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Aqueous Phase Adsorption of Pb (II) Ions onto *Hymenoptera sphecidae* (Mud-wasp) Nest

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Authors' contributions

This work was carried out in collaboration among all authors. Author DTK designed the study, wrote the protocol and produced the final draft of the manuscript. Author PAA managed the lab protocol and reviewed the first draft of the manuscript. Author REK managed the instrumental analysis of the study author PDK managed the literature compilation, the lab protocol and wrote the first draft of the manuscript. All the authors read and approved the final manuscript.

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ABSTRACT

Removal of Pb (II) ion from aqueous solution using *Hymenoptera sphecidae* (mud-wasp) nest was investigated using a batch process. The effect of pH, contact time and adsorbent dose were also investigated. The result showed that the adsorption of Pb (II) ion onto mud-wasp nest was dependent on pH, contact time and adsorbent dose. Adsorption patterns were analysed in terms of three bi-parameter isotherms of Langmuir, Freundlich and Temkin. Freundlich isotherm gave the best fit to the adsorption data with a correlation coefficient of 0.992, while monolayer sorption capacity yielded 41.667 mg/g. Lagergren's pseudo first-order and pseudo second-order kinetic models were used to test the adsorption kinetics. The kinetic data were well described by the pseudo second-order kinetic model, suggesting that the process was chemisorption type. The results showed that mud-wasp nest can be used as a low-cost adsorbent for the removal of Pb (II) ion from aqueous solutions.

Keywords: Lead (II) ions; adsorption isotherms; kinetic models; mud-wasp nest.

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1. INTRODUCTION

Lead is often found in wastewaters as a result of its wide industrial applications such as batteries, construction, lead crystal glass, radiation protection and petrol as anti-knock agent [1]. This metal ion, unfortunately, is also found in drinking water at levels that could be injurious to the human system [2]. It has significant effects on humans even at low levels of exposure. Some of these effects include neurobehavioral disorder, neurological damage, hypertension, renal damage and infertility in women [1,2].

Low-cost adsorbents have attracted so much interest in recent years in attempts to minimise processing costs for water and wastewater treatment. Some of these include the use of agricultural wastes, plastic wastes, charcoal and activated carbon, clay and zeolites [3,4,5,6,7,8]. In the search for more low-cost adsorbents, mud-wasp nest was characterised and found to have promising application in adsorption studies [9]. Mud-wasp is a species of solidary wasps that are able to construct nests majorly from mud (clay), which they plaster on walls, plant stems and other surfaces [10]. These mud-wasp nests, even though have destructive tendencies and are often removed and thrown away, could have a positive use as adsorbents. This paper is a compliment of an earlier paper [9] and presents the use of mud-wasp nest as adsorbent for the removal of Pb (II) from aqueous solution.

2. MATERIALS AND METHODS

2.1 Pb (II) Ions Adsorption Studies

Adsorption experiments were carried out using batch techniques at room temperature (30±2°C) using aqueous solutions of lead (II) ion. The effect of variables such as initial Pb (II) ion concentration, pH, contact time, and adsorbent dose, were carried out with one parameter changed at a time while the other parameters were kept constant [11].

2.2 Preparation of Lead (II) Ion Solutions

A stock solution of lead (5000 mg/L) was prepared by accurately weighing 8.0 g of $Pb(NO_3)_2$, which was then dissolved in distilled deionised water and made up to the mark in a 1L volumetric flask. Serial dilutions of the stock solution were prepared using 10, 20, 30, 40 and 50 mL volumes to obtain 50, 100, 150, 200 and 250 mg/L standard solutions [12].

2.3 Batch Aqueous Phase Adsorption of Pb (II) Ion

100 mL aliquots of the prepared Pb (II) ion standard solution were measured into five separate 250 mL conical flasks labelled 1 to 5; and 1 g of mud-wasp nest sample dispersed in each of them and corked. Agitation of the samples was carried out on an H-Y-2 high speed adjusting vibrator for an equilibration time of 1 hour at room temperature and pH 3.0. The slurries were then filtered using plastic funnels impregnated with glass wool in their stem. The filtrates were collected and stored in clean, well-labelled plastic sample bottles. The equilibrium Pb (II) ion concentration, C_e, in the filtrates was determined by diluting 10 mL of the filtrates to the required dilution ratio and analysed with a SHIMADZU AA 6800 model atomic absorption spectrometer (AAS). The difference between the respective initial concentrations, C_o, (50-250 mg/L) of the Pb (II) ion samples and the determined C_e values gave the amount of Pb (II) ion (q) adsorbed.

Adsorption isotherms were generated for each set of q-C_e data obtained. Saturated adsorption capacity, q_o (mg/g mud-wasp nest) and affinity constant, k, for each adsorbate (Pb (II) ion) was determined by fitting the experimental data to the Langmuir, Freundlich and Temkin models using linear regression analysis. All experiments were carried out in duplicate for reproducibility. Percent removal of Pb (II) ion from aqueous solution was estimated using Equation (1).

$$\%\text{Adsorption} = [(C_o - C)/C_o] \times 100 \quad (1)$$

Where C_o = initial metal ion concentration; C = final metal ion concentration (mg /L) [13].

Metal uptake (q_e) at equilibrium was calculated using Equation (2).

$$q_e = \frac{\left(C_o - C_e\right)}{1000}\frac{v}{m} \quad (2)$$

Where C_e is the concentration (mg/L) of Pb (II) ion at equilibrium, v is the volume (mL) of aqueous solution and m is the mass (g) of the adsorbent.

2.3.1 Effect of pH on Pb (II) ion adsorption

The influence of changes of pH on the metal ion adsorption was investigated as earlier described

[14]. 100 mL aliquots of 50 mg/L solution of Pb^{2+} ion were measured into five 250 mL conical flasks. 1 g portions of mud wasp nest samples were weighed out separately and added into each of the flasks. The pH of the contents of each flask was adjusted with 0.1 M HCl and 0.1 M NaOH such that the pH of the solutions in the flasks was 3, 4, 5, 6 and 7 respectively. The content of each flask was agitated for 1 hour at the elapse of which the solutions were filtered with plastic funnels impregnated with clean glass wool. 10 mL aliquots of the filtrates were collected and kept in plastic sample bottles for residual Pb^{2+} ion analysis using the Shimadzu atomic absorption spectrophotometer model AA 6800.

2.3.2 Effect of contact time (CT) on Pb (II) ion adsorption

Contact time of Pb (II) ion with adsorbent was varied as fresh mixtures were agitated in the flasks for 10, 20, 30, 40, 50 and 60 minutes respectively, as other parameters were kept constant. Adsorption of the metal ions was then measured and recorded after each run.

2.3.3 Effect of adsorbent dose (AD) on Pb (II) ion adsorption

Samples of mud-wasp nest material were weighed separately into 0.5, 1.0, 1.5, 2.0 and 2.5 g and contacted with 50 mL of Pb (II) ion solution and other parameters remained unchanged [15]. Each run was done in duplicate. Adsorption of Pb (II) ion was measured and recorded after each run.

2.4 Kinetics of Pb (II) Ion Adsorption

The mechanism of Pb (II) ion-mud-wasp nest interaction was described using the pseudo first-order and pseudo second-order models [16].

3. RESULTS AND DISCUSSION

3.1 Effects of the Initial Metal Ion Concentration

Equilibrium adsorption of Pb (II) ions onto the mud-wasp nest from aqueous solutions are presented in Table 1.

Fig. 1 shows that Pb (II) ion uptake (loading capacity) increases as the initial metal ion concentration increases. This increase from 4.5915 mg/g to 21.1896 mg/g is as a result of the increase in the driving force, which is the concentration gradient [17]. The percentage of Pb (II) ion adsorbed on mud-wasp nest decreased from 91.829 to 84.7583% as the initial Pb (II) ions concentration increased as shown in Fig. 2. This may be to the effect that at lower concentrations, all the active sites of the adsorbent were available to adsorb Pb (II) ions and further increases in the initial metal ion concentration led to competition for the available sites, which resulted to saturation of the mud-wasp nest's surface, thus leaving more Pb (II) ions in solution [18,19].

3.2 Effects of pH on Pb (II) Ion Adsorption

The effects of pH on adsorption of lead was studied at room temperature (30±2°C) and the results of batch equilibrium studies are presented as an adsorption envelope in Fig. 3.

The uptake of Pb (II) ion increased slightly with an increase in pH from 3 to 4.3 with Pb removal recording its minimum value at pH 3. For oxides, solid-solution interphase of some weathered soils, within a critical pH interval less than 2 units, there is an increase of metal ion adsorption percentage and higher values are recorded [20]. This critical pH interval, which is referred to as the "adsorption edge", defines the hydrolysis constant of the metal ions [20]. Increasing the pH from 3 to 4 enhanced adsorption by 5.741% (from 46.1725 mg/L at pH 3 to 49.0287 mg/L at pH 4) signifying that adsorption edge for the adsorption of Pb (II) ion onto the mud-wasp nest was between pH 3-4. The Optimum adsorption was attained at a pH of 4.3 with 98.0573% of Pb (II) ion removed. This phenomenon might be explained by converting some unstable form of Pb (IV) ion to the more stable Pb (II) ion. At this low pH, there is also the protonation of functional groups present in the adsorbent, which thus makes its chelation with the stable anions readily possible and thus increases the adsorption value [21]. This turning point at pH 4.3 implies that increasing pH more than 4.3 would not significantly affect the adsorption of Pb (II) ion [16]. These results are in tandem with many others in literature [17,21].

3.3 Effects of Contact Time (CT) on Pb (II) Ion Adsorption

The effects of contact time on removal of Pb (II) ion from aqueous solution were investigated and the outcomes of the batch equilibrium studies are presented in Fig. 4.

Adsorption of Pb (II) ion by mud-wasp nest was very rapid with about 89.8121% of Pb (II) ion removed within the first 40 minutes of interaction indicating that 40 minutes was sufficient to achieve equilibrium and that adsorption did not change significantly with further increase in contact time. Rapid sorption implies that smaller reactor volumes can be used. Similar results have been reported in literature [15,21].

3.4 Effects of Varying Adsorbent Dose (AD) on Pb (II) Ion Adsorption

With the Pb (II) ion concentration constant at 50 mg/L, 0.5, 1.0, 1.5, 2.0 and 2.5 g of adsorbent were weighed separately into 50 mL solution and treated as reported in section 2.3.3. The results of batch equilibrium sequestration of Pb (II) ion using the mud-wasp nest material follow the trend presented in Fig. 5.

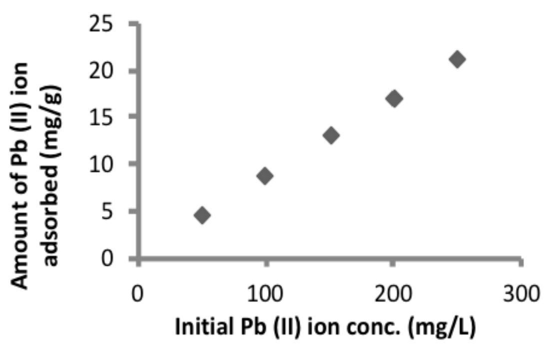

Fig. 1. Effect of initial Pb (II) ion concentration on amount adsorbed

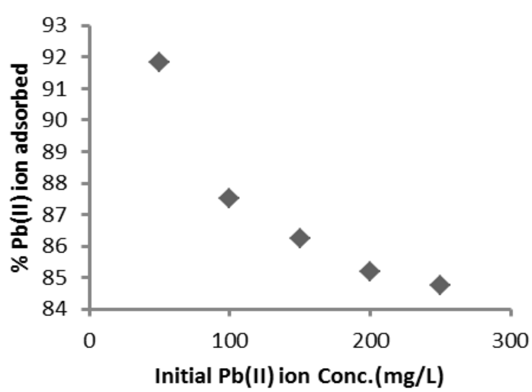

Fig. 2. Variation of % adsorbed with initial Pb (II) ions concentration

From the data obtained, increasing the adsorbent dose from 0.5 g through to 2.5 g resulted in a leap in the percentage of Pb (II) ion adsorbed from a value of 84.5774% to 98.5022%. This increase can be attributed to the greater availability of binding sites for the complexation of Pb (II) ions as a result of the increased surface area of mud-wasp nest. This is in tune with previous related studies [15,17].

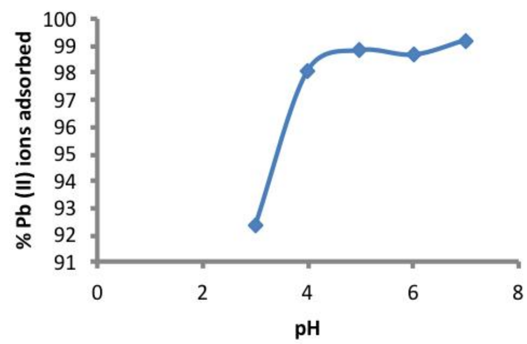

Fig. 3. Effect of pH on Pb (II) ion adsorption onto mud-wasp nest

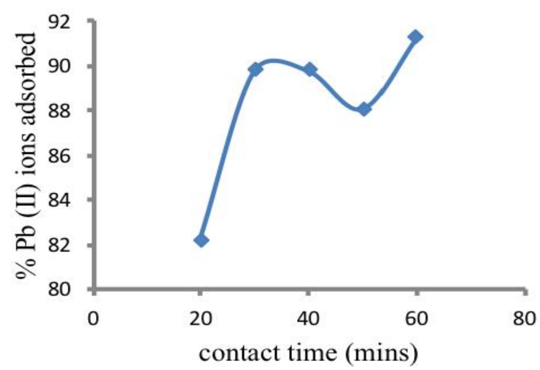

Fig. 4. Effect of contact time on adsorption of Pb (II) ions onto mud-wasp nest

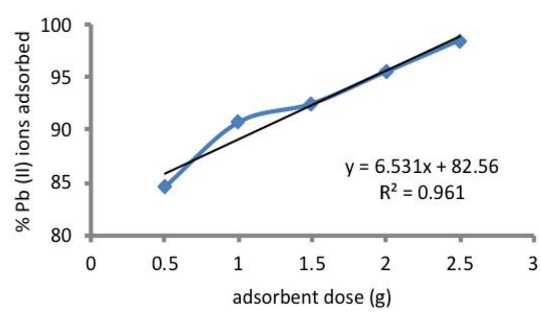

Fig. 5. Effect of adsorbent dose on Pb (II) ion adsorption onto mud-wasp nest

3.5 Correlations between Variables

Linear regression correlations were carried out between the variability of contact time (CT), adsorbent-dose (AD), pH and the initial Pb (II) ion concentration (C_o). The results of these correlations are presented in Figs. 6-10.

Correlations revealed a sound positive linear relationship for each pair of parameters considered. This implies that increasing these parameters simultaneously during the sequestration process would enhance the amounts of Pb (II) ion that would be adsorbed by the mud-wasp nest material. However, Fig. 11 shows a non-linear relationship as pH was varied with contact time, signifying that these two variables cannot be manipulated simultaneously during the adsorption process to enhance improved adsorption of Pb (II) ion onto the mud-wasp nest surface.

3.6 Mechanism of Pb (II) Ion Adsorption

The mechanism of Pb (II) ion adsorption onto the mud-wasp nest was established using equilibrium adsorption isotherms [13]. The equilibrium data obtained for Pb (II) ion adsorption onto mud-wasp nest was fitted in the linearized forms of Langmuir, Freundlich and Temkin isotherm models.

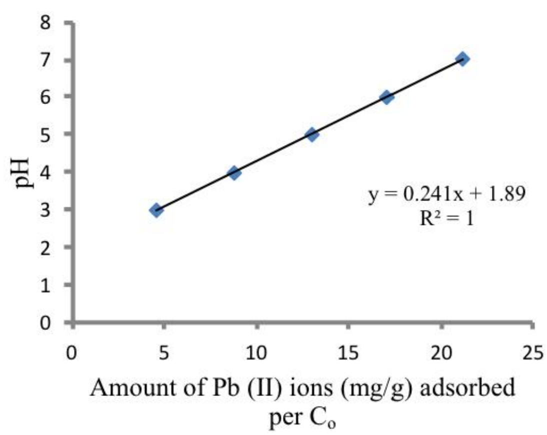

Fig. 6. Correlation between C_o and pH

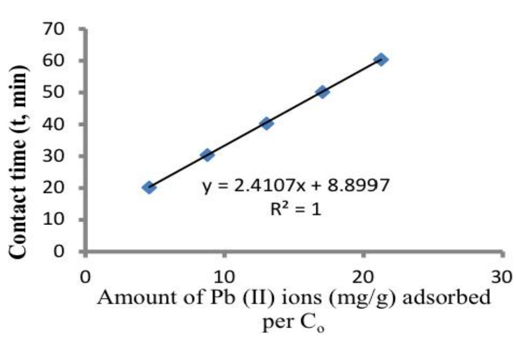

Fig. 7. Correlation between C_o and CT

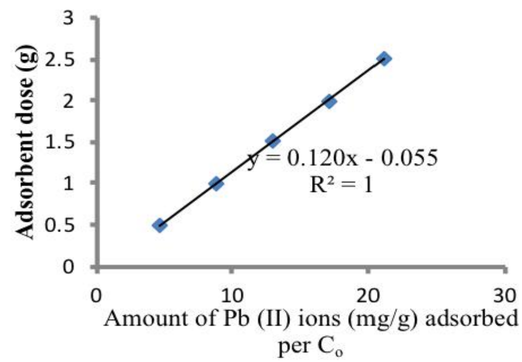

Fig. 8. Correlation between C_o and AD

3.6.1 Langmuir adsorption isotherm

The empirical data fitted the Langmuir adsorption isotherm model, which is given by Equation (3) [22].

$$q_e = q_m \frac{k_L C_e}{1 + k_L C_e} \tag{3}$$

And one of the linear forms of Equation (3) is given by Equation (4)

$$\frac{C_e}{q_e} = \frac{C_e}{q_m} + \frac{1}{k_L q_m} \tag{4}$$

Where q_e is amount of solute adsorbed per unit mass of adsorbent (mg/g) at equilibrium, C_e is the metal ion concentration in the aqueous phase (mg/L) at equilibrium, q_m is the maximum adsorption capacity corresponding to complete monolayer coverage, k_L is a constant, which defines to the affinity of the active sites and the energy of adsorption and is measured in L/mg. The Langmuir isotherm model was used to estimate maximum adsorption capacity (q_m) corresponding to complete monolayer coverage on the mud-wasp nest surface; the term, (C_e / q_e) is the specific sorption of the system and plotting (C_e / q_e) versus C_e gives the trend in Fig. 12.

From the plot in Fig. 12, the adsorption capacity, q_m , corresponding to complete monolayer showed that mud-wasp nest had a maximum adsorption capacity of 41.667 mg/g, a value competitive and comparable with many values for various adsorbents previously studied [23, 24]. The Langmuir affinity constant, also referred to as the Langmuir adsorption coefficient, k_L which is related to the surface energy of adsorption was obtained as 0.024 L/mg. The

Langmuir separation factor R_L, which is defined by Equation (5) was used to test the favourability of adsorption of Pb (II) ion on mud-wasp nest material [25].

$$R_L = \frac{1}{1 + k_L C_o} \quad (5)$$

The separation factor obtained ranged between 0.4545 and 0.1429. Values of R_L range between zero and unity ($0 < R_L < 1$) and convey the favourable adsorption attributes [26,27,28]. Therefore, the mud-wasp nest material can be described as a good adsorbent for Pb (II) ion from aqueous solutions. Coefficient of determination, R^2, was obtained from Langmuir least squares fits as 0.845 which is slightly lower compared with other adsorbents previously studied [23,24]. This shows that the Langmuir model does not give a perfect fit to the experimental data. However, caution should be employed in using R^2 as the sole measure to judge suitability of a model for a given set of empirical data. Nonetheless, the degree of suitability may be implied.

3.6.2 Freundlich adsorption isotherm

The Freundlich adsorption isotherm describes reversible adsorption and is not restricted to the formation of a monolayer [29]. It gives an expression describing the surface heterogeneity and the exponential distribution of active sites and their energies [29]. The infinite surface coverage is predicted mathematically, indicating multilayer adsorption on the surface [30].

$$q_e = k_F C_e^{1/n} \quad (6)$$

The logarithmic linear form of the equation is

$$\ln q_e = \ln k_F + \frac{1}{n} \ln C_e \quad (7)$$

Where q_e and C_e carry the same meaning as in Equations (3) and (4); k_F and *n* are constants of adsorption that define the extent of adsorption (or adsorption capacity), and adsorption intensity (or the degree of non-linearity) of mud-wasp nest respectively. It shows the relationship between the amount of Pb (II) ions adsorbed by mud-wasp nest and equilibrium concentration of Pb (II) in solution [31]. A plot of $\ln q_e$ against $\ln C_e$ is shown in Fig. 13, which is linear and enables the determination of the constants k_F and *n*.

The values of Freundlich isotherm constants k_F and *n*, obtained from the linearized isotherm were 1.6871 and 1.47 respectively. The numerical value of *n* is a useful index of adsorption efficiency/intensity [32]; for beneficial adsorptions, the values of *n* are such that $1 \leq n \leq 10$ [33]. Thus the value of *n* obtained proves the favourable nature of the absorption of Pb (II) ion onto the mud-wasp nest surface. Also, the fact that $n > 1$ shows that the empirical data fit into the convex Freundlich isotherm [13,14]. This implies that significant adsorption may take place even at high Pb (II) ion concentrations [13]; k_F is a constant, which is an approximate indication of total adsorption capacity. Values of k_F in the range of 0.001 to 64.2 have been reported for Cu (II), Pb (II) and Zn (II) ions by several types of adsorbents [24,34,35]. The value of k_F obtained from this study (1.687) is suggestive of beneficial adsorption by the mud wasp nest. The value of the coefficient of determination, R^2 for the linearized Freundlich isotherm was obtained to be 0.992. Based on the values of R^2, it can be concluded that data from the isothermal experiments fitted the Freundlich model better than the Langmuir model.

3.6.3 Temkin adsorption isotherm

The Temkin isotherm evaluates the adsorption potential with explicit adsorbent-adsorbate interactions [36]. Kobya [26] and Mohammad et al., [36] posited that the Temkin isotherm assumes that (i) the heat of adsorption of all the molecules in the layer decreases linearly with coverage due to adsorbate-adsorbent interactions and (ii) adsorption is characterized by uniform distribution of binding energies, up to some maximum binding energy. Temkin isotherm is expressed mathematically by Equation (8).

$$q_e = \beta_T \ln(C_e k_T) \quad (8)$$

Expanding Equation (8) gives Equation (9)

$$q_e = \beta_T \ln C_e + \beta_T \ln k_T \quad (9)$$

Where k_T is the binding constant (L/mg) at equilibrium, which is equivalent to the maximum binding energy, β_T defines the heat of adsorption. Empirical data obtained from batch adsorption of Pb (II) ion using the mud-wasp nest material fitted into the linear Temkin equation (Equation 9) and is presented in Fig. 14.

Fig. 14. Linearized Temkin adsorption of Pb (II) ions using mud-wasp nest material.

An examination of the Temkin Isotherm constantsk_T, β_T and coefficient of determination, R^2 revealed values that suggest favourable adsorption behaviour. The Temkin adsorption potential, k_T of mud-wasp nest was obtained as 0.38 (L/mg). The Temkin constant β_T, related to the heat of adsorption for Pb (II) ion was obtained as 7.091. The β_T parameter is directly proportional to RT

$$\beta_T \propto RT \tag{10}$$

Where R and T are the general gas constant (J mol^{-1}K^{-1}) and thermodynamic temperature (K) respectively [15,34]; and is therefore related to the binding energy of the adsorbate. Kumar and Kirthika [13] reported that typical values of binding energy for ion-exchange mechanisms fall in the range 8 -16 kJ. The value of 7.091 kJ obtained in this study thus suggests that there is strong binding energy of interaction between mud-wasp nest and Pb (II) ion. The values of k_T and β_T obtained for the adsorption of Pb (II) ion onto mud-wasp nest surface are also comparable with those of other adsorbents in earlier studies [15,36]. The coefficient of determination,R^2 obtained from the least squares linear regression plot was 0.911 indicating that the equilibrium data also fitted the Temkin model better than the Langmuir model.

3.7 Kinetics of Pb (II) Ion Adsorption onto Mud-wasp Nest

Kinetics unveils the dynamics of systems and/or system components relative to time. In adsorption studies therefore, it is paramount to describe the rate of adsorption, which controls the equilibrium time [16,23]. Kinetic models are therefore, useful tools to design and optimize parameters aimed at selecting optimum operating conditions for full scale batch, semi-batch and continuous processes [28]. The Lagergren pseudo first-order and chemisorption pseudo second-order kinetic models were analysed for the mechanism of Pb (II) ion adsorption by mud-wasp nests.

3.7.1 Lagergren pseudo first-order kinetic model

The Lagergren pseudo first-order kinetics model is described by Equation (11).

$$\frac{dq_t}{d_t} = k_1(q_e - q_t) \tag{11}$$

The integrated linear form of this model is expressed in Equation (12).

$$\log(q_e - q_t) = \log q_e - \frac{k_1}{2.303}t \tag{12}$$

Where q_e and q_t (mg/g) are the amounts of Pb (II) ion adsorbed per unit mass of mud-wasp nest at equilibrium and at any contact time t respectively. k_1 (min^{-1}) is the Lagergren pseudo first-order rate constant [28]. Plotting $\log(q_e - q_t)$ versus t gives a linear trace from which the values of k_1 and q_e are obtained from the slope and intercept respectively. The intercept of the plot was expected to equal log q_e. Data for Pb (II) ion removal using mud-wasp nest material were substituted into Lagergren pseudo first-order kinetic model and the trend is shown graphically in Fig. 15. The correlation coefficient was found to be 0.306, and the calculated equilibrium uptake, q_e (0.2618 mg/g) was not even near the experimental value of q_e (4.5662 mg/g), suggesting the insufficiency of the pseudo first-order model to describe the mechanism of adsorption for the system.

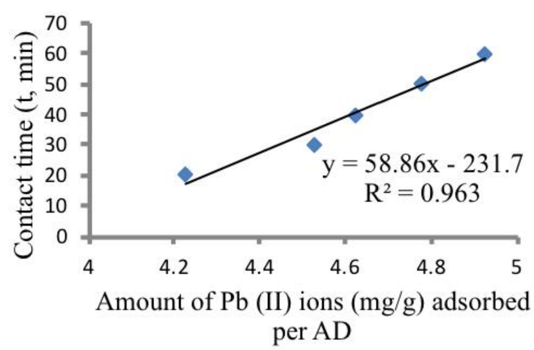

Fig. 9. Correlation between AD and CT

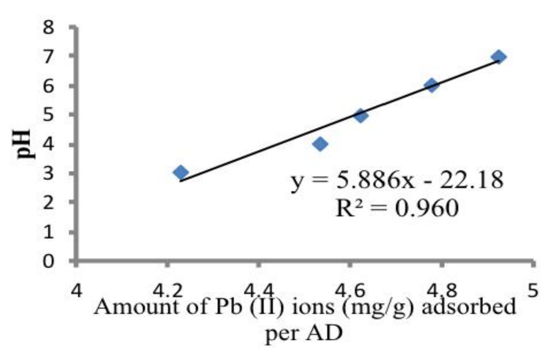

Fig. 10. Correlation between AD and pH

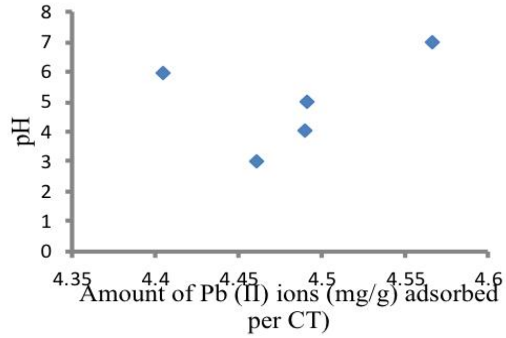

Fig. 11. Correlation between CT and pH

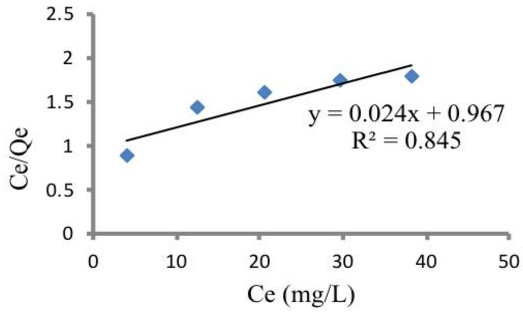

Fig. 12. Linearized Langmuir adsorption of Pb (II) ions onto mud-wasp nest

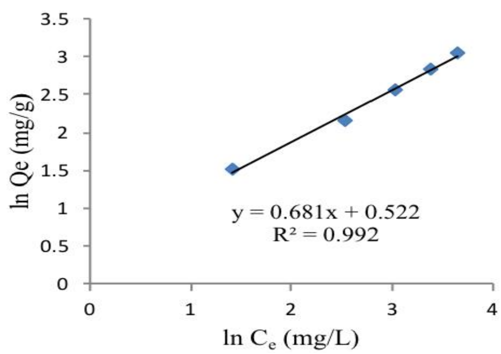

Fig. 13. Linearized Freundlich adsorption of Pb (II) ions onto the mud-wasp nest

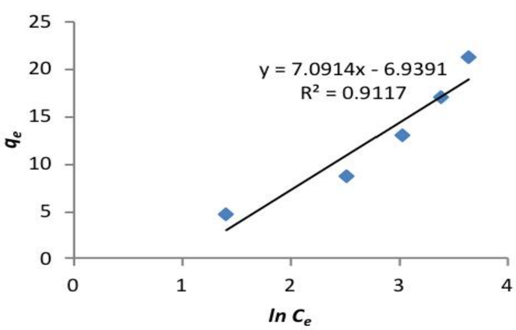

Fig. 14. Linearized Temkin adsorption of Pb (II) ions onto mud-wasp nest

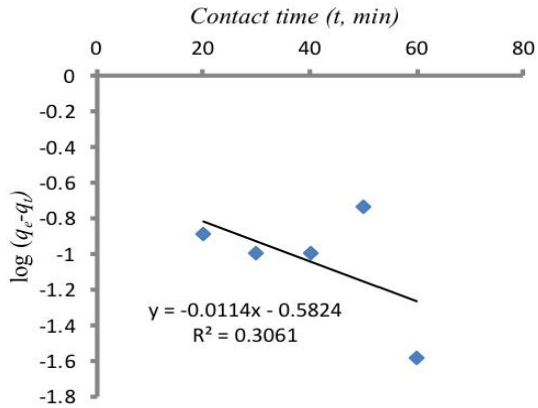

Fig. 15. Pseudo first-order adsorption kinetics of Pb(II) on mud-wasp nest

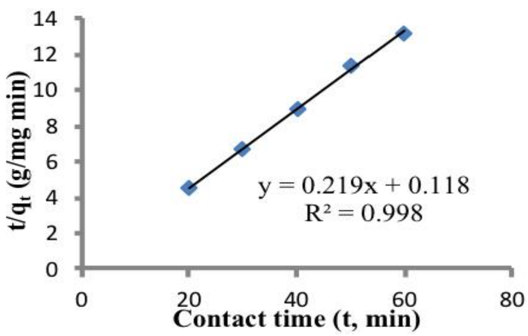

Fig. 16. Pseudo second-order adsorption kinetics of Pb (II) ions onto mud-wasp nest

3.7.2 Pseudo second-order kinetic model

Experimental data were also substituted into the pseudo-second order kinetic model, which is expressed by Equation (13).

$$\frac{t}{q_t} = \frac{1}{\left(k_2 q_e^{\ 2}\right)} + \frac{1}{q_e} t \tag{13}$$

Where q_e (mg/g) and q_t (mg/g) are the amounts of metal adsorbed at equilibrium and at any time t respectively, t is the contact time, in minutes, and k_2 (g/mg min) is the rate constant for the pseudo-second order adsorption [37]. The initial adsorption rate, h (mg/g min), as t→0, can be defined as given in Equation (14).

$$h = k_2 q_e^{\ 2} \tag{14}$$

Equation (13) applies to systems where the graph of t/q_t versus t is linear, from which the constants q_e and k_2 are obtained from the slope and the intercept of the plot respectively [37].

Table 1. Equilibrium adsorption of Pb^{2+} ions onto mud-wasp nest

Initial Pb^{2+} ion Conc. (C_o, mg/L)	Equilibrium Pb^{2+} ion Conc. (C_e, mg/L)	Amount of Pb^{2+} ion adsorbed (q_e, mg/g)	% Pb^{2+} ion adsorbed
50	4.0855 ± 1.6	4.5915 ± 1.58	91.829 ± 3.167
100	12.4939 ± 2.3	8.75062 ± 1.88	87. 5062 ± 1.877
150	20. 6278 ± 3.3	12.9372 ± 3.27	86.2482 ± 2.181
200	29.9471 ± 5.6	17.0356 ± 2.48	85.1780 ± 1.237
250	38.1043 ± 2.8	21.1896 ± 2.76	84. 7583 ± 1.103

Table 2. Kinetic constants for adsorption of Pb (II) ions onto mud-wasp nest

Pseudo first order kinetics			Pseudo second-order kinetics			
q_e (mg/g)	k_1 (min^{-1})	R^2	q_e (mg/g)	k_2 (g/mg min)	h (mg/g min)	R^2
0.2618	0.0253	0.306	4.5662	0.4065	8.4755	0.998

The linear plots of t/q_t versus t for the pseudo-second order model for the adsorption of Pb (II) ion onto mud-wasp nests at 30±2°C follow the trend in Fig. 16. From the results, the pseudo-second order rate constant,k_2, was obtained as 0.4065 (g/mg min). Equilibrim sorption capacity, q_e and initial sorption rate, h yielded 4.5662 mg/g and 8.4755 mg/g min respectively, while the correlation coefficient was obtained as 0.998. These results, as tabulated in Table 2, suggest that adsorption of Pb (II) ions onto mud-wasp nest is best described by the pseudo-second order kinetics; and the aquous Pb (II) ion adsorption onto mud-wasp nest surface is typically chemisorption.

4. CONCLUSION

Pb (II) ion adsorption onto mud-wasp nest was in the range 84.8 - 91.8% depending on the initial metal ion concentration. The Pb (II) ion loading capacity increased with increasing metal ion concentration from 4.9 mg/g to 21.9 mg/g. Correlations between the parameters investigated revealed a strong positive linear relationship. This implies that increasing these parameters simultaneously during adsorption would enhance the removal of Pb (II) ion quantity from aqueous solution by the mud-wasp nest. Linear relationships also exist between adsorption dose/ contact time (Fig. 9) and adsorption dose/pH (Fig. 10). However, a non-linear relationship exists between contact time/pH (Fig. 11).This implies that contact time and pH cannot be manipulated simultaneously during adsorption to enhance increased amounts of Pb (II) ion adsorbed.

Adsorption of Pb (II) ion onto mud-wasp net surface was best described by the Freundlinch isotherm and the pseudo second order kinetic model, which suggests that the adsorption process was accompanied by chemical bonding and hence, chemisorption.

These results show that mud-wasp nest can be used as low-cost adsorbent for the removal of Pb (II) ion from solution.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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