biodegradable, environmentally friendly, low cost and abundantly available (Ling Pua *et al.* 2013). In recent times, activated carbons with very high surface area, high porosity, and high adsorptive capacity have been obtained by chemical activation method has and these have been extensively used for the removal of pollutants. Activating agents act as dehydrating agents and oxidants (Üner *et al.* 2015; Yahya *et al.* 2015). Many studies have been carried out to utilise agricultural by-products as adsorbent material in wastewater treatment; peanut husk (Salam *et al.* 2011), plant bark (Ighalo and Adeniyi 2020a), rice husk (Hegazi 2013), *Amaranthus hybridus* stalk (Egila *et al.* 2011), groundnut shell (Isah and Yusuf 2012), orange peel (Geremew 2017), almond shell (Largitte *et al.* 2016), coconut shell (Achaw 2012; Babarinde and Onyiaocha 2016), dates stone (Alhamed 2006), sugarcane bagasse (Geremew 2017) and a host of others (Adeniyi and Ighalo 2019; Dai *et al.* 2018; Kyzas and Matis 2015; Lakherwal 2014).

Biomass such as cocoa pod is an excellent precursor for adsorbent development for water treatment applications (Eletta *et al.* 2020). Both biomasses are readily available in Nigeria with no competitive use and this study attempts to valorize them as solutions to environmental problems. This study aims to study the removal Pb(II) and Fe(II) from aqueous solutions by treating with a cost-effective mesoporous adsorbent

prepared from *Theobroma cacao* pod and blended with *Tithonia diversifolia* stalk. Two adsorbents were produced; *Theobroma cacao* activated carbon (TC-AC) and *Theobroma cacao-Tithonia diversifolia* mixed activated carbon blend (TT-AC). *Tithonia diversifolia* adsorbent alone has been reported elsewhere (Eletta *et al.* 2019b).

2. METHODOLOGY

— Preparation of Adsorbent

Theobroma cacao husk was sourced from Owo, Ondo State in Nigeria. Sunflower stalk (*Tithonia diversifolia*) was sourced from Ilorin, Kwara State, Nigeria. Both *Theobroma cacao* and *Tithonia diversifolia* stalks were rinsed several times with tap water and finally with distilled water to remove dirt and dust; thereafter, it was sundried for 24 h to reduce moisture content before oven drying. Both adsorbents were oven-dried at 105°C until no weight loss was observed (Bello and Ahmad 2011). The dried biomass was pulverized with a ball milling machine and sieved to 100 µm size (Odubiyi *et al.* 2012). H_3PO_4 (98 vol.%) was used for chemical activation with impregnation ratio of 1:2. The mixture was stirred continuously using magnetic hot plate stirrer at ambient temperature for 1 h and left to age for 24 h. The mixture was filtered and dried in an oven at 110°C for 24 h. The sample was transferred to a muffle furnace and heated at 500°C for 1 h to produce activated carbon. Finally, the powdered sample was washed with 0.5 M of KOH and distilled water to remove residual acids until the washing solution become neutral (Eletta *et al.* 2019b). The samples were then dried overnight at 100°C and cool to room temperature to obtain H_3PO_4 activated carbon (Krishna 2014). The samples were ground with mortar and pestle and sieved to obtain a maximum particle size of 100 µm (Krishna 2014). Two adsorbents were produced; *Theobroma cacao* activated carbon (TC-AC) and *Theobroma cacao-Tithonia diversifolia* mixed activated carbon blend (TT-AC). The blend was in a *Theobroma-Tithonia* mass ratio of 75-25 wt%. This blend gave the optimal result at 2 h from the preliminary experiment when compared with other blends. The yield of the activated carbon was calculated using the Eqn. 1.

$$\text{Yield } (\%) = \frac{W_f}{W_i} \times 100 \quad (1)$$

where W_i = weight of raw material measured before carbonisation (g) and W_f = final weight of the dried activated carbon (g). The yield % obtained was 72.86% for *Theobroma cacao* and 66.5% for *Tithonia diversifolia* showed that activation and carbonisation liberate most of the non-carbon elements e.g. hydrogen, oxygen, nitrogen which are in the form of liquid and gases thereby leaving behind a rigid carbon skeleton (Zolue 2013).

— Adsorbent Characterisation

FTIR spectrometer (Model: Cary 630; Agilent Technologies) was used to identify the functional groups responsible for the heavy metals uptake and bonding present on the surface of the adsorbents. The scan range was set to 650-4000 cm^{-1}. BET analysis (Model: NOVA Station A) was employed to determine the surface area, pore size and pore volume of the adsorbent. The surface properties of the sample were determined using Multipoint BET surface area and DR (Dubinin-Radushkevic) method for the pore volume and width (diameter) respectively. The sample was characterized by N_2 adsorption test at 77K. A small amount of dry nitrogen gas was introduced into the sample tube to prevent contamination of the clean surface. The sample tube was then removed, and the sample weighed. The sample tube was fixed to the volumetric apparatus then the sample was evacuated down to 2 Pa pressure. Adsorbate was introduced to give the lowest desired relative pressure then the volume adsorbed was measured. SEM (Model: Phenom ProX, Manufacturer: Phenom-World Eindhoven Netherland) was used for a morphological structure such as the size and shape of the adsorbent. The sample was sprinkled on the sample stub and subsequently taken to a sputter coater (quorum-Q150R Plus E) with 5 nm of gold. The sample stub was placed on a charge reduction sample holder and introduced into the column of the SEM machine. On the SEM machine, it was viewed from a navigation camera before being sent to SEM mode. Different magnifications were stored in a USB stick after adjustment of brightness and contrast.

— Preparation of Stock Solutions

All reagent used in this study were analytical grade (>99.9% purity). The reagents used were Nitric acid (HNO_3), Hydrochloric acid (HCl), Phosphoric acid (H_3PO_4) Iron sulphate ($FeSO_4.7H_2O$), Lead Nitrate ($Pb(NO_3)_2$) and distilled water (H_2O). For the preparation of the stock solution of Fe(II), 4.6790 g of $FeSO_4.7H_2O$ was dissolved in 1 litre of distilled water to give a 1000 mg/l of Fe(II). For the stock solution of Pb(II), 1.5985 g of $Pb(NO_3)_2$ was dissolved in 1 litre of distilled water to give a 1000 mg/l solution.

— Batch Adsorption Experiments

The experiments were performed using 50 ml of synthesised wastewater in 250 ml conical flasks at 30°C, 150 rpm and natural solution pH (6.4) for a contact time of 180 min. The parameters studied were adsorbent dosage (1 – 6 g/l), initial Pb(II) and Fe(II) concentration (25 – 150 mg/l), time (30 – 180 minutes). The amount of pollutant adsorbed was determined by the expression in Eqn. 2

$$q = \frac{V(c_i - c_e)}{m} \quad (2)$$

where q is the amount of heavy metal adsorbed (mg/g), C_i is the initial concentration of heavy metal (mg/l) and c_e is the concentration of heavy metal (mg/l) at equilibrium. V is the volume of metal solution (l) and m is the mass of the adsorbent used (mg). The removal efficiency was determined by the expression in Eqn. 3 (Obike *et al.* 2018).

$$q_{\%} = \frac{c_i - c_e}{c_i} \times 100 \quad (3)$$

The equilibrium isotherm experiments were carried out at 30°C, initial metal concentration (C_i) was 25 – 150 mg/l and contact time of 120 minutes were used for TC-AC, 60 mins for TT-AC. The difference in choice of contact time was based on information from preliminary experiments conducted. The adsorbent dosage was 4g/l for TC-AC and TT-AC. For the kinetic studies, the temperature was set at 30°C, initial metal concentration was at 100 mg/l and dosage at 4g/l for TC-AC and TT-AC.

3. RESULTS AND DISCUSSION

— Adsorbent Characterization

≡ FTIR

The spectra for *Theobroma cacao* activated carbon has a strong absorbance band. At 2985.6 cm^{-1}, there is a strong absorbance band showing the existence of C-H which indicates alkane and alkyl (Figure 1) (Kumar and Jena 2016). The bands in the region between 3652.8-3857.8 cm^{-1} show N-H stretch indicating the presence of an amine. The bands located at 2113.4 cm^{-1} indicate C≡C stretch in alkyne group. The band at 1699.7 cm^{-1} indicates carboxylic acid and aldehydes which shows strong C=O groups (Tao *et al.* 2015; Üner *et al.* 2015). The band located at 1524.5 cm^{-1} corresponds to amides showing medium-strong N-H bend. Figure 2 shows the spectra for the mixed adsorbent (TT-AC); the has absorbance band at 3131 cm^{-1} shows the existences of C-H groups indicating alkanes (Albadarin *et al.* 2014) and the bands 2985.6 cm^{-1} shows strong C-H stretch indicating the presence of alkanes (Cherdchoo *et al.* 2019). The bands located at 2754.5 cm^{-1} suggest strong broad O-H stretch in a carboxylic acid group (Tao *et al.* 2015). The band at 2344.5 cm^{-1} indicates an amino group. The band located at 1699.7 cm^{-1} corresponds to aldehyde showing strong C=O bend. The band at 1054.8 cm^{-1} depicts medium-strong C-O stretch. The band region between 900 and 1300 cm^{-1} depicts the characteristic of phosphorous and phosphorous carbonaceous compounds present in the phosphoric acid activated carbon as suggested by Kumar and Jena (2016).

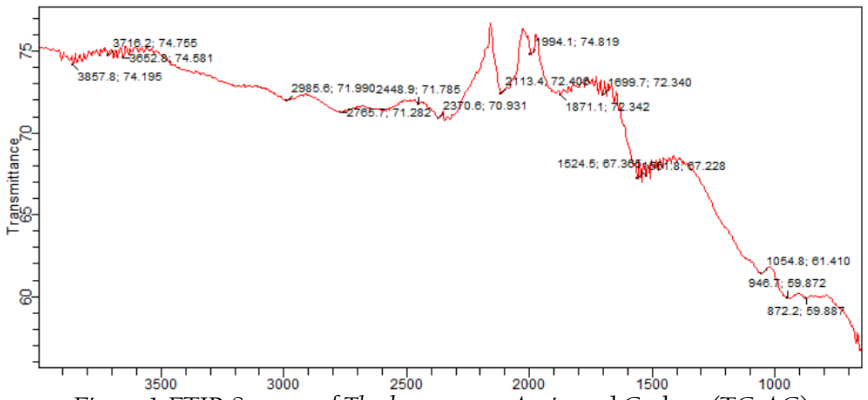


Figure 1. FTIR Spectra of *Theobroma cacao* Activated Carbon (TC-AC)

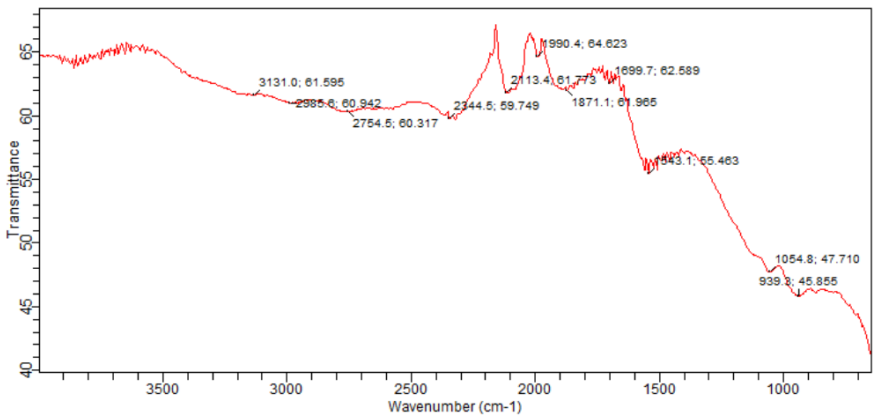


Figure 2. FTIR Spectra of Mixed Activated carbon (TT-AC)

≡ BET

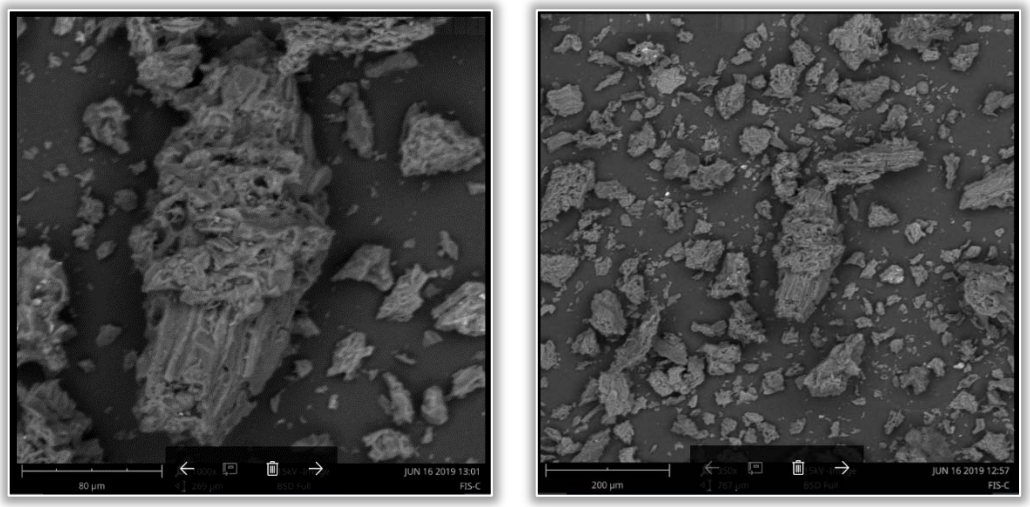
The specific surface area of TC-AC and the mixture TT-AC was 237.445 m^2/g and 392.508 m^2/g respectively; this was determined using the Brunauer-Emmett-Teller (BET) standard method. These values were found to be higher when compared with 95.51 m^2/g for peanut shell (Al-Othman et al. 2012), 13.86 m^2/g for mixed waste tea, and 13.01 m^2/g for coffee ground (Cherdchoo et al. 2019). Eletta et al. (2019b) observed a specific surface area of 325.375 m^2/g for sunflower stalk alone, which is lower than for the mixed adsorbent. This is suggestive of the synergistic effect of the two biomass (at the carbonisation stage) to improve the specific surface area of the final product. The total pore volume obtained was 0.095 m^3/g and 0.1502 m^3/g. for TC-AC and TT-AC respectively. The pore size width obtained was 6.006 nm and 6.214 nm suggesting a mesoporous structure (Cherdchoo et al. 2019).

≡ SEM-EDS

Morphological characterisation of the adsorbents was conducted by SEM-EDS and shown in Figures 3(a-b) and Table 1. *Theobroma cacao* activated carbon contained 63.25 wt% carbon and trace levels of phosphorous, zinc, potassium, selenium, nickel, Iron manganese and others; this is similar to the result obtained by Tsai *et al.*,(2018). Figure 3 shows a fairly smooth underlying surface composed of overlying agglutinative flakes of *Theobroma cacao*.

Table 1. Elemental composition of TC-AC

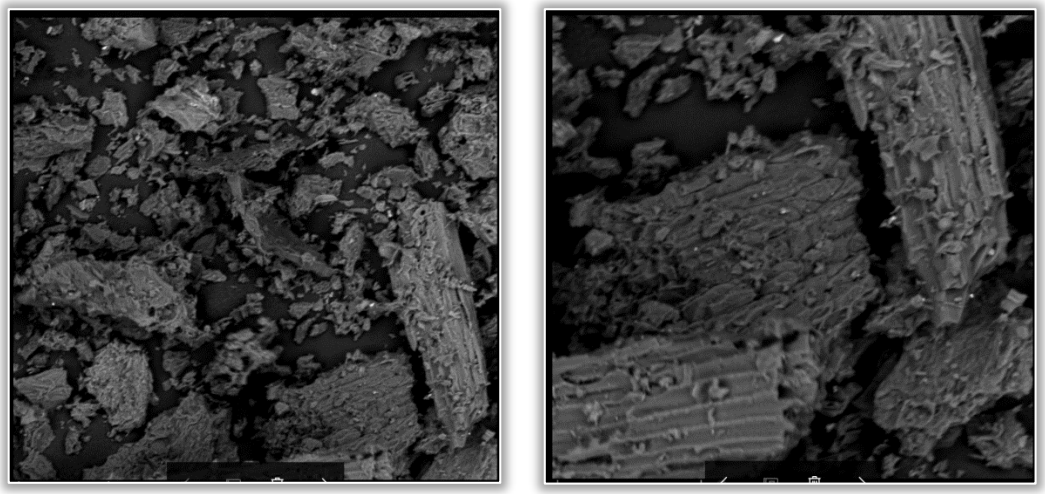
Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
6	C	Carbon	70.50	63.25
8	O	Oxygen	15.23	18.20
5	B	Boron	7.00	5.65
7	N	Nitrogen	4.78	5.00
15	P	Phosphorus	0.78	1.81
30	Zn	Zinc	0.25	1.23
19	K	Potassium	0.29	0.84
34	Se	Selenium	0.13	0.77
28	Ni	Nickel	0.16	0.69
26	Fe	Fe^{2+}	0.16	0.67
25	Mn	Manganese	0.14	0.56
33	As	Arsenic	0.09	0.50
9	F	Fluorine	0.30	0.42
13	Al	Aluminium	0.18	0.36
16	S	Sulphur	0.02	0.05



(a) (b)

Figure 3(a-b). SEM Image of the TC-AC

Morphological characterisation of the mixed adsorbents was conducted by SEM-EDS and shown in Figures 4(a-b). EDS results were summarised in Table 2. The cocoa pod (*Theobroma cacao*) and *Tithonia diversifolia* (sunflower) mixed activated carbon was very rich in carbon 61.89 wt% carbon. SEM image indicates rough surface and composes of the agglutinative flakes of both *Theobroma cacao* and *Tithonia diversifolia*, few white substances, small and big pebbles which suggest that the adsorbent has a heterogeneous surface which makes it very suitable for use as an adsorbent (Ighalo and Adeniyi 2020b).



(a) (b)

Figure 4(a-b). SEM Image of the Mixed Adsorbent (TT-AC)

Table 2. Elemental Composition of the Elements Present in TT-AC

Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
6	C	Carbon	70.18	61.89
8	O	Oxygen	21.99	25.83
15	P	Phosphorus	3.22	7.32
7	N	Nitrogen	4.07	4.19
9	F	Fluorine	0.51	0.71
14	Si	Silicon	0.03	0.06

— Parametric Studies

≡ Effect of Initial Concentration

The effect of different initial concentrations on the removal of Fe(II) and Pb(II) was investigated and shown in Figures 5 and 6.

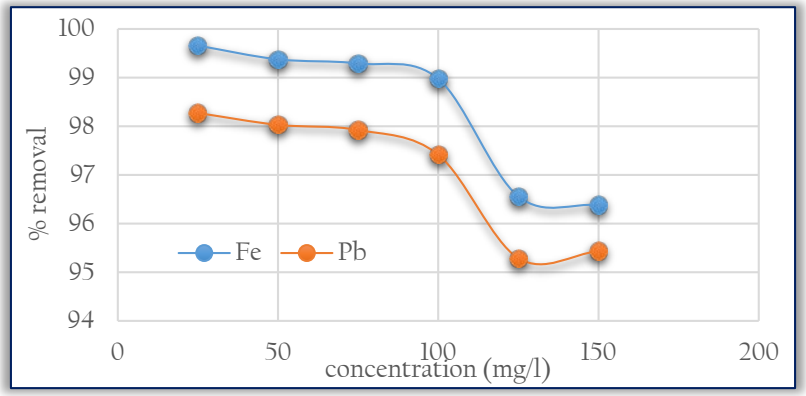


Figure 5. Effect of initial concentration on Pb(II) and Fe(II) Removal with TC-AC

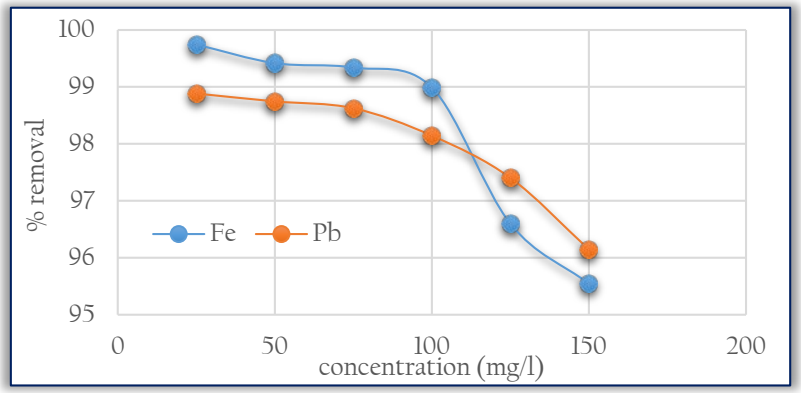


Figure 6. Effect of Concentration on Pb(II) and Fe(II) Removal with TT-AC

It was observed that there was a decrease of adsorption on Pb(II) and Fe(II) with an increase in the initial concentrations of Pb(II) and Fe(II). This is similar to the observation made for *Tithonia diversifolia* adsorbent

alone for Pb(II) and Fe(II) (Eletta *et al.* 2019b). The ratio of surface active sites to the total amount of metal ions was higher in lower metal ion concentrations compared with higher metal ions. A similar pattern of adsorption efficiency was observed in other studies (Tao *et al.* 2015) albeit for activated carbon from sugarcane bagasse. The slow rate of adsorption comes from limited adsorbent capacity at the equilibrium which is in agreement with Cherdchoo *et al.* (2019).

≡ Effect of Adsorbent Dosage

The effect of adsorbent dosage on the removal of Fe(II) and Pb(II) was investigated and shown in Figures 7 and 8. The percentage removal of Fe(II) and Pb(II) increased from 91.65% to 99.19% and 88.21% to 97.1% for Fe(II) and Pb(II) respectively for TC-AC. It also increased from 90.22 % to 99.23% and 91.38 % to 99.64 % for Fe(II) and Pb(II) respectively for TT-AC. This showed that as the adsorbent dose increased more surface area was available and so there were more active sites for binding metal ions. The optimum adsorbent dosage is 0.2 g beyond which there was little or insignificant increase in heavy metals removed with increasing dosage.

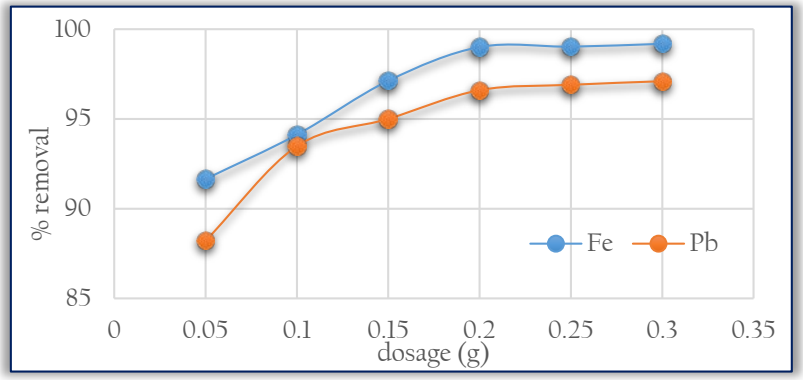


Figure 7. Effect of Adsorbent dosage on Pb(II) and Fe(II) Removal for TC-AC

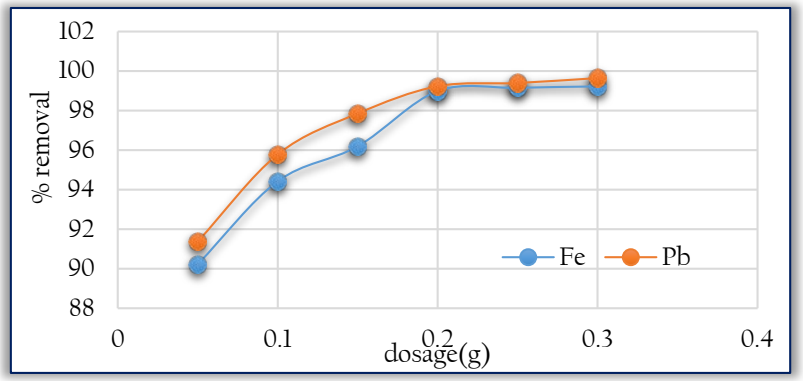


Figure 8. Effect of Adsorbent Dosage on Pb(II) and Fe(II) Removal for TT-AC

≡ Effect of Contact Time

The effect of contact time on the adsorption of Fe(II) and Pb(II) was investigated and shown in Figures 9 and 10. It can be observed that for both adsorbents, the amount of heavy metals adsorbed increased with time. The observations made are similar to those by Malakootian *et al.* (2009) and Eletta *et al.* (2019b). Adsorption rate increases rapidly initially because the adsorption sites are unoccupied on sorbent-sorbate contact but approach equilibrium as the sites become saturated (Odubiyi *et al.* 2012; Tao *et al.* 2015).

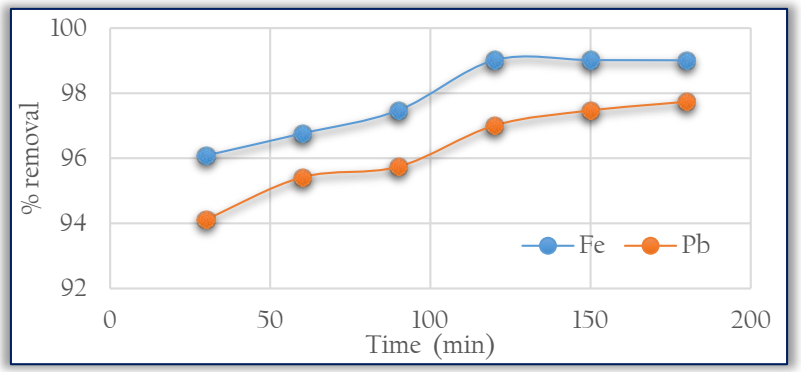


Figure 9. Effect of Time on Pb(II) and Fe(II) Removal on TC-AC

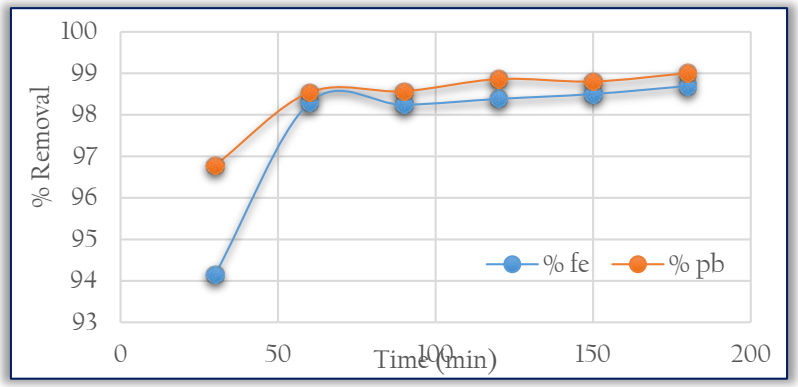


Figure 10. Effect of Time on Pb(II) and Fe(II) Removal on TT-AC

— Adsorption Isotherm

Langmuir, Freundlich and Temkin isotherms were used to study the adsorption of Pb(II) and Fe(II) and summarised in Table 3 and Table 4 respectively. From the coefficient of determination (R^2), it can be observed that the Langmuir isotherm was the best fit for describing the adsorption data suggesting that the adsorption was monolayer. The equilibrium parameter (R_L) was also evaluated. The R_L values of 0.0218 for Fe(II) and 0.0976 for Pb(II) was obtained for TC-AC, TT-AC showed 0.1708 for Fe(II) and 0.0646 for Pb(II) which indicates a favourable adsorption (Albadarin *et al.* 2014; Cherdchoo *et al.* 2019). The maximum adsorption capacity was 47.17 mg/g for Pb(II) and 37.45 mg/g for Fe(II) for TC-AC and 46.95 mg/g for Pb(II) and 37.04 mg/g for Fe(II) for TT-AC. The lower adsorption capacity observed for the mixed adsorbent suggests that that is no advantage obtained (in the domain of the selectivity or affinity to lead) by using the combined adsorbent.

Table 3. Adsorption Isotherm Data for TC-AC

Model	Parameter	Metal ion	
		Pb(II)	Fe(II)
Langmuir	q_{max} (mg/g)	47.17	37.45
	b	0.37	1.7918
	R_L	0.0976	0.0218
	R^2	0.9727	0.9859
Freundlich	K_F (L/mg)	11.907	8.85×10^{-4}
	n	1.6734	0.4251
	1/n	0.5976	2.3523
	R^2	0.9528	0.932
Temkin	α (L/mg)	1.777	2.60
	β (kJ/mol)	2.3807	6.941
	R^2	08893	0.9701

Table 4. Adsorption isotherm data for TT-AC

Model	Parameter	Metal ion	
		Pb(II)	Fe(II)
Langmuir	q_{max} (mg/g)	46.95	37.04
	b	0.5788	0.1942
	R_L	0.0646	0.1708
	R^2	0.9983	0.9911
Freundlich	K_F (L/mg)	15.36	19.92
	n	1.731	2.756
	1/n	0.5777	0.3628
	R^2	0.9538	0.9379
Temkin	α (L/mg)	6.172	36.37
	β (kJ/mol)	10.103	6.32
	R^2	0.9965	0.9756

— Adsorption Kinetics

The experimental data of adsorption of Pb(II) and Fe(II) onto TC-AC and TT-AC at different time intervals were examined with pseudo-first-order and pseudo second-order models, using the plots of Log (q_e- q_t) against t and t/q_t versus t, respectively. All the results obtained are summarised in Table 5 and Table 6. The Pseudo second-order gave a higher correlation coefficient ›0.99, which implies that both the number of available sites for adsorption and the concentration of adsorbate in solution are responsible for the rapidity of the adsorption process. The close range between $q_{e\ exp}$ and $q_{e\ calc}$ for pseudo-second order suggests that the experimental results for Pb(II) and Fe(II) was consistent with the pseudo second-order kinetic model.

Table 5. Adsorption kinetic data for TC-AC

Model	Parameters	Metal ion	
		Pb(II)	Fe(II)
	q_m exp (mg/g)	24.43	24.75
Pseudo first order	k_1 (min^{-1})	0.02	0.0661
	q_e calc (mg/g)	2.132	16.5
	R^2	0.9218	0.8116
Pseudo second order	k_2 (min^{-1})	0.0205	0.024
	q_e calc (mg/g)	24.69	25.0
	R^2	0.999	0.999

Table 6. Adsorption kinetic data for TT-AC

Model	Parameters	Metal ion	
		Pb(II)	Fe(II)
	$q_{m,\ exp}$ (mg/g)	24.75	24.67
Pseudo first order	k_1 (min^{-1})	0.0322	0.0219
	$q_{e,\ calc}$ (mg/g)	1.33	0.99
	R^2	0.9428	0.719
Pseudo second order	k_2 (min^{-1})	0.061	0.046
	$q_{e,\ calc}$(mg/g)	24.8	24.75
	R^2	0.9999	1.000

— Comparison with other Adsorbents

The adsorption capacity of the adsorbents obtained in this study is compared with those obtained for other biomass materials for the same pollutants and summarised in Table 7. The adsorption capacities for Fe(II) for both adsorbents used in this study were comparatively better those reported elsewhere. However, for Pb(II), the adsorption capacity was intermediate compared to other activated carbons and biosorbents from other biomass materials. The adsorbents in this study can be surmised to be efficacious for the intended purpose. Much advantage is furthermore gained from the fact that the parent raw materials are waste that does not have any competitive use thereby ensuring it is low cost. The materials are also available all year round. The utilisation of these materials for the preparation of mesoporous adsorbents will fulfil both the goal of waste valorisation and environmental sustainability.

Table 7. Comparison with other adsorbents

Adsorbent	Adsorption capacity (mg/g)		Reference
	Fe(II)	Pb(II)	
Theobroma cacao pod AC	37.45	47.17	Current study
Theobroma cacao-Tithonia mixed AC	37.04	46.95	Current study
Tithonia diversifolia stalk AC	35.84	31.55	Eletta *et al.* (2019b)
Pongamia pinnata bark biosorbent	-	100.0	Mamatha *et al.* (2012)
Ailanthus excelsa bark biosorbent	22.72	-	Waghmare and Chaudhari (2013)
Date palm AC	-	88.61	Soliman *et al.* (2016)
Ficus religiosa leaves biosorbent	-	37.45	Qaiser *et al.* (2009)

4. CONCLUSION

The study has been able to successfully show that high-quality mesoporous adsorbent can be obtained from the carbonisation of *Tithonia diversifolia* stalk and *Theobroma cacao* pod for water treatment applications. The removal of Pb(II) and Fe(II) from aqueous solutions using mixed mesoporous adsorbent prepared from *Tithonia diversifolia* stalk and *Theobroma cacao* pod were examined. Fourier Transform Infra-Red Spectroscopy (FTIR) revealed that the adsorbent possesses numerous functional groups that can assist the sorption of heavy metals. Branueur Emmet and Teller analysis (BET) revealed that the adsorbents are mesoporous and possess large surface areas. The study evaluated the effect of initial heavy metal concentration, adsorbent dosage and contact time were investigated. Adsorbate uptake reduced with increased initial concentration and increased with increasing dosage and contact time. The monolayer adsorption capacities of both adsorbents for Fe(II)and Pb(II) compared favourably with other adsorbents investigated in previous studies. The Langmuir isotherm was best fit to the adsorption process indicating monolayer adsorption. For all adsorbent and all pollutants, pseudo-second order kinetics was the best fit indicating that both the number of available sites for adsorption and the concentration of adsorbate in solution are responsible for the rapidity of the adsorption process.

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