Kinetic, Isothermal, and Thermodynamics Studies of the Biosorption of Pb (II) from Aqueous Solution by White Star Apple (*Chrysophyllum albidum G.*) Seed Shells

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ABSTRACT

The existence of metal ions in an aqueous solution represents an environmental problem. A high level of pollution that poses a serious threat to man and his environment has been recorded due to technological and industrial advancements. These inorganic species are non-biodegradable, toxic to man and his environment, and must be eliminated from the water. The conventional methods available for the removal of heavy metals are expensive, and also produce some toxic sludge that is hardly disposed of. This has led to the invention of an economical, environmentally friendly, efficient, and effective alternative technology at little or no cost like biosorption.

In this work, the effects of solution pH, contact time, initial metal ion concentration, and biosorbent dosage were investigated. The optimum pH of the metal ions was obtained as the biosorption of the metal ions was found to be pH-dependent. The study of the effect of time shows that time affects biosorption. A kinetic study indicated that the pseudo-second-order kinetic model best represents the biosorption of metal ions. Furthermore, the sorption of metal ions was analyzed with Freundlich and Langmuir models, in each case, Freundlich models appear to have a better regression co-efficient.

Thermodynamically, the biosorption of the metal ions is endothermic. Similarly, a positive change in entropy was observed.

(Keywords: biosorption, metal ions, toxic, pH, initial metal ion concentration, kinetic study, thermodynamics, Freundlich and Langmuir models)

INTRODUCTION

Over the past years, a high level of pollution that poses a serious threat to man and his environment has been recorded due to technological and industrial advancements. The generation and disposal of waste materials from several activities such as mining operations, sludge disposal, metal plating, manufacturing of electrical materials, chemical production, agricultural practices, alloy manufacturing industries, etc. have continued to trouble man and his environment by the introduction of metal ions such as Pb (II), Cd (II), Zn (II), Mn (II), Cu (II), and others either in large or trace amounts to be released into the environment. Most of these metal ions are introduced due to improper and inappropriate handling of sewage effluents that are released into the aquatic media which can detrimental to humans, animals, and plants (Gupta, et al., 2008; Bansode, et al., 2003).

These metals are stable elements that cannot be metabolized by the body and get passed up in the food chain to human beings. When waste is disposed into the environment, a further long-term hazard is encountered. There are possibly more problems from these metals, which interfere with normal bodily function, than have been considered in most medical circles (Babarinde and Oyedipe, 2001). Reviewing all of our vitamins and minerals has shown us that almost every substance that is useful can be a toxin or poison, as well. Metals are known primarily and almost exclusively for their potential toxicity in the body, though commercially they may have great advantages (Babarinde, 2011).

In this respect, many physicochemical methods have been developed for the removal of metal ions from aqueous solutions including precipitation, evaporation, electrodeposition, ion exchange, membrane separation, coagulation, etc. (Ajmal, et al., 2003). Nevertheless, these have negative effects such as secondary pollution, high cost, high energy input, and a large number of chemical reagents. It can be said that these conventional methods for the removal of metal ions from aqueous solutions are limited by technical and economic barriers. To maneuver this barrier, simpler, low-cost, efficient metal removal processes are of higher importance (Holan and Volesky, 1994).

The search for new, effective, and economical technologies involving the removal of toxic metals from wastewaters has directed attention to biosorption based on metal binding capacities of various biological materials at little or no cost (Babarinde and Oyedipe, 2001; Aksu, 2002; Annadurai, et al., 2002; Babarinde, et al., 2002; Babarinde, 2002; Bansode, et al., 2003; Abia, et al., 2003; Ajmal, et al., 2003; Dang, et al., 2009). Biosorption is an efficient and effective alternative technology for cleaning up water at little or no cost.

MATERIALS AND METHODS

Materials

White star apple (*Chrysophyllum albidum*) seeds were obtained from a fruit seller at Ago-Iwoye market, Ago-Iwoye, Ijebu-North Local Government Area, Ogun State, Nigeria. The seeds were properly rinsed with de-ionized water and air-dried immediately, removing the endosperm of the seed by breaking and recovering the pericarp into smaller sizes of about 0.5g. The seed sample was kept in an air-tight polythene bag till the time of usage.

Preparation of Stock Solutions

All chemicals used in this study were of analytical reagent grade and were used without further purification. Standard solutions of Pb (II) used for the study were prepared from Pb $(NO_3)_3$. Each was made up to the mark inappropriate standard volumetric flask. The precise concentrations of these metals were determined using a Perkin-Elmer Analyst 700 Flame Atomic Absorption Spectrophotometer with a deuterium background corrector.

Biosorption Experiments

The effect of pH on the biosorption of lead was carried out within a range that would not be influenced by the metal precipitated. This was done by contacting 0.5g of White star apple (*Chrysophyllum albidum*) seed shells with 25ml of 100 mg/L metal ion solution in a boiling tube within the range pH 1- 7. The pH of each solution was adjusted to the desired value by drop-wise addition of 0.1M HNO_3 and/or 0.1M NaOH solutions using a glass electrode (Jenway 3510 model) pH meter. The boiling tubes containing the mixture were left in a water bath for 3 hours. The biomass was decantated from the solution. The residual metal ion concentration in the solution was analyzed. The optimum pH was determined as the pH with the highest biosorption of each metal ion (Zhou et al, 2004).

The effect of contact time of White star apple (*Chrysophyllum albidum*) seed shells was studied at various time intervals from (0-300 mins) and at the concentration of 100 mg/L. This was done by weighing 0.5g of White star apple (*Chrysophyllum albidum*) seed shells into each boiling tube and 25ml of 100 mg/L of metal ion solution at optimal pH was introduced into it. The seed shells were left in the solution for varying periods. The solution in the boiling tube was decanted at different time intervals from the first to the last tube. The aliquot was then taken for analysis using an Atomic Absorption Spectrophotometer. The number of metal ions sorbed was calculated for each sample.

Effect of biosorbent dosage was studied at various doses of White star apple (*Chrysophyllum albidum*) seed shells ranging from 0.2g to 2.0g. The percentage of Pb (II) removed increases with an increase in White star apple (*Chrysophyllum albidum*) seed shells dosage 15 mL of 0.3 mM each of lead (II) and chromium (III) solutions, adjusted to pH 6. These were then agitated at 200 rpm for 2 hours and centrifuged at 8,000 rpm for 10 min. to separate the supernatants.

A batch biosorption study of metal ions was carried out using a concentration range of 10-100 mg/L. This was done by introducing 0.5 g of the White star apple (*Chrysophyllum albidum*) seed shells into each of the boiling tubes employed and 25 ml of 100 mg/L of metal ion in the solution at optimal pH was added to the tube. Two boiling tubes were used for each concentration. The tubes were left in a water bath maintained at 27˚C. The metal-bound White star apple (*Chrysophyllum albidum*) seed shells were removed from the solution and the concentration of a residual metal ion in each solution was determined.

The batch biosorption process was studied at different temperatures of 20-50°C to investigate the effect of temperature on the biosorption process. This was done by contacting 0.5 g of White star apple (*Chrysophyllum albidum*) seed shells with 25ml of 100 mg/L of metal ion solution at the optimal pH.

The thermodynamic studies were investigated by carrying out batch studies at optimal conditions and different temperatures. The temperatures chosen for study were 15°C, 25°C, 37°C, and 50°C.

Statistical Analysis

On graphical representation, the curve fittings of the data obtained were performed using Microcal Origin 6.0 software.

RESULTS AND DISCUSSION

FT-IR Studies of the Free and Metal-Bound White Star Apple (*Chrysophyllum albidum*) Seed Shells

The FT-IR spectra of dried unloaded, Pb-loaded White star apple (*Chrysophyllum albidum*) seed shells were taken to obtain information on the nature of possible interactions between the functional groups of White star apple (*Chrysophyllum albidum*) seeds biomass and the metal ions as presented in Figure 1.

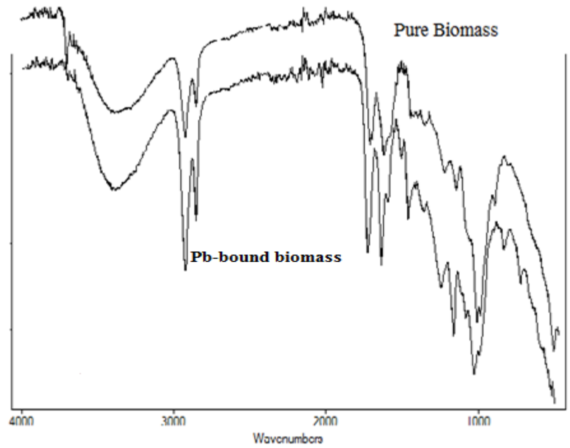

Figure 1: FT-IR Spectra of the Free and Metal-Bound of White Star Apple (*Chrysophyllum albidum*) Seed Shells before and after Biosorption of Pb (II) for 3 hours.

The IR spectra of the biomass showed distinct and sharp absorptions indicative of the existence of the functional groups such as N=O, –OH, and C=O groups as shown in Figure 1. These bands are due to the functional groups of White star apple (*Chrysophyllum albidum*) seed shells that participate in the biosorption of Pb (II). In comparison, there are clear band shifts and a decrease in the intensity of bands as reported in Table 1.

Table 1: FT-IR spectra characteristics White star apple (*Chrysophyllum albidum*) seed shells before and after biosorption of Pb (II) for 3 hours.

Absorption band (cm^{-1})		
Before	After	Functional groups
3350.00	3314.23	O-H Stretch
2922.57	2922.53	C-H Stretch
2852.71	2853.71	C-H Stretch
1723.04	1726.56	C=O Stretch (Ester)
1638.79	1638.20	N-H bend (Amine)
1367.49	1366.67	C-H bond
1239.72	1243.25	C-N Stretch
1163.09	1162.63	C-O Stretch (Ester)
1028.87	1028.40	C-O Stretch (Ester)

The FT-IR spectra of the White star apple (*Chrysophyllum albidum*) seed biomass indicated slight changes in the absorption peak frequencies since the binding of the metal ions causes a reduction in absorption frequencies. These shifts in absorbance observed implies that there were metal-binding processes taking place on the active sites of the biomass. Analysis of the FT-IR spectra showed the presence of ionizable functional groups (C=O, O-H) which can interact with cations (Sun, et al., 2008; Ertugay and Bayhan, 2008; Uluozlu, et al., 2010; Zhou, et al., 2004; Volesky, 2003). This implies that these functional groups would serve in the removal of positively charged ions from the solution.

Effect of pH on Biosorption

The effect of pH on the solution has been established to be a vital parameter in the biosorption process (Babarinde, 2011; Sun, et al., 2008). The overall charge of the sorbate and that of the sorbent are dependent on the pH of the solution. At low pH, the metal ion uptake is inhibited by a net positive charge on the sorbent and the competition between the metal ions and the hydrogen ions in the solution. As the pH increases, the negative charge density on biomass increases as a result of deprotonation of the metal-binding sites on the leaf, consequently, the biosorption of the metal ions increases.

Figure 2 shows the variation of the metal ion sorbed on White star apple (*Chrysophyllum albidum*) seed shells at various solution pH values. In each case, the biosorption increased steadily as the pH increased from pH 1 to pH 7. The increase observed in the biosorption with an increase in pH implies that the ion-exchange process is involved. The reaction involved the biosorption of metal ion (represented as M^{2+} for a metal ion) from the liquid phase to the solid phase, the biosorbent with lone pair of electrons (represented as Ä), and can be considered as a reversible reaction with an equilibrium being made between the two phases as schematically shown below for a divalent metal ion in solution:

$$\text{Ä} + M^{2+} \rightleftharpoons \text{A-M} \quad \textbf{(1)}$$

The reversibility of the biosorption process is observed when the metal-bound biomass is treated with dilute HNO_3 which is a desorption process.

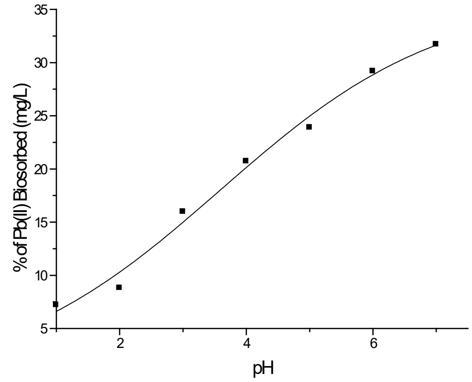

Figure 2: The Effect of pH on the Biosorption of Pb (II) using 0.5g of White Star Apple (*Chrysophyllum albidum*) Seed Shells at Constant Temperature of 300K and Initial Metal Ion Concentration of 100mg/L.

Effect of Contact Time on Biosorption

The plot of percentage Pb (II) removed against contact time for Pb (II) at optimum pH values is shown in Figure 3. It was observed that the adsorption of Pb (II) onto White star apple (*Chrysophyllum albidum*) seed shells were highly influenced by contact time. The data obtained from the adsorption of Pb (II) onto White star apple (*Chrysophyllum albidum*) seed shells showed that biosorption increases with increasing contact time.

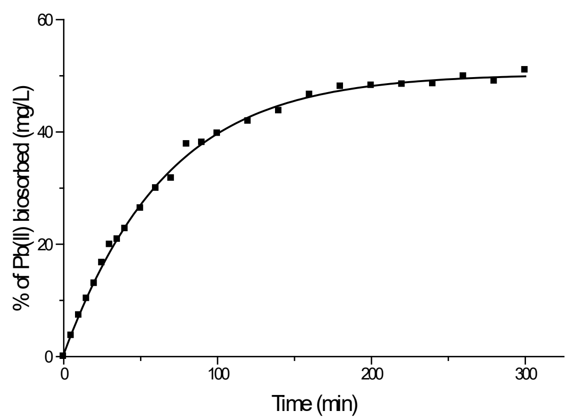

Figure 3: Time-Dependence Profile for the Biosorption of Pb (II) using 0.5g of White Star Apple (*Chrysophyllum albidum*) Seed Shells at Constant Temperature of 300K, pH 6, and Initial Metal Ion Concentration of 100mg/L.

The fast-initial uptake that occurred in the early stage of adsorption was because most of the binding sites on White star apple (*Chrysophyllum albidum*) seed shells were free which allowed quick binding of Pb (II) on the biomass (Gupta *et al.*, 2008). The binding sites became exhausted, the uptake rate slowed down due to competition for decreasing availability of active sites by Pb (II). According to the test results, at an equilibrium time of 300 minutes, the metal ion uptake was 51%. Equilibrium time is a crucial parameter for the optimal removal of metal ions in wastewater. The increased uptake of Pb (II) with contact time can due to the decreased mass transfer coefficient of the diffusion-controlled reaction between the adsorbent the metal ion

Kinetic Studies

Pseudo-first-order model: To investigate the kinetics of the biosorption of these metal ions on White star apple (*Chrysophyllum albidum*) seed shells, four kinetic models were applied to the biosorption process. These are the pseudo-first-order and the pseudo-second-order. One of such models is the Lagergren pseudo-first-order model which considers that the rate of occupation of the biosorption sites is proportional to the number of the unoccupied sites (Ertugay and Bayhan, 2008):

$$rate = -\frac{d[A]}{dt} = k\,[A]^n \quad \textbf{(2)}$$

This can also be written as:

$$\frac{d}{dt}q_t = k_1(q_e - q_t) \quad \textbf{(3)}$$

Integrating between the limits q_t = 0 at t =0 and q_t = q_t at t =t, we obtain:

$$\log\left[\frac{q_e}{(q_e - q_t)}\right] = \frac{k_1}{2.303}t \quad \textbf{(4)}$$

This can be rearranged to obtain a linear form:

$$\log(q_e - q_t) = \log q_e - \frac{k_1}{2.303}t \quad \textbf{(5)}$$

Where k_1 is the Lagergren rate constant of the biosorption (min^{-1}); q_e and q_t are the amounts of metal ions sorbed (mg/g) at equilibrium and at time t, respectively.

The plot of $\log(q_e - q_t)$ versus t for the biosorption of Pb(II) metal ions on the White star apple (*Chrysophyllum albidum*) seed shells at an initial concentration of 100 mg/L should give a straight line for a process that follows first-order kinetic model as represented in Figure 4.

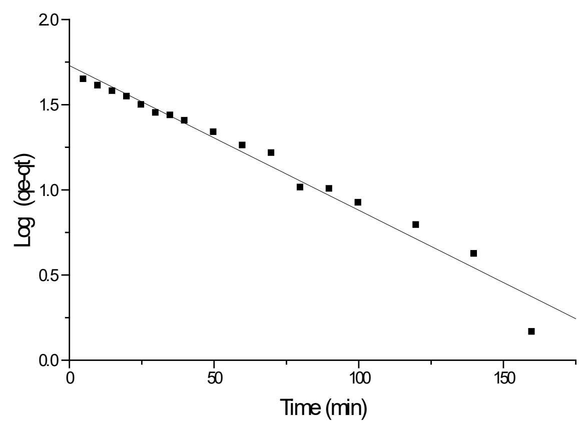

Figure 4: Pseudo-First Order Kinetic Plot for the Biosorption of Pb (II) using 0.5g of White Star Apple (*Chrysophyllum albidum*) Seed Shells at a Constant Temperature of 300K, pH 6, and Initial Metal Ion Concentration of 100mg/L.

Pseudo-second-order model: The kinetic data were examined with the pseudo-second-order kinetic model. The pseudo-second-order kinetic model is represented as:

$$\frac{d}{d_t}q_t = k_2(q_e - q_t)^2 \quad \textbf{(6)}$$

On integrating between boundary conditions, we have:

$$\frac{1}{q_e - q_t} = \frac{1}{q_e} + k_2 t \quad \textbf{(7)}$$

On rearrangement, we have:

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e}t \quad \textbf{(8)}$$

Where k_2 is the equilibrium rate constant of the pseudo-second-order biosorption process (g mg^{-1}

min⁻¹). From lead metal ions under the study, the straight-line plots of t versus t/q_t showed good fitness of experimental data with the second-order kinetic model as presented in Figure 5.

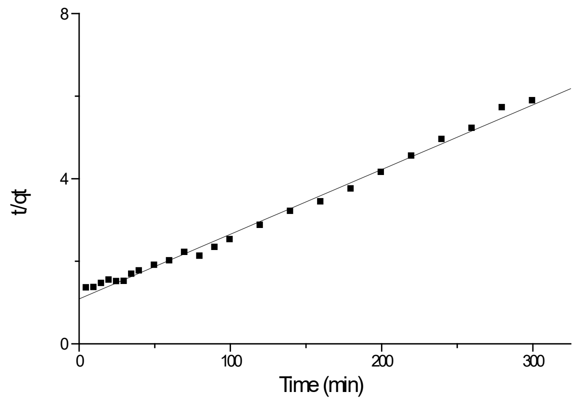

Figure 5: Pseudo-Second-Order Kinetic Plot for the Biosorption of Pb (II) using 0.5g of White Star Apple (*Chrysophyllum albidum*) Seed Shells at Constant Temperature of 300K, pH 6, and Initial Metal Ion Concentration of 100mg/L.

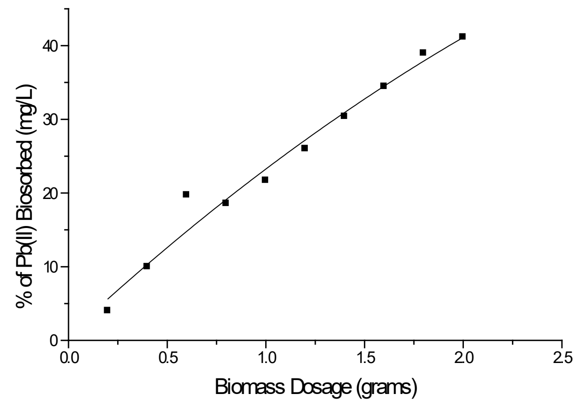

Figure 6: The Effect of Biomass Dosage Plot on the Biosorption of White Star Apple (*Chrysophyllum albidum*) Seed Shells at Constant Temperature of 300K, pH 6, the Optimum Time of 180 min, and Initial Metal Ion Concentration of 100mg/L.

Effect of Biosorbent Dosage on Biosorption

The biosorption of Pb (II) was studied at various doses of White star apple (*Chrysophyllum albidum*) seed shells ranging from 0.2g to 2.0g. The percentage of Pb (II) removed increases with an increase in White star apple (*Chrysophyllum albidum*) seed shells dosage due to an increase in adsorption surface area.

The effect of biomass dosage on biosorption efficiency is reported in Figure 6. The general trend of increase in metal ion sorbed with an increase in uptake due to more binding sites on the biomass available for biosorption. Hence, the number of metal ions available for biosorption per gram of biosorbent will be less when the amount of biosorbent is increased.

The difference in biosorption capacity at the same initial concentration and contact time may also be attributed to a difference in their chemical affinities and ion exchange capacity, to the chemical functional group on the surface of the biosorbent.

Effect of Metal Ion Concentration on Biosorption

The initial metal concentrations (10mg/L to 100mg/L) of Lead metal in the solution influenced the equilibrium uptake of Pb (II). It was noted that as the initial concentration increase it favors the removal of Pb (II) in the solution. The increase in uptake capacity of the biosorbent with the increased initial lead ions concentration is due to the higher availability of lead ions for the sorption.

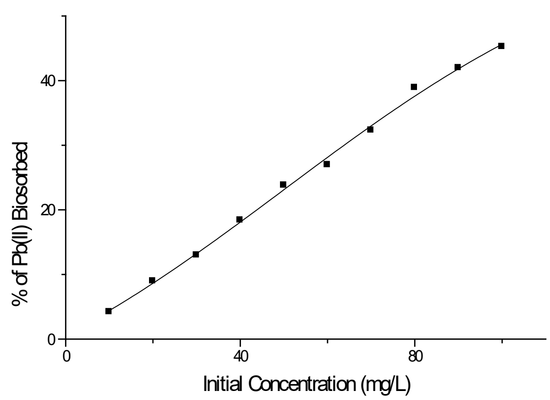

Figure 7: The Effect of Initial Metal Ion Concentration Plot for the Biosorption of White Star Apple (*Chrysophyllum albidum*) Seed Shells at Constant Temperature of 303K, pH 6, Varying Initial Metal Ion Concentrations, and Optimum tTme of 180 mins.

Moreover, higher initial lead ions concentrations provide increase driving force to overcome all mass transfer resistance of metal ions between the aqueous and solid phase resulting in a higher probability of collision between Pb (II) and White star apple (*Chrysophyllum albidum*) seed shells.

Some experimental models were applied, the simplest of these terms are Langmuir and Freundlich isotherms. Both terms are described based on the physical interaction of adsorption and desorption.

Biosorption Isotherm

Langmuir Isotherm Model: The Langmuir model was used to describe observed sorption phenomena and suggests that uptake occurs on a homogeneous surface by monolayer sorption without interaction between adsorbed molecules. The Langmuir equation is expressed as:

$$q_e = \frac{(q_{max} k_2 C_e)}{1 + k_L C_e} \quad \textbf{(9)}$$

Where Ce is the equilibrium solute concentration in the fluid (mg/L), k_L represents Langmuir equilibrium adsorption constant (mg/L), q_{max} is the Langmuir maximum metal uptake in mg/G, q_e is the metal uptake in mg/g related to the energy of biosorption which quantitatively reflects the affinity between the biosorbent and the biosorbate. Where; q_{max} and k_L can be determined from the linear plot of $1/q_e$ versus $1/C_e$. The shape of the Langmuir isotherm can be used to predict whether sorption is favorable or unfavorable in a batch biosorption process. The essential features of the isotherm can be expressed in terms of a dimensionless constant separation factor, R_L, (Anirudhan and Radhrtishan, 2008)

The Langmuir equation is expressed as:

$$\frac{1}{\Gamma} = \frac{1}{b_m}\frac{1}{C_e} + \frac{1}{\Gamma_m} \quad \textbf{(10)}$$

Where Γ, Γ_m, and b_m are the Langmuir parameters. The parameters of the Langmuir isotherms show that the Langmuir isotherm is a better isotherm than the Freundlich isotherm.

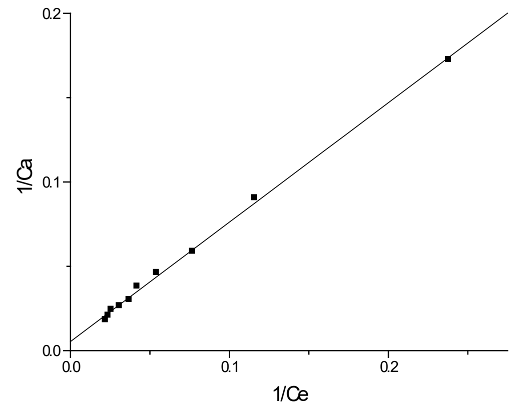

Figure 8: Langmuir Isotherm Plot for the Biosorbed of White Star Apple (*Chrysophyllum albidum*) Seed Shells at Constant Temperature of 300K, pH 6, the Optimum Time of 180 mins, Varying the Initial Metal Ion concentrations.

Freundlich Isotherm Model: Freundlich isotherm model is an empirical equation describing adsorption onto a heterogeneous surface. It is used to estimate the adsorption intensity of sorbent towards the adsorbate and is given by the equation (Freundlich, 1907) below:

$$q_e = k_f C_e^{1/n} \quad \textbf{(11)}$$

Where q_e is the metal uptake in mg/g, C_e is the equilibrium solute concentration in the fluid (mg/L), n represents the Freundlich constant. It is related to adsorption intensity, k_f is Freundlich adsorption constants related to adsorption capacity.

The Freundlich equation is expressed as:

$$\log\Gamma = \frac{1}{n}\log C_e + \log K_f \quad \textbf{(12)}$$

Where K_f and $\frac{1}{n}$ are the Freundlich constants related to the biosorption capacity and biosorption intensity of the biosorbent, respectively. A plot of q_e against log C_e gives a straight-line graph with (1/n) as slope and log k_f as intercept. The corresponding constants and coefficients of correlation, R^2 associated with linearized models of Langmuir and Freundlich adsorption isotherm at 300K for Pb (II) ions. The Freundlich isotherms for the biosorption of Pb (II) on White star apple (*Chrysophyllum albidum*) seed shells are reported.

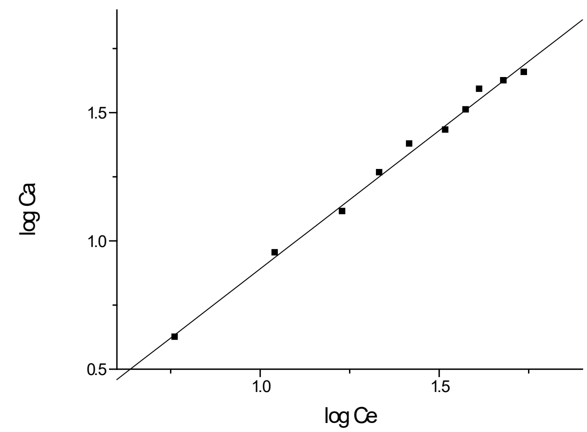

Figure 9: Freundlich Isotherm Plot for the Biosorption of White Star Apple (*Chrysophyllum albidum*) Seed Shells at Constant Temperature of 300K, pH 6, the Optimum Time of 180 mins, Varying the Initial Metal Ion Concentrations.

Biosorption Thermodynamics

The variation of temperature affects the biosorption of metal ions onto solid surfaces of biomass since the biosorption process is a reversible one. The nature of each side of the equilibrium determines the effect temperature has on the position of equilibrium. The endothermic side is favored by an increase in temperature while the contrary holds for the exothermic side. The corresponding free energy change was calculated from the relation (Sun, et al.,2008; de la Rosa, et al., 2008)

$$\Delta G^{\circ} = -RT In\, K_c \quad \textbf{(13)}$$

Where T (K) is the absolute temperature. The equilibrium constant (K_c) was calculated from the following relationship.

$$K_c = \frac{C_{ad}}{C_e} \quad \textbf{(14)}$$

Where C_e and C_{ad} are the equilibrium concentrations of metal ions (mg/L) in solution and on biosorbent, respectively. Consequently, the thermodynamic behavior of the biosorption of Pb (II) onto White star apple (*Chrysophyllum albidum*) seed shells was evaluated through the change in free energy (ΔG˚), enthalpy (ΔH˚) and entropy (ΔS˚). The thermodynamic parameters like enthalpy and entropy are obtained using van't Hoff equation (Uluozlu, *et a*l., 2010; Qu, *et al.*, 2010). The alteration in free energy is related to other thermodynamic properties as:

$$\Delta G^{\circ} = \Delta H^{\circ} - T\Delta S^{\circ} \quad \textbf{(15)}$$

$$\ln K_c = \frac{\Delta S^{o}}{R} - \frac{\Delta H^{o}}{RT} \quad \textbf{(16)}$$

Where T is the absolute temperature (K); R is the gas constant (8.314 $Jmol^{-1}.K^{-1}$). ΔH˚ ($J.mol^{-1}$) and ΔS˚ ($J.mol^{-1}.K^{-1}$) were calculated from the slope and intercept of the linear plot of lnK_c vs 1/T. The thermodynamic parameters obtained for this study are presented in Figure 10 and are linear over the entire range of temperature investigated.

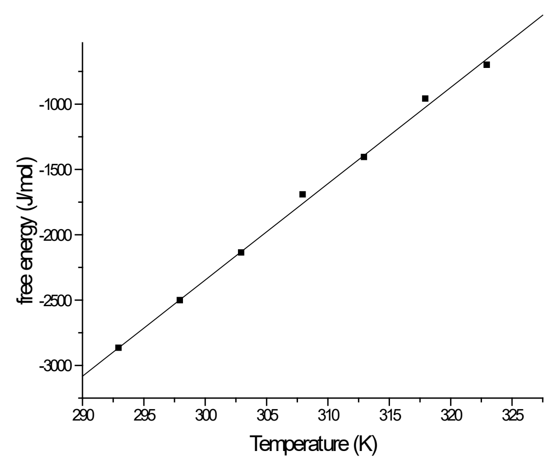

Figure 10: Thermodynamics Data for the Biosorption of White Star Apple (*Chrysophyllum albidum*) Seed Shells Varying the Temperature, pH 6, the Optimum time of 180 mins, and Initial Metal Ion Concentrations of 100mg/L

The negative values of $\Delta G°$ indicates spontaneity of each biosorption process. The positive value of $\Delta H°$ for the biosorption of Pb(II) suggests endothermic nature of the biosorption processes. This is also supported by the increase in the value of biosorption capacity of the biosorbent with rise in temperature. The positive value of $\Delta S°$ observed for the biosorption of this metal ion indicate an increase in randomness at the solid/solution interface during biosorption.

Generally, the charge of standard free energy for physisorption is in the range of -20 to 0kJ/mol and for chemisorption varies between -80 and 400kJ/mol (Vimoses, et al., 2009; Sen et al, 2011). In the present study, the overall delta G has values ranging from -6.9 to 2.1kJ/mol. These results correspond to a spontaneous physical adsorption of the metal ions, indicating that this system does not gain energy from external source (Vimoses, et al., 2009). The decrease in $\Delta G°$ with increase in temperature indicates more efficient biosorption at higher temperature. This is also supported by the increase in the value of biosorption capacity of the biosorbent with rise in temperature.

Furthermore, the magnitude of activation energy (A) gives an idea about the type of adsorption which is mainly diffusion-controlled process (not diffusivity of solute through micro pore wall surface of a particle) or chemical reaction processes (Ajmal, et al., 2003). Energies of activation, A, below 42 kJ/mol indicate diffusion-controlled processes, and higher values give chemical reaction-based processes. Therefore, energy of activation, A, has been calculated as per the following relation:

$$\mathrm{A} = \Delta \mathrm{H}° + \mathrm{RT} \quad \textbf{(17)}$$

In this study, energy of activation, a value was less than 42 kJ/mol indicating diffusion-controlled adsorption process.

CONCLUSION

White star apple (*Chrysophyllum albidum*) seed shells have much potential as an efficient and useful biosorbent for the removal of Pb (II) from wastewaters and industrial effluents. The FT-IR study demonstrates the involvement of functional groups with lone pairs of electrons on the biomass for binding with the Pb (II) metal ions in the aqueous solution.

In this work, we have studied the biosorption of Pb (II) by White star apple (*Chrysophyllum albidum*) seed shells under various conditions. The biosorption of each was influenced by each of the physiochemical. The pH has many impacts on the biosorption of these metal ions from aqueous solutions. The kinetic study revealed that the pseudo-second-order model describes best the biosorption process. The sorption isotherms of these metal ions onto the biosorbent are well described by the Freundlich isotherm model. The thermodynamic study shows that the biosorption of each of Pb (II) was spontaneous. This study shows that coconut leaf has a high potential for treating industrial effluents containing Pb (II).

The successful application of White star apple (*Chrysophyllum albidum*) seed shells as biosorbent for the removal of Pb (II) from aqueous solution has further strengthened the call for the use of agricultural waste to replace the conventional and expensive methods in the treatment of industrial effluents.

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