



(RESEARCH ARTICLE)



## Biosorption of Fe (II) and Pb (II) on unmodified *Senna tora*: Isotherm and kinetic modeling

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### Abstract

Contamination of environment by heavy metals has become a major concern worldwide. The role of conventional methods in remediating heavy metals has become ineffective and costly. Therefore, it becomes imperative to explore bioremediation using a cost effective, efficient and environmentally friendly alternative method of removing heavy metals. In this study, the adsorption behaviour of *Senna tora*, a low-cost adsorbents, with respect to Fe(II) and Pb(II) ions, has been studied in order to consider its application to the treatment of wastewater. The physicochemical properties of the unmodified *Senna tora* were predetermined. The batch experimental method was employed: parameters such as pH, contact time, dosage and initial metal concentration were studied. The influence of the pH of the metal ion solutions on the uptake levels of the metal ions by the adsorbent used was carried out between pH 4 and 10. The optimum pH for both Fe (II) and Pb(II) removals by *Senna tora* was 7. An equilibrium contact time of 60 min was required for the adsorption of Pb(II) ions onto *Senna tora*. Percentage sorption of Fe(II) increased from 94 to 99% and that of Pb (II) from 94.4 to 96% as adsorbent dose was increased from 2 to 10 g. The isotherms data provide information on the capacity of the adsorbent or the amount required to remove a unit mass of pollutant under the operating conditions. The equilibrium data of Fe(II) and Pb(II) adsorbed onto *Senna tora* pods were fitted by the Langmuir, Freundlich, and Temkin isotherms. On the basis of correlation coefficients  $R^2$ , it is concluded that the Fe(II) and Pb(II) biosorption is better fitted to the Freundlich model. This suggests that the biosorption of Fe(II) and Pb(II) on the surface of *Senna tora* pods occurs on heterogeneous binding sites with equivalent adsorption energies and multilayer coverage. The results demonstrated that *Senna tora* pod holds potential to remove cationic heavy metal species from industrial wastewater.

**Keywords:** Biosorption; Heavy metals; *Senna tora*; Isotherm; Kinetic

### 1. Introduction

Heavy metals have been identified as very dangerous class of environmental pollutants. Heavy metals are natural elements that have been extracted from the earth and harnessed for industrial raw materials and products [1]. The increased use of metals and chemicals in industries has resulted in the generation of large quantities of effluents containing high levels of toxic heavy metals [2]. Among these heavy metals, copper, cadmium, lead and iron are notable for their wide environmental dispersion from various industrial activities. This in effect increases their tendency to accumulate in selected tissues of the human body and their overall potential to be toxic even at relatively low levels of exposure [3]. Cadmium has been implicated in kidney dysfunction, hepatic damage and hypertension [4]. Toxic levels of lead affect neurobehavioral development, brain function and have been associated with encephalopathy, seizures and mental retardation [5].

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Excess copper accumulates in the liver, brain, skin, pancreas and myocardium and the most toxic form of copper is thought to be Cu (I) [6]. Iron is a toxic heavy metal that is commonly found in industrial effluents. The presence of iron in water results in undesirable colour, odour and taste which makes water unfit for industry use and domestic consumption [7]. The effects of iron exposure on human health include respiratory problems, heart attack, seizures, tissue damage and depression [8].

Following the need to remove Cu (II), Cd (II), Pb (II) and Fe (II) from industrial wastewater effluents to reduce environmental pollution, various conventional methods have been developed over the years. [9] These methods include chemical precipitation, ion exchange, oxidation and reduction, fixation or cementation and solvent extraction [10]. These methods are economically unfavourable or technically complicated and are used only in special cases of wastewater treatment. Recently, attention has been directed towards biosorption as a new technology for removing toxic metals from wastewaters. This is based on the binding capacities of various biological materials.

Biosorption technique is one of the preferred methods for the removal of heavy metals because of its efficiency and low cost [11]. Biomass viability does not affect the metal uptake. Therefore, any active metabolic uptake process is currently considered to be a negligible part of biosorption [12]. Recent studies have shown that heavy metals can be removed using biosorption materials, like agricultural by-products, orange waste, tamarind peel, groundnut shell, maize cob and husk [13], modified corn stalks, boiler fly ash sawdust, *Zea mays* Tassel and so on. Cocoa pod husk has also been used for the sorption of Al (III), As (V), Cr (VI) and Ni (II) [14, 15]. The major advantages of these agricultural by-products are that they are economical, eco-friendly, abundant, renewable and more efficient.

*Senna tora* (L.) Roxb. (*S. tora*) belonging to the family Fabaceae is an annual undershrub which grows all over the tropical countries (India, Pakistan, Bangladesh, and west China). It grows well in wasteland as a rainy season weed [16]. The *Senna tora* seed is composed of hull (27%), endosperm (32%), and germ (41%). Seeds of *Senna tora* contain about 23.2% of proteins, rich in all essential amino acids, particularly, methionine and tryptophan. Several compounds belonging to anthraquinone and naphthopyrone groups have been isolated from seeds of this plant. It also contains phenolic glycosides, namely, rubrofusarine triglucoside, norrubrofusarin gentiobioside, demethylflavasperone gentiobioside, torachryson gentiobioside, torachryson tetraglucoside, and torachryson apioglucoside. Seed oil contains different percentage of oleic, linoleic, palmitic, stearic, and lignoceric acids [17, 18]

Several studies have been conducted throughout the last decade to investigate the biological properties of *Senna tora* using different parts of the plant (leaves, seed, and root) for their medicinal value [19]. The leaves of *S. tora* are reported to have antirheumatic activity in folklore practice. This agricultural wastes is a promising clean up agents that could be harnessed and utilized for treatment of heavy metal contaminated wastewater due to their availability, potential cost-effectiveness, metal binding potential, non-hazardous nature and ease of disposed by incineration. Although, activated carbon is extensively used as an adsorbent due to its high level of effectiveness, but it is expensive and has high usage costs. This has motivated many environmental scientists to embark on exploration for inexpensive and locally available adsorbents so that the process can become economically viable. In this study, the adsorption isotherm and kinetic studies of *Senna tora* has been investigated.

## 2. Material and methods

### 2.1. Preparation of Adsorbent

*Senna tora* was obtained from a local farm in Wukari local government area of Taraba state, Nigeria and identified at the Botany unit, Department of biological science, Federal University Wukari. The *Senna tora* leaves was then washed with tap water and then rinsed with distilled water to remove dust and impurities deposited on the surface. They were further air-dried at constant mass. The dried biomass was then pulverized and sieved using an electromagnetic sieve to obtain particle sizes less than 250  $\mu\text{m}$ . The dried biomass was then preserved in air-tight polyethylene paper to protect it from moisture and make ready for analysis. The adsorbent was used in their natural form without any form of modification.

### 2.2. Preparation of stock solutions

Spectroscopic grade chemicals were used in preparing all the solutions that were used in the study. Synthetic stock solution of  $\text{FeCl}_3$  Into effluent (1000 mg/L) were prepared by dissolving separate 162.5 g of  $\text{FeCl}_3$  and 2.9 g of  $\text{Pb}(\text{NO}_3)_2$  in 1000 ml of deionized water. All other concentrations of the metal ions were prepared by serial dilution of the stock solutions. Hydrochloric acid 0.1 M and 0.1 M NaOH was used for adjustment of the aqueous solution pH.

The stock solutions were calculated using the equations below;

$$\begin{aligned} & \text{FeCl}_3 \\ & \text{Mass of Fe} = 56 \\ & \text{Cl}_3 = 3 \times 35 = 106.5 \\ & \text{Molar mass of FeCl}_3 = 56(3 \times 35.5) \\ & = 162.5 \text{ g} \\ & \text{Molecular weight of FeCl}_3 = (56 \times 1) + 32 + (16 \times 3) \\ & = 223 \text{ g/mol.} \end{aligned}$$

The amount of salt needed to prepare 1000 mg/L stock solution

$$\begin{aligned} & = 1000 \text{ mg/L} \times \frac{\text{molecular weight}}{\text{mass of the metal ion}} \\ & = 1000 \times 162.5 / 56 \\ & = 1000 \times 2.9 \\ & = 2.900 \text{ mg} \\ & \text{To gram} = 2900 / 1000 \\ & = 2.9 \text{ g} \end{aligned}$$

### 2.3. Batch Equilibrium Adsorption Studies

Batch experiments were carried out in 100 ml plastic bottles according to the methods described by Nharingo *et al.* [20] and Dawodu *et al.*, [21] to investigate how critical experimental parameters affects the adsorption process. The critical parameters investigated in this study include effects of pH, contact time, dosage, particle size and initial metal ion concentrations. Solution temperature, volume of synthetic effluent and rate of agitation were maintained constant throughout the study at  $25 \pm 2$  °C, 50ml and 180 rpm for 120 min respectively.

### 2.4. Effect of Adsorbent Dosage on Adsorption

To each separate 50ml portion of 200mg/l of Fe(II) and Pb(II) ions solutions in a 100 mL plastic bottle, varying amounts of biomass ranging from 0.1 to 1 g were separately added. The mixtures were agitated over a shaker at 180 rpm for 120 mins at a temperature of  $25 \pm 2$ °C, pH of 6.0. The mixtures were finally filtered and analyzed for residual metal ions by an atomic absorption spectrophotometer (Buck Scientific, model 210VGP).

### 2.5. Effect of pH on adsorption

The effect of pH on the percentage removal Fe (II) and Pb (II) ions by SH was investigated using Fe(II) and Pb (II) ions aqueous solutions of initial concentration 200 mg/l. Separate volumes of 50ml of 200mg/l of Fe (II) and Pb (II) ions were transferred into separate 100 ml plastic bottles. The pH was adjusted between 3.0-8.0, using 0.1M HCl and 0.1M NaOH solutions. 1g SH, was added to each plastic bottles containing metal solutions of varying pH and the mixtures were placed on an electronic shaker operated at 180rpm for 120mins at temperature of  $25 \pm 2$ °C. The samples were finally filtered and analyzed for residual metal ions using an atomic absorption Spectrophotometer (Buck Scientific, model 210VGP).

### 2.6. Effect of Initial Metal Concentrations on Adsorption

The effect of initial concentrations of metal ion on adsorption was examined under optimum conditions by mixing 1 g SH powder with 50ml of Fe(II) and Pb (II) ion solutions of different initial concentrations ranging from 50 to 200 mg/L at pH of 6.0. The experiments were conducted at a temperature of  $25 \pm 1$ °C, shaking rate of 180rpm for 120 mins. The

samples were finally filtered and analysis for residual metal ions by an atomic absorption spectrophotometer (Buck Scientific, model 210VGP).

## 2.7. Effect of Contact Time on Adsorption

Batch adsorption studies were conducted at different contact times from 5 to 120 minutes, by contacting 50 ml of 200 mg/l of Fe(II) and Pb(II) ions with 1.0 g adsorbent dose at pH of 6.0, flask shaking rate of 180 rpm and room temperature of  $25 \pm 2^\circ\text{C}$ . Duplicate analysis of the residual metal ions was done at each predetermined time by an atomic absorption spectrophotometer (Buck Scientific, model 210VGP). The equilibrium time was found to be 60 minutes for Fe (II) and 80 for Pb(II). Hence, 100 mins was used for subsequent experiments to ensure that equilibrium was achieved.

## 2.8. Data Analysis

The experimental equilibrium and kinetic data for the sorption of Fe (II) and Pb(II) ions onto the *Senna tora* adsorbent were modelled using the equilibrium and kinetic models described in this study. To determine the model which best describes the sorption a number of fitting parameters were used to correlate the experimental data based on the magnitude of the correlation coefficient for the regression, that is the model which gives an  $r^2$  value closest to unity is deemed the best fit [22]

## 3. Results and discussion

### 3.1. Effect of pH

The percentage removal and equilibrium sorption capacity of metal ions is strongly affected by pH [23]. At the same time, the state of chemically binding sites is changed by the solution pH [24]. At low pH, higher concentration and mobility of  $\text{H}^+$  ions favour  $\text{H}^+$  sorption compared to metal ions, this creates a competition between the protons and metal ions for the binding sites of the adsorbent. According to Onundi *et al.* [25] metal ions are more soluble in solution at lower pH values and this reduces their sorption. The low sorption of Fe (II) and Pb (II) ions at low pH in this study as shown in Figure 1 was therefore due to saturation of binding sites of *Senna tora pods* with hydrogen ions. However, an initial metal sorption observed with increase in pH was due to a decrease in competition between hydrogen ions and metal ions for the adsorbents surface binding sites and also due to decrease in positive surface charge, which resulted in less electrostatic repulsion between the surface and metal ions before ion exchange which is the major mechanism of metal uptake [26]. As the pH of the solution increases, more negatively charged surface becomes available thus facilitating greater metal sorption. Giri *et al.* [27] reported a similar trend on studies of the effect of pH on the removal of Cr (VI) using *Eichhornia crassipes* root activated carbon. However, at higher pH metal ions tend to precipitate out of solution.

Therefore the removal of metal ions at higher pH values was due to the formation of metal ion precipitates rather than sorption [28].

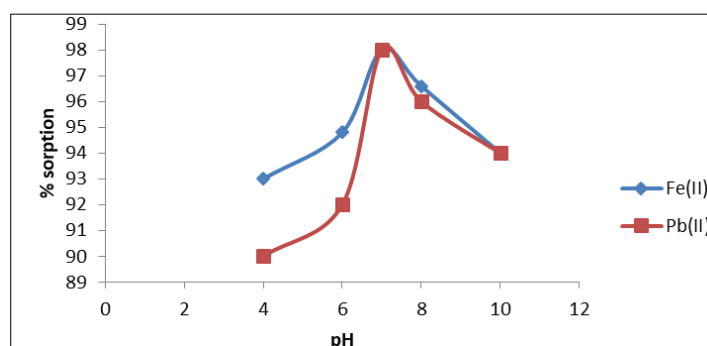
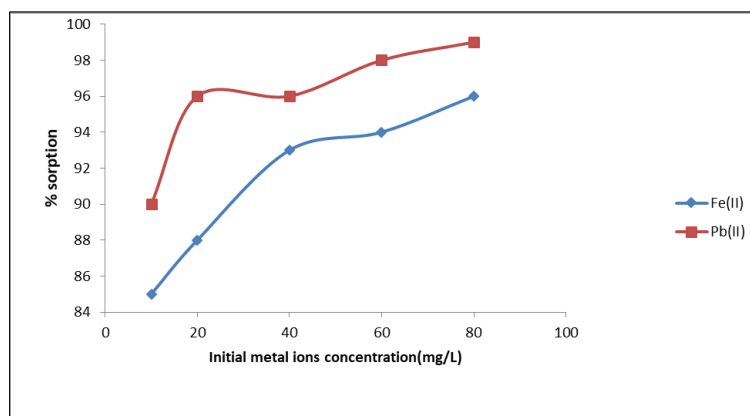


Figure 1 Effect of pH on the sorption of Fe and Pb onto *Senna tora*

### 3.2. Effect of Initial Metal Ion Concentration

The amount of metal ions sorbed is a function of the initial concentration of the metal ion, making it an important factor in effective adsorption. The sorption capacity of *Senna tora* for

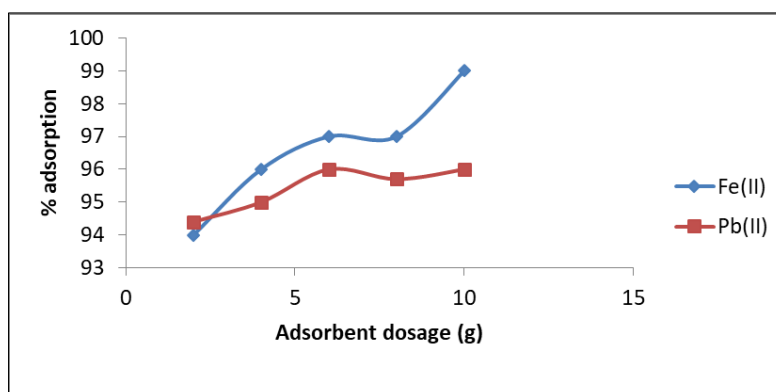
Fe (II) and Pb(II) ions in this study increased with increasing metal ion concentration from 50 to 200 mg/L, resulting to an increase metal ion concentration gradient that overcomes the resistance to mass transfer of metal ions between the aqueous phase and the adsorbent. A higher concentration in a solution implies a higher concentration of metal ion to be fixed on the surface of the adsorbent [29]. The high sorption capacity of *Senna tora* for Fe(II) and Pb(II) ions as shown in Figure 2 is possibly attributed to its surface porosity, better still may be due to its larger surface area and good cation exchange capacity. Dowodu and Okpomie, [24] reported a similar observation on simultaneous adsorption of Ni(II) and Mn(II) ions from aqueous solution onto a Nigerian kaolinite clay. A higher metal concentration saturated the adsorbent sites more quickly thereby decreasing the overall percentage metal removal. A similar trend was observed by [30].



**Figure 2** Effect of Initial Metal Concentration on the uptake capacity of *Senna tora*

### 3.3. Effect of Dosage

Adsorbent dosage has proved to be a useful parameter for determining the capacity of a adsorbent for a given initial metal ion concentration. The percentage removal of Fe(II) and Pb(II) ions in this study, increased with increasing adsorbent dosage from 2-10 g, due mainly to an increase in the number of available exchangeable binding sites for metal ion sorption. However, the equilibrium sorption capacity of *Senna tora* per unit mass of the adsorbent decreased considerably with increase in sorbent dose for both metal ions as shown in Figure 3. This may be due to a decrease in the total sorption surface area available to the metal ions, possibly caused by the aggregation/agglomeration of sorption sites, as a result the sorption capacity of the adsorbent is not fully utilized. Conversely, a higher adsorbent dose may also provide more active sorption sites, so that sorption sites remain unsaturated, leading to their full utilization as reported by Barka *et al.* [31].



**Figure 3** Effect of dosage on the % sorption of Cd and Pb onto *Senna tora*

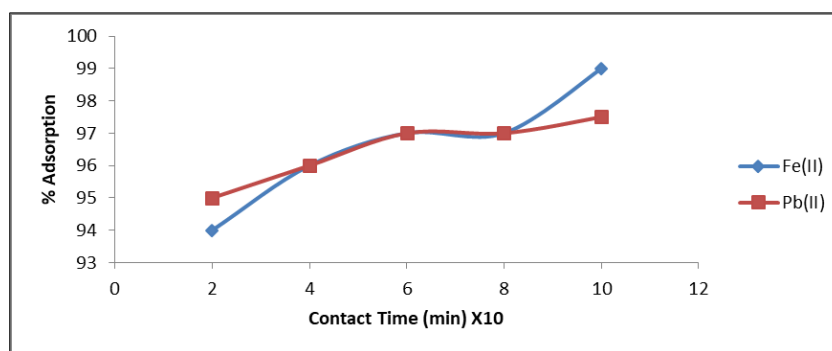
### 3.4. Effect of Contact Time

The effect of contact time on the adsorption of Fe(II) and Pb(II) ions onto *Senna tora* is shown in Fig. 4. An initial increase in percentage removal with increased contact time from 5-60 minutes was observed, and adsorption became fairly stable over time. Equilibrium removal was achieved around 60 min for Pb(II) after which further increases in contact time did not result in significant adsorption. However, for Fe(II), there was a significant increase in adsorption between

60 and 100 min indicating strong affinity of the active sites for Fe(II) ions. Maximum adsorption was achieved at 100 min for both metal ions, and this time was used in all experiments to ensure maximum removal.

The faster removal rate with Fe(II) than with Pb(II) may be due to the smaller ionic radius of Fe(II) (0.72 Å) than Pb(II) (0.80 Å), which makes for easier, more rapid diffusion to the surface of the adsorbent. The rapid adsorption during the initial stages might be due to the presence of abundant active sites on the surface of *Senna tora*, which become saturated with time.

Initially, sorption is controlled mainly by diffusion from the bulk to the surface of the adsorbent, whereas, later, sorption is probably an attachment-controlled process due to the presence of fewer active sites [32].



**Figure 4** Effect of contact time on the sorption of Fe and Pb onto *Senna tora*

### 3.5. Equilibrium Isotherm Modeling

Equilibrium adsorption isotherms are used to relate the adsorbate concentration in solution and the amount on the adsorbent at equilibrium [33]. These parameters often provide fundamental information on the sorption mechanism, surface properties and the affinity of adsorbents, which helps to determine the applicability of sorption as a unit operation. Therefore, it is important to establish the most suitable correlation of equilibrium curves in order to optimize the conditions for designing adsorption systems. The most frequently used isotherms, the Langmuir, Freundlich and the Temki models, were therefore used to analyse the data (Table1).

### 3.6. The Langmuir Isotherm

This model describes monolayer adsorption onto the surface of an adsorbent with a finite number of identical adsorption sites and no interaction between sites. The model is expressed as (Dawodu and Apomie, 2014).

$$\frac{C_e}{q_e} = \frac{1}{qL K_L} + \frac{C_e}{qL}$$

Where,

$q_L$ (mg/g) = monolayer adsorption capacity of the adsorbent

$K_L$ (L/mg) = adsorption constant, which reflects the affinity between the adsorbent and adsorbate.  $q_L$  and  $K_L$  were determined from the slope and intercept of the plots of  $C_e/q_e$  versus  $C_e$ . An essential feature of the Langmuir isotherm can be expressed in terms of a dimensionless separation factor ( $R_L$ ), defined as:

$$R_L = 1/[1 + K_L C_0]$$

It was observed in this study that the Freundlich adsorption isotherm provided a very good fit for the sorption of Fe (II) and Pb(II) ions from aqueous solutions on *Senna tora* as indicated by the high correlation coefficients ( $R^2$ ) 0.79 and 0.620. The applicability of the Langmuir isotherm indicated good monolayer coverage of Fe(II) and Pb(II) ions on the surface of the adsorbent, which consequently suggests the formation of a mono layer on the adsorbent surface in the given concentration range [34].

The fact that the Langmuir isotherm fitted the experimental data well may be attributed to the homogenous distribution of binding sites on the adsorbents [35]. The calculated model parameters with their correlation coefficients are shown

in Table 1. The adsorption capacity  $q_L$ (mg/g) for Fe (0.019mg/g) was lower than that of lead (0.028mg/g), suggesting that the amount of Pb(II) sorbed per unit mass of the adsorbent was higher than that of Fe(II). Kaiser *et al.* [36] reported the maximum sorption capacities for lead on groundnut hull (31.54 mg/g) and baggase fly ash (2.5 mg/g) [37, 38].

The affinity of the two metals for the adsorbent surface in terms of  $K_L$ (l/mg) is higher for iron (III) chloride than lead. The values of  $K_L$ (L/mg) were fairly low, which implies low surface energy in the process and consequently weak bonding between metal ions and adsorbent (indicating a physisorption mechanism) marking recovery of the metal ions through desorption easy. This is a major criterion in selecting a adsorbent [26].

### 3.7. The Freundlich Isotherm

The Freundlich isotherm is based on the assumption that sorption takes place on a heterogeneous adsorbent surface, where the sorption energy distribution decreases exponentially and is expressed in equation:

$$\log Q_e = \log K_F + \left(\frac{1}{n}\right) \text{Log} C_e$$

Where;

$K_F$ (mg/g)(mg/L) $^{1/n}$  and  $n$  are the constants for adsorption capacity and intensity, respectively. A plot of  $\log q_e$  versus  $\log C_e$  gives a straight line of slope  $1/n$  and intercepts  $\log K_F$ . As can be seen in Table 1, the  $r^2$  values for both Fe(II) and Pb(II) ions, 0.979 and 0.920 respectively were higher than those of the Langmuir model, indicating a good fit of the Freundlich model to the adsorption process. Though the values of  $n$  obtained for both metal ions lie between 1 and 10, suggesting favourable adsorption.

The values of  $n$  (0.542 and 0.531) for Fe(II) and Pb(II) on senna tora respectively, confirms that the adsorbent have a heterogeneous surface since the values satisfy the heterogeneity condition where  $n$  must be between one to 10 ( $1 < n < 10$ ). The low values of  $K_F$  (0.459-0.688) for both heavy metals imply that there was low uptake of the metal ions onto the adsorbent surface. Barka *et al.* [26] also reported a low  $K_F$  values for cadmium and lead uptake onto eco-friendly dried *Cactus cladodes*.

### 3.8. The Temkin Isotherm

This model is based on the assumption that the free energy of adsorption is a function of the surface coverage; it is expressed as ():

$$q_e = B \ln A + B \ln C_e$$

Where;

$B = RT/b$  (mg/g) is the isotherm constant related to the heat of adsorption, and  
 $A$  (L/g) is the equilibrium binding constant corresponding to the maximum binding energy,  
 $R$  is the gas constant and,  
 $T$  (K) is absolute temperature.

The constants  $A$  and  $B$  shown that values rang from (3.781-4.652) which were determined from the plot of  $q_e$  versus  $\ln C_e$  (Table 1). The  $r^2$  values obtained (Table 1) for both metal ions (0.623 – 0.733) showed a poor fit for the data compared to the Langmuir and Freundlich models.

**Table 1** Langmuir, Freundlich and Temkin Isotherm constants for the sorption of Fe (II) and Pb(II) ions unto senna tora

Isotherm models	Fe (II) Pb (II)
<b>Langmuir model</b>	
q <sub>L</sub> (mg/g)	5.291 3.510
K <sub>L</sub> (L/mg)	0.019 0.028
R <sup>2</sup>	0.789 0.620
<b>Freundlich model</b>	
K <sub>F</sub> (L/g)	0.459 0.688
1/n	0.542 0.531
R <sup>2</sup>	0.979 0.920
<b>Temkin model</b>	
A (L/g)	3.781 4.652
B (mg/g)	1.245 2.670
R <sup>2</sup>	0.623 0.733

### 3.9. Kinetic Modelling

The kinetic mechanism controlling adsorption was investigated with pseudo-first order and pseudo-second order rate equations. The kinetic parameters are shown in Table 2.

#### 3.9.1. The Pseudo-First Order or Lagergren Equation

This is based on the assumption that the rate of adsorption site occupation is proportional to the number of unoccupied sites. The linear form of the Lagergren equation is given as:

$$\log (q_e - q_t) = \log q_e - (K_I t/2.303)$$

Where;

K<sub>I</sub> (min<sup>-1</sup>) is the rate constant and,

q<sub>t</sub> and q<sub>e</sub> are the amounts of metal ion adsorbed at time t(min) and equilibrium respectively.

The constant K<sub>I</sub> and q<sub>cal</sub> (calculated sorption capacity) as presented in Table 2 were obtained from the slope and intercept of the plot of log (q<sub>e</sub> - q<sub>t</sub>) versus t.

The model presented a good fit to the kinetic data base on r<sup>2</sup> values obtained for the two metal ions as shown in Table 2.

However, the values of the calculated sorption capacity (q<sub>cal</sub>) were lower than those of experimental sorption capacity (q<sub>exp</sub>) obtained, indicating a disagreement as also reported by [24, 39].

#### 3.9.2. The Pseudo-second Order Kinetic Model

The model is based on the assumption that chemisorptions is the rate determining step, provided a good fit to the experimental data as can be seen from the very high linear regression (R<sup>2</sup>) values (table 2). Several studies have also reported high regression (R<sup>2</sup> = Fe(II) 0.781 and Pb (II) 0.805) values for this model [40, 41, 42]. The values of q<sub>cal</sub> for pseudo-second order were almost equivalent to the experimental values (q<sub>e exp</sub>) obtained, confirming it as the model that best described the kinetic mechanism of the removal of Fe (II) and (Pb) ions from wastewater in this study. This has also been reported in several studies [24, 39, 43].



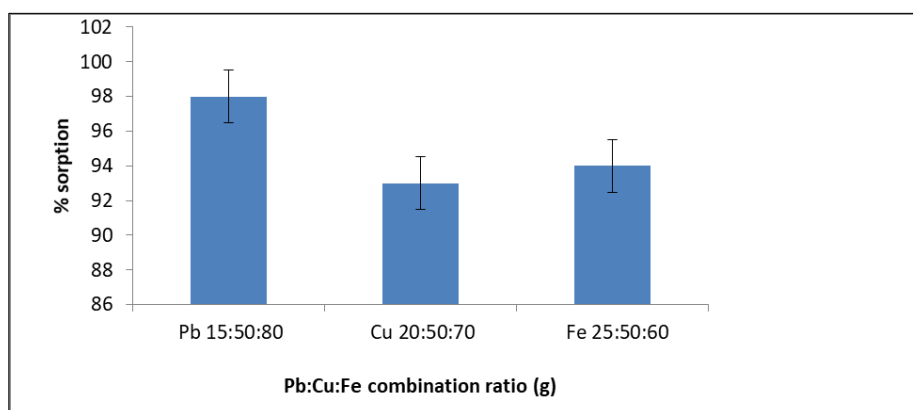
**Table 2** Kinetic parameters for the adsorption of Fe (II) and Pb (II) on senna tora

Kinetic models	Fe(II) Pb(II)	
$q_e \text{ exp (mg/g)}$	0.460	0.75
<b>Pseudo-first order</b>		
$q_{e\text{cal, (mg/g)}}$	0.574	0.481
$K_1, (\text{min}^{-1})$	0.015	0.023
$R^2$	0.983	0.920
<b>Pseudo-second order</b>		
$q_{e\text{cal, (mg/g)}}$	1.299	6.403
$K_2 (\text{gmg}^{-1}\text{min}^{-1})$	0.048	0.023
$h (\text{mg/gmin})$	1.592	0.954
$R^2$	0.781	0.805

Where;  $q_{\text{exp}}$  (mg/g) is the experimental adsorption capacity and  $q_{\text{cal}}$  (mg/g) is the calculated sorption capacity.

### 3.10. Adsorption of Multi-Component Heavy Metal Ions

In order to obtain a deeper understanding of the adsorption efficiency and competition between heavy metal ions, adsorption experiment was performed in deionised water of multicomponent mixed system containing Pb(II), Cu(II), Fe(II) of different concentration and the results. A comparison of the performance of adsorption-driven removal of antimony by previously studied materials and the work reported here is shown in Fig 5. Our Fe(III)- unmodified antimony-resistant bio-adsorbent has a lowest adsorption capacity compared with Fe(III)-modified humus sludge [44], cyanobacteria and microcystis [27]. Many other sorbents perform best under strongly acidic conditions which makes our system of great potential value in the treatment of grossly polluted environments.

**Figure 5** Comparison of Adsorbents Using the Maximum Adsorption Capacity ( $Q_{\text{max}}$ -Mg/L)

## 4. Conclusion

This study has demonstrated favourable properties of *Senna tora* for the bioremediation of Pb(II) and Fe(II) ions from wastewater through batch adsorption studies. The study has been found to be influence by pH, initial metal concentration, adsorbent dosage and contact time. From the study of adsorption isotherms, it is observed that the adsorption data is found to be best described by Freundlich isotherm with higher value of coefficient of correlation as compared to Langmuir and Temkin isotherm models. The pseudo first order equation has been found to be the best application adsorption kinetics to describe the adsorption process *Senna tora*. It has been concluded that the preparation made from *Senna tora* leaves can be used as adsorbent for the removal of Fe (II) from aqueous media.

## Compliance with ethical standards

### *Disclosure of conflict of interest*

No conflict of interest to be disclosed.

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