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Kinetic and equilibrium studies of adsorption of Pb(II) on low cost agri-waste adsorbent Jute Stick Powder

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ABSTRACT

A lingo-cellulosic material Jute Stick Powder was used as a biosorbent to remove Pb(II) ions from aqueous solution and the biosorption behavior was investigated as a function of pH, metal ion concentration, adsorbent dosages and agitation time. Sorption binding sites present in JSP was assessed by Infrared spectroscopy (IR) and Scanning Electron Micrograph (SEM). The determined experimental data were fitted to some common kinetic and equilibrium models. Langmuir isotherm and pseudo-second-order kinetic model gave better fit to experimental data. The study revealed that spontaneous ion-exchange and complexation process involved in the adsorption mechanism. When the repeated adsorption-desorption cycles were performed, JSP kept its adsorptive efficiency even after three cycles of reuse.

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1. Introduction

Drinking water is adversely affected by lead contamination which causes fatal diseases to human body. The harmful and dangerous elements enter into the human body by different ways. Lead paints and leaded gasoline spreads lead dust which can be inhaled. Some pipe lines made of lead releases inorganic lead (Pb^{2+}) which creates metabolic poison and inhibit enzyme in the human body. Another form of lead organic lead, as tetra ethyl lead (TEL) or tetra methyl lead (TML) which is several times more venomous than inorganic form of lead. Exposure to lead in a high concentration in the body can cause death or permanent damage to the central nervous system, the brain, and kidneys [1]. The toxic effect of lead is observed in behavior and learning problems, memory and concentration problems, hearing problems, headaches, slowed growth, reproductive problems in men and women, digestive problems, muscle and joint pain. Child's health is prone to attack of lead toxicity which is a result of some symptoms such as a child's growth, damage the nervous system, and learning disabilities. Common methods have been practiced for removals of heavy metals in the past decades are chemical precipitation, ultra-filtration, ion exchange, reverse osmosis, electro winning, carbon adsorption and phytoremediation *etc.* [2]. Conventional methods of heavy metal ions removal have some disadvantages such as partial metal removal, high energy and reagent requirements, and production of noxious sludge. Thus an economical and environment friendly method with a high efficiency to eliminate the heavy metal ions from water should be introduced. It is a great interest to the present researchers to identify an inexpensive alternative technique of removal of harmful heavy metal ions from the waste water [3,4]. Biosorption process is a new technology by which using living or non-living biomaterial heavy metals are adsorbed from the aqueous solution. There are some agricultural byproducts such as sugarcane biomass, rice husks, coconut husk, orange peel, banana peel, neem leaf etc, [5-7] which can be defined as efficient biosorbent because, they are cost effective, easily available, environment friendly, degradable and came from renewable sources [8]. In the present study, jute stick powder (JSP) is used as an adsorbent to remove Pb(II) from aqueous solution. Bangladesh is the second largest jute producing country where jute is called first cash crop for its demand in the national and international level. After collecting the jute fiber, the inner woody jute sticks are kept almost abandoned. There is no major use of this agricultural waste product except burning for cooking purpose or fencing. Therefore, our research objective is to incorporate jute stick as

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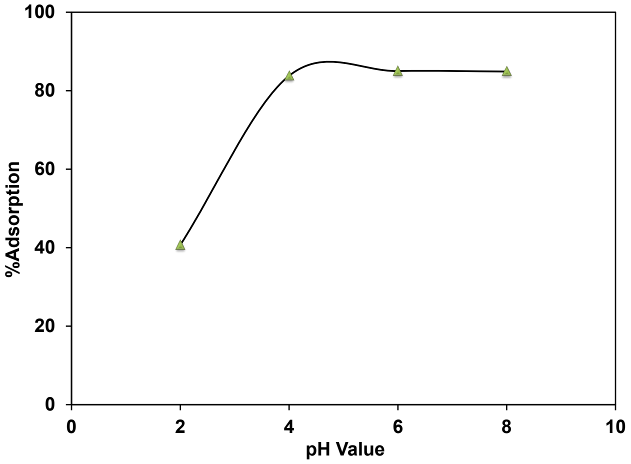

Figure 1. Effect of pH on biosorption of Pb(II) onto to JSP (C_i = 50 mg/L; Dose = 0.5 g/100 mL).

a potential biosorbent for removal of Pb(II) ions from aqueous solution.

2. Methodology

2.1. Preparation of biosorbent

Jute sticks were collected from the local agricultural firm; making small pieces washed with water to remove adhering substances. After that the chopped jute sticks were dried at 80 °C in a kitchen oven. This was powdered by grinding in a mechanical grinder and sieved. The jute stick powder 80-100 mesh size fractions were stored in an air tight container for subsequent uses.

2.2. Preparation of solutions

Necessary chemicals such as $Pb(NO_3)_2$ (>99% purity), anhydrous NaOH (>98% purity), and concentrated HCl (>37% purity) were of A.R. Grade (Merck Germany). All these chemicals were used without further purification. Stock solution of Pb(II) was prepared by dissolving 1.598 g of $Pb(NO_3)_2$ in one liter of double distilled water to achieve a concentration of 1000 mg/L. This stock solution was diluted to various working concentrations when needed.

2.3. Biosorption experiment in batch method

In a conical flask of 250 mL Pb(II) solution of varying concentration range from 20 to 100 mg/L was poured and the pH of each solution was adjusted to the required experimental value using a pH meter (Hanna, HI2209). Drop wise 0.1 M NaOH or 0.1 M HCl was added until the desired value was obtained. The effect of parameters was determined by using a range such as pH (2-8), adsorbent dose (0.25-1.00 g), initial Pb(II) ion concentration (20-100 mg/L), contact time (0-120 min) and shaking speed 180 rpm at a room temperature of 28 °C. To optimize the conditions one parameter was kept different while other parameters were kept constant. The solutions in conical flasks with predetermined conditions were subjected to shake in an orbital shaker (Stuart, Orbital shaker, SSL1) for a time interval. After finishing shaking the solution was filtered and the filtrate was analyzed for residual Pb(II) ion concentration using an atomic absorption spectrophotometer (AAS) (AA7000, Shimadzu). In a particular study this experiment was done for each experiment, the experiment was repeated in each case and the mean value was calculated to minimize errors. The adsorption uptake capacity and adsorption efficiency (% adsorption) of JSP for Pb(II) was determined by using following equations.

$$\text{Equilibrium uptake capacity},\ q_e = \frac{V(C_i - C_f)}{S} \quad (1)$$

$$\%Sorption = \frac{C_i - C_f}{C_i} \times 100 \quad (2)$$

where, q_e = Equilibrium uptake capacity (mg/g), C_i = Initial metal ion concentration, before the sorption analysis (mg/L), C_f = Final metal ion concentration after the sorption analysis (mg/L), S = Amount of biosorbent (g), V = Volume of experimental solution (L). The amount of biosorbent adsorbed was calculated from the difference between the initial metal ion concentration and final metal ion concentration of analyzed solution.

3. Result and discussions

3.1. Investigation of affecting condition of adsorption

3.1.1. Effect of pH

pH of the solution is a key parameter as it affects the biosorption performance of the metal ion to be removed and sorption sites of the surface of the biosorbent. In the present study, the effect of pH on Pb(II) removal is shown in Figure 1. The results point out that the Pb(II) sorption capacity of JSP increased sharply from pH = 2.0 to 4.0 with increase of pH and reached a plateau, followed by a small decrease from pH = 6.0 to 8.0. The maximum Pb(II) metal ion removal efficiency for JSP (85.00%) observed at pH = 6.0. The biosorbent surface would remain protonated at high concentration of H^+ ions and biosorbent surface charge become positive which make a repulsion force for Pb(II) at low pH value. Thus removal of metal ions at low pH is less [9]. Less number of H^+ would bind with more number of negative charged sites in JSP come to higher number of Pb(II) ions uptake at higher pH value. The Figure 1 shows that further increase of pH after 6.0 removal of metal was not significantly increased rather slightly decreased. This is because at higher pH Pb(II) ions to form precipitates as $Pb(OH)_2$. In our study, during optimization of pH, it was found practically that a white cloudiness was formed immediately in the metal solution when pH was adjusted to 8.0, probably it was happen due to the precipitation of $Pb(OH)_2$.

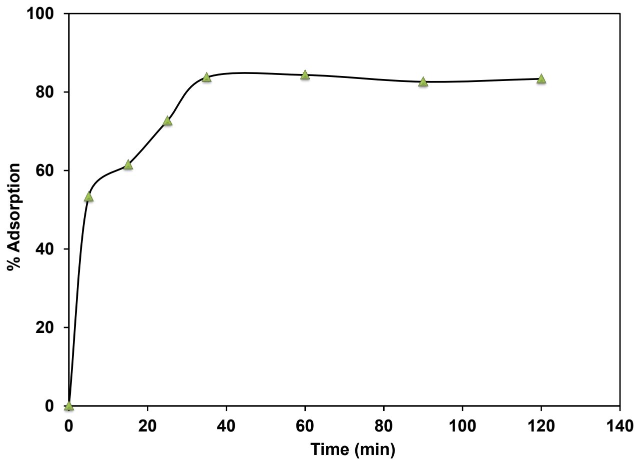

Figure 2. Effect of contact time on %Adsorption of Pb(II) with the increase of time.

Similar result reported by other authors [10], who observed that $Pb(OH)_2$ precipitation occur in aqueous solution at the pH of 7.18. Therefore, the biosorbents used for removal of Pb(II) the pH should be maintained at pH = 6.0 or lower, to avoid lead precipitation.

3.1.2. Effect of contact time

In the experiment reactions were undergone for adsorption of metal ions by JSP at a specific time intervals (0-120 min). Effect of contact time on % adsorption of Pb(II) with the increase of time has been shown Figure 2. Reaction conditions were pH = 6.0, Metal conc. = 50 mg/L; Dose = 0.5 g/100 mL. It was observed that the % removal increased rapidly (in the first 5-35 min) and then obtained equilibrium at about 40 minutes. Initially the active binding sites on the biosorbent were abundant result in gradual occupancy of these sites quickly [11]. After 40 minutes adsorption became less efficient due to the lacking of vacant sites.

3.1.3. Effect of initial metal ion concentration

The Figure 3(a) shows that the metal uptake of *JSP* increased gradually as the Pb(II) metal ion concentration increased from 20 to 100 mg/L. Dang *et al.* [12] reported that effect of the initial metal ion concentration is the driving force to overcome mass transfer resistances between the aqueous and solid phases. The number of collision between Pb(II) metal ion and the biosorbent is increased during increase of the metal ion concentration resulting increase of lead metal uptake [13]. On the contrary, Figure 3(b) shows that the removal percentage of the Pd(II) by Jute stick powder decreases from 94.42 to 86.62% with the increasing of initial metal ion concentration. Because all sorption sites are free to take metal ions at low concentrations of metal for a fixed amount of binding sites. When concentration of metal is higher for the same amount of adsorbent the percent removal became less because the binding sites become insufficient [14].

3.1.4. Effect of adsorbent dosage

Figure 4(a) shows that the %removal of lead(II) ions by the adsorbent increased sharply from 56.45 to 85.0% while adsorbent dosage increased from 0.25 to 0.50 g, respectively. The initial rapid increase observed could be due to the increased availability of binding sites and surface area which makes the adsorption of the ions quite easy until equilibrium was reached [15]. Removal of heavy metal may remain constant in the further increase of biosorbent amount because of aggregation or overlapping of the adsorption site may occur. On the other hand Figure 4(b) depicts adsorption capacity (mg/g) decreases from 11.29 to 4.46 mg/g with the increasing of biomass dosage. This is because less number of active sites can easily occupied by adsorbate but large number of active sites cannot be occupied fully in a same condition.

3.2. Characterization of biosorbent

3.2.1. Identification of binding sites

The Figure 5(a) represents the FTIR spectra having a number of peaks of some specific functional groups present in lignin, hemicelluloses and α-cellulose of JSP. The wide band observed from 3338 to 3429 cm^{-1} indicated that free and intermolecular hydrogen bonded –O-H groups were present, whereas the bands at 2849 and 2915 cm^{-1} was assigned as the stretching vibration mode of the C–H groups that were present in the lignin structure [16]. The IR spectra reveals that from 1593 to 1750 cm^{-1} range of band depicts the C=O bands of carboxylate groups [17]. An intensive band range from 1037 to 1163 cm^{-1} is assigned to deformation vibrations of the C-H bonds in the quaiacyl ring and to deformation vibrations of C-O bonds which are very typical for softwood lignin. The spectra have absorption band 668, 694, 720 and 778 cm^{-1} which are caused by the deformation vibrations of C-H bonds in the aromatic ring of the lignin. It is considered that intense peaks in 2360 and 2310 cm^{-1} are caused by the fault in the IR machine. Figure 5(b) represents that after adsorption of Pb(II) weak interactions between the JSP surface and Pb(II) was evidenced by a shift in the O–H from 3338 to 3294 cm^{-1} and carboxylate group bands 1750 and 1593 cm^{-1} changed to 1748 and 1592 cm^{-1}, respectively. Other than, the peaks in the raw JSP 2849 and 2915 cm^{-1} changed to 2846 and 2914 cm^{-1}, respectively, after adsorption of lead ions. Moreover, for the Pb(II) loaded JSP, the intensity of –OH group peak is decreased tremendously which confirms the substitution of H^+ by metal ion. These results obtained in the FTIR study offer strong support for the adsorption of Pb(II) onto the JSP surface.

3.2.2. Identification of morphological structure of the biosorbent surface

Using a scanning electron microscope (SEM) the surface constitution of JSP was observed directly with different magnifications.

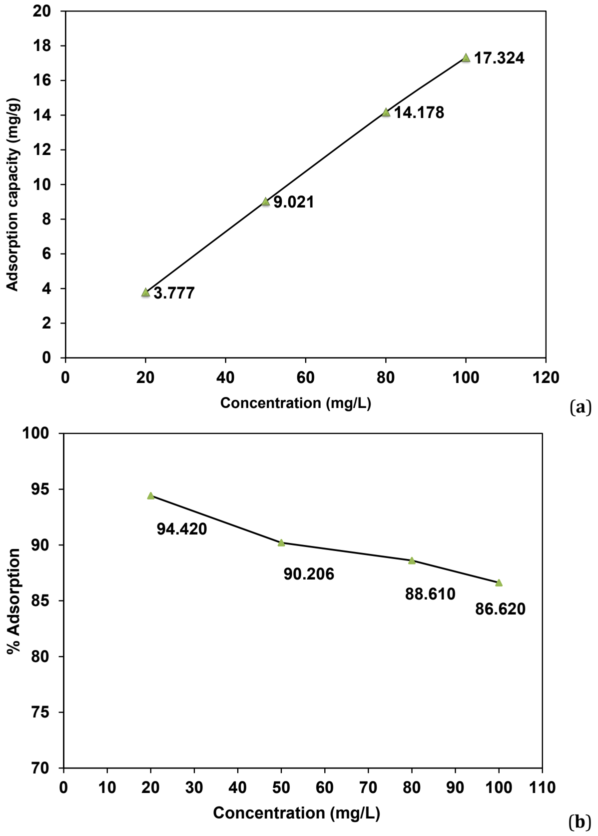

Figure 3. Effect of initial concentrations of Pb(II) on (**a**) adsorption capacity (mg/g) and (**b**) percent removal by JSP.

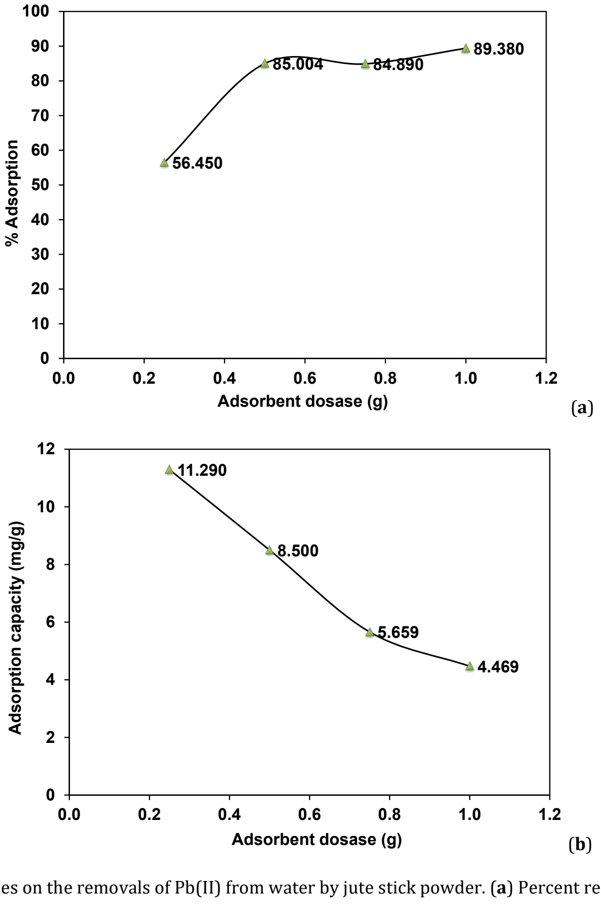

Figure 4. Effects of different doses on the removals of Pb(II) from water by jute stick powder. (**a**) Percent removal; (**b**) Adsorption capacity.

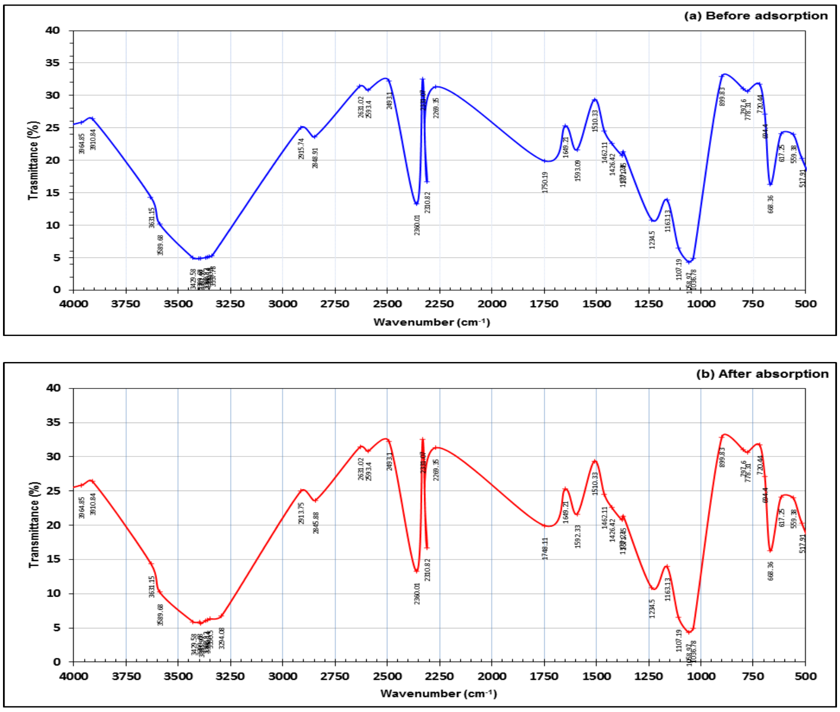

Figure 5. FT-IR spectra of JSP (a) before and (**b**) after adsorption of Pb(II) ions.

The Figure 6(a, b) shows that particle size is asymmetrical and irregular as tread-nodule like in the surface of the JSP. Figure 6(b) with Pb(II) metal loaded rough surfaces of JSP particles are visible in higher magnification. The surface consistency and morphological features of the biosorbent can be identified using scanning electron microscope (SEM). Small micro pore is visible in Figure 6(a) for raw biosorbent, which is capable of trapping the metal ions. Some intra-particle spaces and grooves are disappeared in the Pb(II) adsorbent surface having micro layer of adsorbed Pb(II) ions.

3.3. Assessment of sorption performance by isotherm model

Partition of adsorbate molecules between the liquid and the solid phase can be explained by adsorption isotherm models when equilibrium reached in an adsorption process [18]. To assess the sorption performance, analysis of adsorption data were completed using four adsorption isotherms such as Langmuir, Freundlich, Temkin and Dubinin-Radushkevich (D-R) model by which important information such as adsorption mechanism, favorability of adsorption process and adsorbate-adsorbent attraction can be studied.

3.3.1. Langmuir isotherm model

The Langmuir isotherm assumes that adsorbent surface should occupy homogeneous binding sites, equivalent sorption energies, and there should not have interaction between adsorbed species. The linear form of Langmuir adsorption can be expressed as Equation (3).

$$\frac{1}{q_e} = \frac{1}{q_m} + \frac{1}{q_m K_L C_e} \qquad (3)$$

where, K_L is Langmuir isotherm constant (L/mg) related to the affinity between the adsorbent and the adsorbate and q_m is the maximum adsorption capacity (mg/g).

Figure 7(a) shows the presentation of experimental data by plot of $1/C_e$ vs $1/q_e$. Langmuir isotherm parameters were determined by calculating the slope and intercept. The values were listed in the Table 1 give significant information about the adsorption process. The maximum monolayer coverage capacity (q_m) was determined to be 21.27 mg/g which is nearly matches with the experimental value 21.32 mg/g. K_L is an important parameter describe the adsorption capacity and energy is calculated as 0.189 L/mg from the isotherm curve. The value expressing the affinity between adsorbent and adsorbate was very high [19]. R^2 value was found 0.99 depicts that the adsorption data well suited to Langmuir Isotherm. The favorability of the isotherm is expressed by a dimensionless constant R_L which indicates the shape of isotherm. The dimensionless constant R_L values were determined from a range of concentration and found 0.05-0.20 which indicate a favorable adsorption of Pb(II) ions in equilibrium as it is within the limit ($0 < R_L < 1$) [20].

3.3.2. Freundlich Isotherm model

When the surface energy is different at certain points and the surface properties are distributed unevenly then Freundlich isotherm model is applicable. For a non-ideal, heterogeneous and multilayer sorption process Freundlich model can be expressed by the linear form of Equation 4.

$$\log q_e = \log K_F + \frac{1}{n} \log C_e \qquad (4)$$

where, K_F is the Freundlich isotherm constant is K_F which is related to the binding energy. 1/n is the heterogeneity factor and n (g/L) signifies the deviation from linearity of adsorption.

Figure 7(b) represents the plot of log C_e against log q_e which reveals a linear curve with $R^2 = 0.998$. Calculating the slope and intercept Freundlich isotherm parameter K_F and n are determined and shown in the Table 1. From the table it is clear that Langmuir constant K_F which is the approximate indicator of adsorption capacity was found 3.491 while 1/n is a meaning of the strength of adsorption in the adsorption process was found 0.619.

Table 1. Parameters of Langmuir, Freundlich, Temkin and D-R isotherm model for Pb(II) biosorption by JSP.

Langmuir isotherm	***q_{max}(exp.)(mg/g)***	***q_{max}(cal.) (mg/g)***	***K_L***(L/mg)	***R_L***	***R^2***
	21.324	21.27	0.189	0.050-0.209	0.990
Freundlich isotherm	-	***1/n***	***n***(g/L)	***K_F(mg/g)***	***R^2***
	-	0.619	1.619	3.491	0.998
Temkin isotherm	-	**B** (J/mole)	***B_T***	***A_T***(L/g)	***R^2***
	-	5.311	469.6291	1.583	0.95
D-R	-	***q_m (mol/g)***	***K_D (mol²/J²)***	***E (J/mol)***	***R^2***
isotherm	-	13.859	5.00E-07	1000	0.881

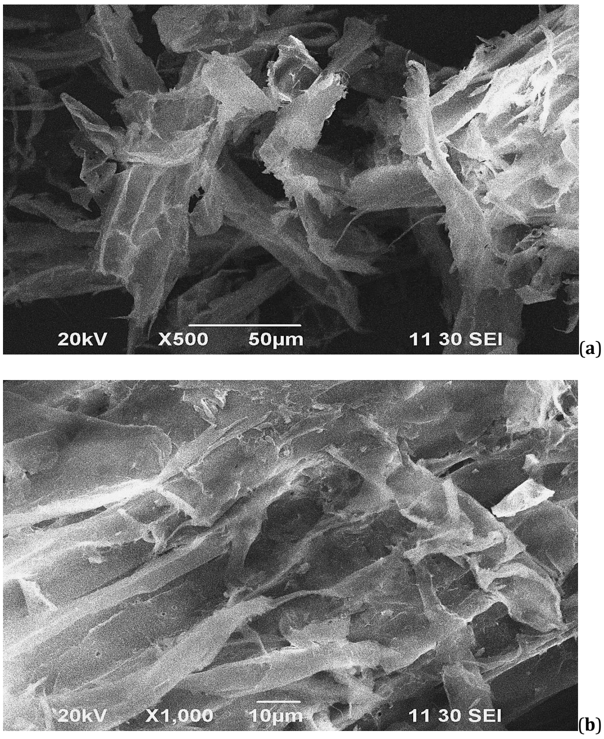

Figure 6. SEM micrographs of (**a**) the unloaded JSP and (**b**) Pb-loaded JSP.

The values of 1/n were lower than 1 which indicated positive removal of heavy metals and heterogeneous sorption on the *JSP* biosorbent [21]. Similarly, value of n is greater than 1 which is in the range 1 to 10 representing a favorable adsorption [22].

3.3.3. Temkin adsorption isotherm model

An important part of studying the sorption mechanism is the Temkin isotherm which explains the interactions between adsorbent and adsorbate. The model assumes that heat of adsorption (function of temperature) of all molecules in the layer would decrease linearly rather than logarithmic with coverage [23]. The expression of the isotherm is defined by Equation (5).

$$q_e = \frac{RT}{b_T}\ln A_T + \left(\frac{RT}{b_T}\right)\ln C_e \tag{5}$$

where, A_T is the equilibrium binding constant (L/g) Temkin isotherm, b_T is the Temkin isotherm constant, R is the universal gas constant, 8.314 J/mol/K, and T is room temperature 301 K.

The Figure 7(c) depicts the plot of q_e against ln C_e. The constants A_T and B_T were calculated from the slope and intercept. The value of A_T and B_T are 1.583429 L/g and 469.6291 J/mol, respectively which is a result of the heat of sorption predicts a physical adsorption. The regression coefficient R^2 obtained 0.950 ensure the fitness of the isotherm for the biosorption of Pb(II) ion onto the JSP.

3.3.4. Dubinin-Radushkevich (D-R) isotherm model

To express the adsorption mechanism with a Gaussian energy distribution onto a heterogeneous surface Dubinin-Radushkevich (D-R) isotherm is generally applied [24]. The D-R isotherm can be expressed as Equation (6).

$$\ln q_e = \ln q_m - K_D\varepsilon^2 \tag{6}$$

where, $\varepsilon = RT\ln\left(1+\frac{1}{C_e}\right)$, $E = \frac{1}{(2K_D)^{\frac{1}{2}}}$, q_m and K_D are the constants of D-R isotherm model represents the maximum adsorption capacity (mol/g) and the adsorption energy, respectively, and ε is the Polanyi potential. The constant K_D is related to the mean free energy (E) of adsorption for each mole of the adsorbent.

To know the sorption performance of Pb(II), q_e *vs* ε^2 is plotted as Figure 7(d) and constant q_m and K_D were determined. The calculated mean free energy was found, E = 1000 J/mol indicating a physisorption process. All the parameters are listed in the Table 1 shows that regression constant is very less than unity which indicates experimental data were not fit enough with the D-R isotherm model.

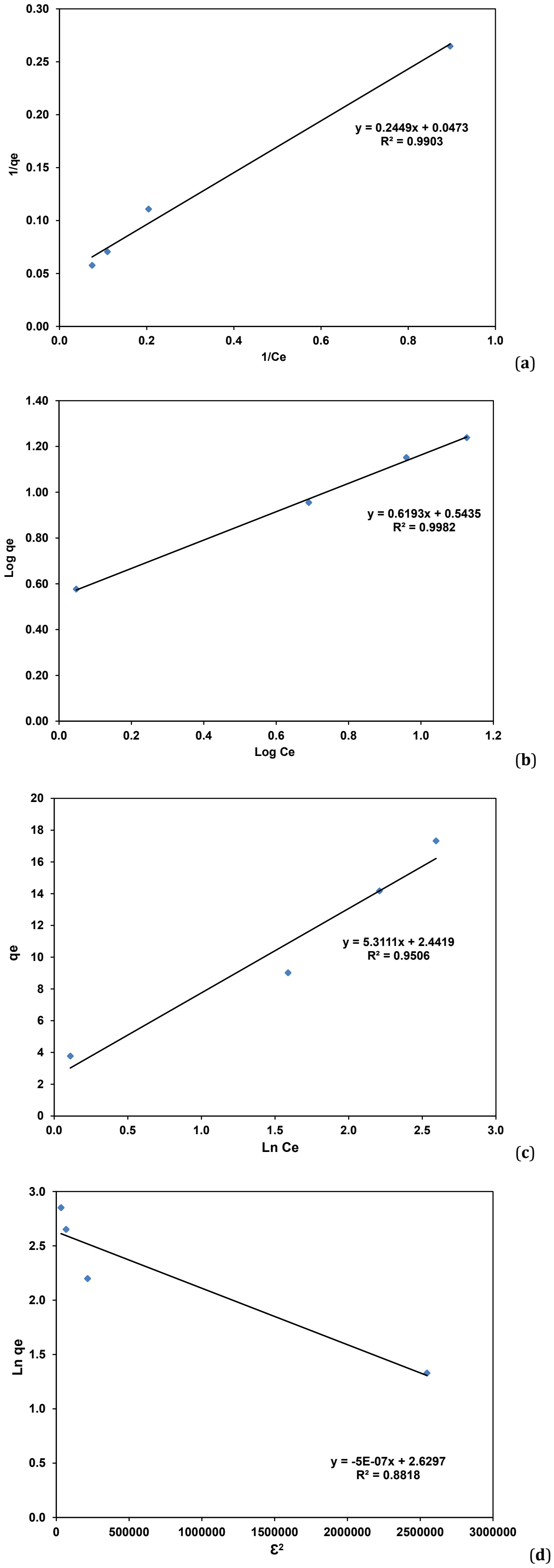

Figure 7. Adsorption isotherm models (**a**) Langmuir, (**b**) Freundlich, (**c**) Temkin and (**d**) D-R for biosorption of Pb(II) by JSP (pH = 6.0, biosorbent dose concentration: 0.5 g/100 mL, Contact time: 60 minute, temperature: 28 °C.

Table 2. Kinetic and diffusion model parameters for biosorption of Pb(II) on to the *JSP*.

Pseudo-first order	q_e, *exp(mg/g)*	q_e, *cal. (mg/g)*	k_1 *(min^{-1})*	r^2
	8.5	8.24	0.1013	0.892
Pseudo-second order	q_e, *exp. (mg/g)*	q_e, *cal. (mg/g)*	k_2 **(g/mg/min)**	r^2
	8.5	8.4	0.0482	0.972
Intra-particle diffusion	-	K_{id} **(mg/g/min$^{-0.5}$)**	C **(mg/g)**	r^2
	-	1.597	0.719	0.940

3.4. Adsorption reaction based models

Biosorption kinetics depends on the interactions between adsorbate and adsorbent. Adsorption reaction based models were employed to investigate the rate controlling steps of biosorption of Pb(II) onto JSP. To observe the biosorption behavior the experimental data were exploited into two kinetic equations such as pseudo-first order and pseudo-second- order kinetic models. The Weber-Morris intra-particle diffusion model was also tested to reveal the adsorption mechanism.

3.4.1. Pseudo- first order reaction model

The Lagergren rate equation was the first rate equation for sorption in a liquid/solid system based on solid capacity [25] is expressed in linear form as Equation (7).

$$\log(q_e - q_t) = \log q_e - \frac{k_1}{2.303}t \tag{7}$$

where, q_e (mg/g) and q_t (mg/g) are adsorption amount at equilibrium and reaction time t (min), respectively. k_1 (min^1) is the rate constant in the pseudo-first-order adsorption process.

Figure 8(a) indicates the pseudo-first-order kinetic plot for the biosorption of Lead onto JSP. The pseudo first order rate constant values were calculated from the slope and intercept of plotting $\log(q_e\text{-}q_t)$ vs t. The calculated values and their corresponding linear regression correlation coefficient values are shown in Table 2. It was observed that the calculated value of maximum adsorption capacity 8.24 mg/g was nearly concordance with the experimental value of maximum adsorption capacity 8.5 mg/g. The value of pseudo-first-order rate constant was found 0.1013 min^{-1} and the correlation coefficient value was found 0.892, which indicates that this model is not applicable for the prediction of the adsorption kinetic model although the other constant value was satisfactory.

3.4.2. Pseudo- second-order reaction model

Experimental data were tested by the pseudo-second-order kinetic model which is given in the form (Equation (8))

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \tag{8}$$

where, k_2 (g/mg/min) is the rate constant of the second-order equation. k_2 and q_e were obtained from intercept and slope of the plot of t/q_t versus t, Figure 8(b).

This model is best described model to predict the kinetic behavior of biosorption with chemical sorption, being the rate-controlling step [26]. The rate constants (k_2), the R^2 and q_e values are listed in Table 2. It is clear from these results that the R^2 value is very high 0.972 for the Pb(II) biosorption. In addition, the theoretical q_e (cal.) value (8.4 mg/g) were closer to the experimental q_e (exp.) value (8.5 mg/g). Considering these results, it can be assumed that the pseudo-second-order kinetic model gave a good correlation for the biosorption of Pb(II) onto JSP in contrast to the pseudo-first-order model. This model provides the better prediction of the biosorption kinetics for whole range of contact time studied. The results found, indicate that chemical bonds formed between the adsorbate and absorbent by forming monolayer onto the surface of the JSP [27].

3.4.3. Intra-particle diffusion model

The mechanism of the rate limiting step of the biosorption process is strongly depended on the intra-particle diffusion process where metal ions are transported from the bulk of the solution. The probability of intra-particle diffusion was examined by using Weber-Morris intra-particle diffusion model (Equation (9))

$$q_t = K_{id} t^{0.5} + C \tag{9}$$

According to the equation a plot of solute adsorbed (q_t) versus the square root of the contact time (t) is shown in the Figure 8(c).The model parameters calculated from the plot, summarized in the Table 2. K_{id} is the rate constant (1.59 mg/g/min$^{-0.5}$) of intra-particle diffusion and C (0.719 mg/g) is a constant describing the thickness of the boundary layer. As the graph make a straight line which pass through the origin, the rate limiting step is intra-particle diffusion [28]. It is observed that the plot has some common features. There are several steps occurring in the biosorption process due to multi-linearity correlations present in the curve. The first linear portion narrates the transfer of metal ions from the solution to the outer surface of the biosorbent by film diffusion process [29]. Transport of Pb(II) onto Jute stick powder is faster in initial stage because of having higher surface area in the biosorbent. Second step indicates the gradual biosorption where rate-limiting step is the intra-particle diffusion. From the analysis of intra-particle diffusion model, it can be assumed that early step of biosorption reaction is film diffusion and the next steps are slower process because of chemical interaction between the metal ions and the biosorbent surface, i.e. rate limiting step of mechanism.

3.5. Desorption and regeneration of jute stick powder

Desorption of metal ions and regeneration of the biosorbent is utmost important to make the biosorption process commercially applicable [30]. In the present study the regeneration potential of JSP was examined using 0.1 M HCl, 0.1 M HNO_3, 0.1 M NaCl and distilled water, as Pb(II) ion desorbing agent. Highest desorption of Pb(II) from the metal loaded JSP by 0.1 M HCl resulted in 76.44 and 22.77% by distilled water as a lowest amount metal recovery for first cycle. For the reuse and regeneration of the biosorbent five times was performed using 0.1 M HCl and found first three times remain almost unchanged and then gradually reduced for the fourth and fifth cycles.

4. Conclusion

The biosorption of Pb(II) onto Jute stick powder biomass was investigated in this study. It was observed that removal of Pb(II) ions from waste water using JSP is greatly influenced by

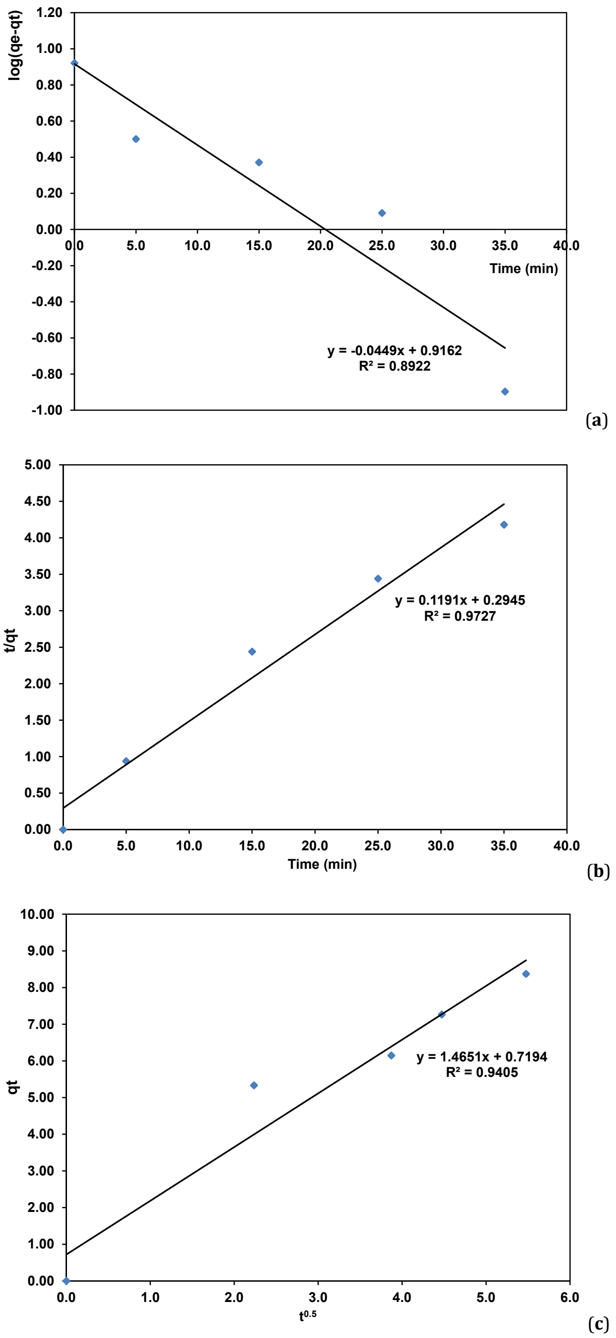

Figure 8. Adsorption kinetic models (**a**) pseudo-first-order equation, (**b**) pseudo-second-order equation, (**c**) Weber and Morris intra-particle diffusion equation, for biosorption of Pb(II) by JSP (pH = 6.0, Biosorbent dose concentration: 0.5 mg/100 mL, Pb(II) concentration: 50 mg/L, Temperature: 28 °C.

pH, initial metal ion concentration, JSP dosages and reaction time. Characterization of the JSP biosorbent with FTIR showed that it possesses -OH functional group which is possibly the leading biosorption site for Pb(II). SEM images of JSP showed relatively large but irregular grooves having intra-particle space which is responsible of adsorption of lead ions. The kinetic study revealed that the adsorption rate was very first and reached in equilibrium at about 40 minutes and the second order rate equation was observed to provide the best correlation of the experimental data. The maximum equilibrium adsorption capacity of JSP was calculated as 21.3 mg/g for Pb(II) adsorption employing Langmuir isotherm model which was the best fit model with the data calculated in experiment. In the present study Jute stick powder biosorbent is stated as a readily available, cheap and environmental friendly biosorbent which may play as a good and cost effective candidate for the treatment of waste water and industrial effluents.

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Disclosure statement DS

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