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Biosorptive removal of Pb(II) and Cd(II) ions from aqueous solution by dried biomass from *Ficus religiosa*

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ABSTRACT

This research work presents the capability of *Ficus religiosa* as an eco-friendly biosorbent to remove heavy metals (lead and cadmium) from their aqueous solutions. The biomass from *Ficus religiosa* is available as waste in the form of dried branches. FTIR analysis indicated the presence of oxygen containing functional groups and a change in the vibrational frequencies indicated the attachment of Pb(II) and Cd(II) ions with these functional groups. Pseudo-second-order kinetic model was followed at all studied initial concentrations of metal ions. Langmuir and Dubinin-Radushkevich models were followed by Pb(II)-FR system and Langmuir model described the equilibrium of Cd(II) biosorption by FR. The maximum biosorption capacity of biosorbent for lead was 91.74 mg/g and for cadmium was 76.21 mg/g. The process was spontaneous, feasible and endothermic in nature. An increase in change in standard entropy indicated the establishment of equilibrium. It can be concluded from this research work that *Ficus religiosa* can be used as an alternative biosorbent for decontamination of lead and cadmium from aqueous solution due to feasible sorption conditions, low cost and biosorbent having good affinity for lead and cadmium ion.

Keywords: Ficus religiosa; Pb(II); Remediation; Non-linear; Pseudo-second-order; Endothermic

1. Introduction

Heavy metal ions have dangerous effects on all forms of life. They enter the food chain through wastewater ultimately causing serious water pollution and health hazards. Lead and cadmium are among the most toxic metals [1]. These elements bioaccumulate and cannot be degraded. The major sources of lead and cadmium are electroplating, pigments, manufacturing of storage batteries and alloy formation [2]. All lead compounds are considered as cumulative poisons whereas cadmium is categorized as carcinogenic by WHO and USEPA [3]. Lead poisoning affects gastrointestinal tract, nervous system, kidney, reproductive system, brain, and causes death. High level exposure causes non-fertility and mental retardation in [4]. Cadmium causes erythrocyte destruction, diarrhea, muscular cramps, renal degradation, and skeletal deformation [5]. The limiting level for lead and cadmium in drinking water by WHO are 0.05 mg/L and 0.003 mg/L respectively [6].

Biosorption is developed to remove the metals from aqueous media using low cost inactive biological materials [7]. The advantages of biosorption over the conventional methods include but not limited to methods include low operating cost, relatively short operational time and no chemical sludge [8]. Biosorption facilitates the selective uptake of ions or other molecules on inactive biomass either by ionic, covalent or coordinate covalent bonding due to functional groups present on biomass, *e.g.* carboxylic, amino and hydroxyl groups,capturing metals from solution [9,10].

A variety of materials have been employed for biosorption study for metal ions including bacteria, fungi, and higher plants [7,11–14]. *Ficus religiosa*, commonly known as

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"peepal" plant is a species native to Pakistan, India, Bangladesh, Nepal, Sri Lanka, and south-west China that belongs to the family *Moraceae*. The specific epithet "*religiosa*" and synonym "bodhi tree" alludes to the religious importance of this tree [15]. *Ficus religiosa* is a large deciduous tree up to 35 m height. Phytochemical analysis of the bark of *F. religiosa* has highlighted the presence of tannins, flavonoids, steroids and terpenoids [16], whiles its leaves contain tannic acid, aspartic acid, and alanine [17].

The purpose of present work was to assess the ability of biomass for the branches of *F. religiosa* to remove Pb(II) and Cd(II) ions from aqueous solutions. Batch biosorption experiments were undertaken, and the biosorbent was characterized to identify potential binding sites, with time of contact, concentration, dose, temperature and pH studied to assess the limiting factors for binding. The nature of interaction between metal and binding sites of biomass was discussed.

2. Material and methods

Analytical reagent grade chemicals (Merck, Germany) were used without purification. Dried branches of *Ficus religiosa* were collected from Chungi Amar sadhu Bahadarabad, Lahore, Pakistan, and shredded. The shredded branches were washed with tap water to remove dust and dirt and dried in the shade. Thereafter, the branches were ground in a domestic electric grinder (HL1632, Philips); the fraction with particle size <177μm was selected for studies. This material was soaked in distilled water for one day to remove water soluble moieties, filtered, dried and stored in labelled airtight container (labelled as FR). The FT-IR spectrum was obtained using a Perkin Elmer RX-I FT-IR. Bulk density, ash content and moisture content were also determined. Brunauer–Emmett–Teller (BET) surface area was determined using Chemisorb 2750 (Micromeritics).The point of zero charge pH was determined as described by Abia and Asuquo [18].

2.1. Batch sorption process

The biosorption potential of *Ficus religiosa* (FR) was studied in a series of batch experiments using metal solutions (Pb(II), 100 mg/L, 50 mL; Cd(II), 50 mg/L, 50 mL). A concentration difference method was used for this purpose. The known amount of biomass (100 mg) was allowed to come in contact with the specified volume of metal solutions in flasks for a specified period at predefined pH and temperature. The contents of the flasks, containing the metal-biomass were agitated on an orbital shaker at 125 rpm. The suspension was filtered and filtrate was analyzed using atomic absorption spectrophotometer (Perkin Elmer, A Analyst 100) for metal ion concentration. The difference in initial (C_0, mg/L) and final (C_e, mg/L) ion concentration was assumed to be the amount of metal sorbed by the biosorbent. The q_e (mg/g) value was calculated as follows:

$$q(q_e) = \frac{C_0 - C_e}{m} \times v \tag{1}$$

where v (mL) is volume of metal solutions used and m (mg) is mass of biosorbent.

Parameters like effect of contact time (5–60 min), metal ion concentration (50–500 mg/L), pH (3–9), and temperature (293–313 K) were optimized by using this method. Control experiments, *i.e.* without biomass, indicated no detectable adsorption by glassware.

The kinetics for sorption of Pb(II) and Cd(II) by biomass from *Ficus religiosa* was studied by famous kinetic models, i.e., Elovich, pseudo-first-order (PFO) and pseudo-second-order (PSO) models. The linear forms of Elovich [Eq. (2)], PFO [Eq. (3)] and PSO [Eq. (4)] models are [19,20]

$$q_t = \frac{\ln(a \times b)}{b} + \frac{\ln t}{b} \tag{2}$$

$$\ln(q_e - q_t) = \ln q_e - k_1 t \tag{3}$$

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \tag{4}$$

Here a (mg g^{-1} min $^{-1}$) and b (g/mg) are Elovich model constants, k_1 (min^{-1}) and k_2 (mg/g min^{-1}) are pseudo first order and pseudo second order rate constants whereas q_e and q_t (mg/g) are the amounts of metal sorbed at equilibrium and at the given the time t, respectively. The graphs were plotted for the respective models and the parameters were calculated. Table 3 shows the parameters at various concentrations.

Langmuir, Freundlich and Dubinin–Radushkevich models were used to study the equilibrium of the process for both Pb(II) and Cd(II). Freundlich isotherm [Eq. (5)] model considers the non-ideal sorption in a multilayer way [21].

$$q_e = \ln K_F C_e^{1/n} \tag{5}$$

K_F and $1/n$ are the Freundlich constants.

Langmuir adsorption [Eq. (6)] occurs at the surface of the sorbent in a homogeneous way forming a monolayer. It is shown as

$$q_e = \frac{q_m K_L C_e}{1 + K_L C_e} \tag{6}$$

where q_m is the monolayer sorption capacity (mg/g), 'K_L' is Langmuir constant [22].

Dubinin–Radushkevich [Eq. (7)] model is shown as follows [23].

$$q_e = q_D \exp(-\beta\varepsilon^2) \tag{7}$$

where β (mol^2/J^2) is the coefficient related to the mean free energy of adsorption. Polanyi potential (ε, J/mol) is calculated using $\varepsilon = RT\ ln(1+(1/C_e))$. The energy of adsorption is determined using $E = (2\beta)^{-1/2}$. Adsorption is physical in nature for energy less than 8kJ/mol, and chemisorption for energy greater than 16 kJ/mol. The process is considered as ion-exchange for energy between 8–16 kJ/mol [24].

The root mean square error [RMSE, Eq. (8)] was determined for the studied models to determine the suitability of the equilibrium model. The sum of the squares of the difference between metal removal experimental data (q_{exp}) and model predictions (q_{cal}) was divided by the number of data points (N) for each data set and the square root of this term was taken.

$$RMSE = \sqrt{\frac{\sum \left(q_{\exp} - q_{cal}\right)^2}{N}} \tag{8}$$

The data from temperature studies was utilized to determine the thermodynamic parameters i.e., changes in standard Gibbs' free energy, standard enthalpy and standard entropy (ΔG°, ΔH° and ΔS°) by using relation

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ \tag{9}$$

where $\Delta G^o = -RTlnK_d$ and $K_d = (C_0 - C_e)/C_e$. The graph was plotted between ΔG^o and T (Fig. 6). $\Delta G°$ was found to be negative for both of the metal ions at all temperatures indicating a spontaneous and feasible process [25].

3. Results and discussions

3.1. Characterization of biomass

The FT-IR spectrum is a useful tool to identify the functional groups that might be responsible for binding of metal ions. The FT-IR spectrum of simple, Pb(II)- and Cd(II)- loaded *F. religiosa* has a broad band centered at 3300.70 cm^{-1} (Fig. 1) that indicates the presence of hydroxyl group (–OH) in FR. The sharp peak at 1730.15 cm^{-1} suggests the presence of carbonyl group (C=O) of aldehyde and ketone groups, whilst the relatively broad peak at 1039.63 cm^{-1} is that of an alkoxy group. When the FTIR of FR is compared with that of metal loaded FR, a change in the vibration frequencies of C=O, and –OH groups was observed. The peaks shifted from 3300.70 (FR) to 3280.92 (Pb(II)) and 3684.04 (Cd(II)) cm^{-1}; 1730.15 (FR) to 1737.86 (Pb(II)) and 1789.94 (Cd(II)) cm^{-1}. Similarly, changes in the vibrational frequencies of other functional groups could be observed in FTIR spectrum. These shifts indicated that Pb(II) and Cd(II) attached to the oxygen-containing functional groups of the biosorbent.

The pH of point of zero charge (pH_{pzc}) is very important factor in assessing the nature of the charge on a surface. When a biomass is placed in a solution below its pH_{pzc}, it behaves as positive charged material due to protonation of surface functional groups and thus attracts the negatively charged ions present in solution. When placed in solution with a pH above the $pH_{pzc,}$ the material deprotonates and can then bind positively charged species. When the solution pH is near pH_{pzc}, the positive charge on the biosorbent is very small and thus almost ineffective in restricting the cations to bind with biosorbent. Hence, a solution pH near or greater than the pH_{pzc} of biosorbent is considered as ideal for biosorption of metal cations [25]. In this case, the pH_{pzc} for biomass from *Ficus religiosa* was found to be 5.73 (Table 1). The bulk density (1.0047g/cm^3), ash content

Table 1
Properties of *Ficus religiosa* biomass

Parameter	Values
pH_{pzc}	5.73
Bulk density (g/cm^3)	1.0047
Ash content (%)	11.6
Moisture content (%)	0.4
BET surface area (m^2/g)	653.515
Pore volume (cm^3/g)	150.123
Particle size (µm)	<177

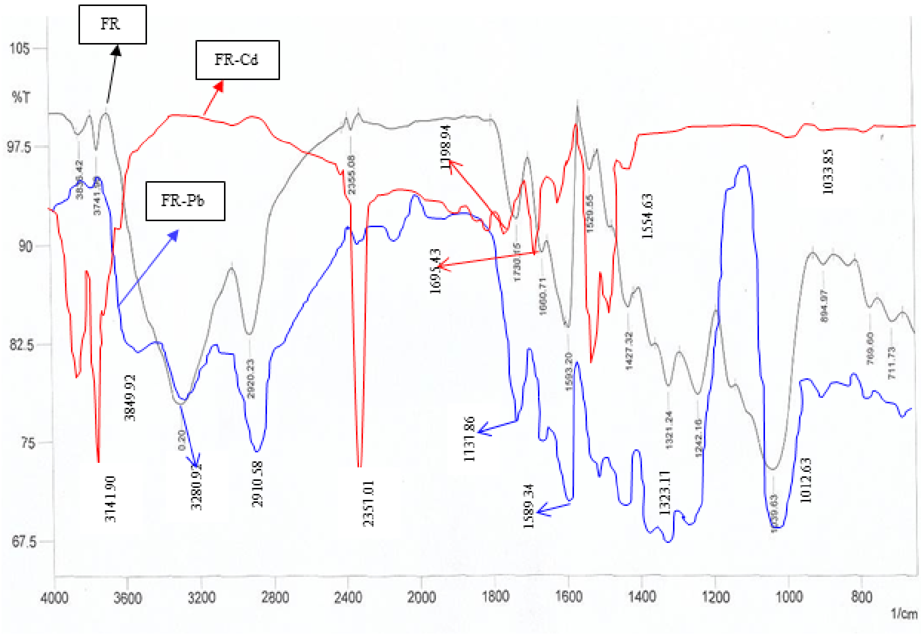

Fig. 1. FTIR spectrum of simple and metal loaded dried biomass from *Ficus religiosa*.

(11.6%) and moisture content (0.4%) were also determined. BET surface area was found to be 653.515 m^2/g and monolayer volume 150.123 cm^3/g. Table 1 summarizes the characteristics of the biomass used.

3.2. *Effect of time of contact at different metal concentrations*

The effect of time of contact was studied in order to determine the minimum time required to remove maximum metals from the solution at different metal ion concentrations (Fig. 2). Data for Pb(II) is shown in Fig. 2a and that of Cd(II) in Fig. 2b. Below 75 mg Pb(II)/L, 100% binding of Pb(II) ions were observed. The biosorption of Pb(II) was faster than that of Cd(II), and in both cases the equilibrium time increased with increase in concentration. Relatively high q_t value were observed. This suggested that FR was a potential candidate for the binding of Pb(II) ions at all studied concentrations. A similar trend was observed for Cd(II) ions, although relatively lower Cd(II) concentrations were used, indicating that FR had a smaller affinity for Cd(II) ions compared to that for Pb(II) ions. Although equilibrium times were same (20–40 min), the q_t values for Pb(II) were almost 5 times greater than for Cd(II) ions. The present times were smaller than a number of reported biosorbents used for biosorption of Pb(II) and Cd(II) ions (Tables 2 and 3).

The rate constant for Elovich model was found to be extremely high (Table 3), for both metal ions, suggesting the process was fast in nature. However, as the time for attainment of equilibrium was very high (40 min), the process was actually unlikely to be a fast process. The unexpectedly high rate constant values obtained indicated that the

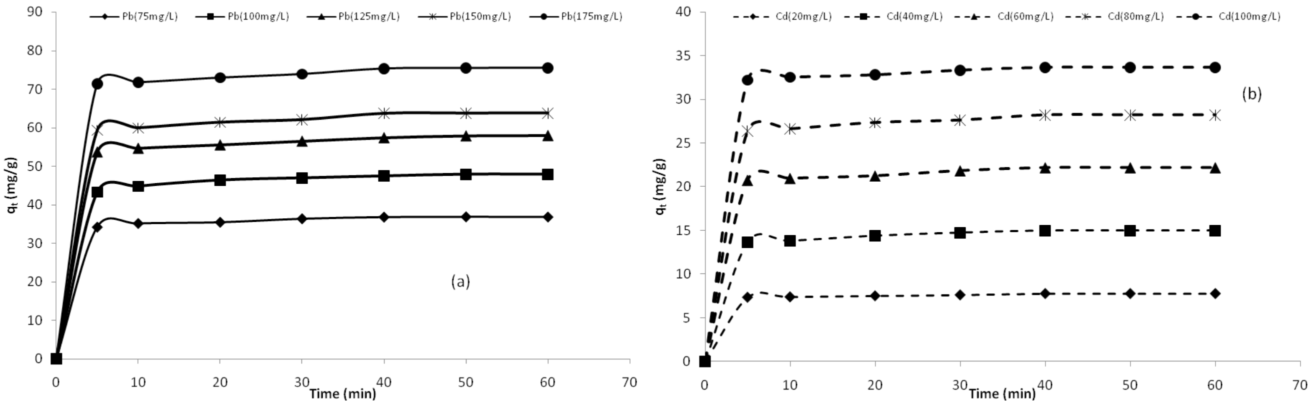

Fig. 2. Effect of time of contact for biosorption of (a) Pb(II) and (b) Cd(II) ions by *Ficus religiosa* at different metal ion concentrations (125 rpm, 50mL, pH 6).

Table 2
Biosorption capacities of various biosorbents for Pb(II) ions

Biosorbent	Time (min)	pH	*q* value (mg/g)	Kinetic Model*	Equilibrium Model†	Reference
Populus alba	60	6	10.13	PSO	L	[10]
Arecha catechu	25	2–7	11.72	PSO	L, F	[26]
Phaseolus aureus	60	6	21.8	PSO	L	[27]
Pineapple fruit peel	30	4	28.55	PSO	L	[12]
Ficus benghalensis L	20	6	28.63	PSO	L	[28]
Moringa olifera bark	30	5	34.6	PSO	F	[29]
Ficus carcia	80	5	37.74	PSO	L	[30]
Romanian peat	30	5.5	41.94	PSO	L	[31]
Cladophora rivularis	30	4	48.14	–	F	[32]
Pinus brutia	240	4	76.8	PSO	L, F	[33]
Zea maize	120	6	80	PSO	F	[34]
Ficus religiosa	40	6	91.74 (L)	PSO	L, DR	Present study
Rice husk	60	5	91.74	PSO	L	[35]
Mustard waste	120	5.5	101.82 (55°C)	PSO	L	[36]
Spirpdela polyrhiza	120	4	137	PSO	L	[37]
Ulva lactua	180	5	181.02 (50°C)	–	L	[38]

*PSO = Pseudo second order model

†L = Langmuir, F = Freundlich, DR = Dubinin-Radushkevich

Table 3
Biosorption capacities of various biosorbents for Cd(II) ions

Biosorbent	Time (min)	pH	q_m value (mg/g)	Kinetic model*	Equilibrium model†	Reference
Populus alba	50	4	8.87	PSO	L	[10]
Romanian peat	30	5.5	12.82	PSO	L	[31]
Phaseolus aureus	60	8	15.7	PSO	F	[27]
Ficus religiosa leaf powder	120	5.5	27.14	PSO	L	[39]
Ficus carcia	80	6	34.13	PSO	L	[30]
Spirpdela polyrhiza	120	6	36	PSO	L	[37]
Triticum aestivum	10	6	39.22	PSO	F	[40]
Mustard waste	120	5.5	40.01 (55°C)	PSO	L	[36]
Pineapple fruit peel	30	4	42.10	PSO	L	[12]
Ulva lactuca	180	5	43.02 (55°C)	–	L	[38]
Ficus religiosa	40	6	76.29	PSO	L	Present study
Rice straw	90	6	144.19	–	L, F	[41]
Azadirachta indica	20–300	2-9	158	PSO	L, F	[42]

*PSO = Pseudo second order model
†L = Langmuir, F = Freundlich

Table 4
Parameters for the kinetics of biosorption of Pb(II) and Cd(II) ions by *Ficus religiosa* at different initial metal concentrations

Model	Parameter	Pb(II)					Cd(II)				
		75 mg/L	100 mg/L	125 mg/L	150 mg/L	175 mg/L	20 mg/L	40 mg/L	60 mg/L	80 mg/L	100 mg/L
Elovich model	Slope	1.1201	1.9025	1.7997	1.986	1.9023	0.215	0.619	0.675	0.851	0.6574
	Intercept	32.399	40.444	50.531	55.738	67.743	6.924	12.58	19.49	24.83	31.036
	b	0.8927	0.5256	0.5556	0.5035	0.5257	4.6512	1.6155	1.4815	1.1751	1.5211
	a	4.09×10^{12}	3.25×10^{9}	2.81×10^{12}	3.07×10^{12}	5.56×10^{15}	2.08×10^{13}	4.15×10^{8}	2.34×10^{12}	4×10^{12}	2.09×10^{20}
	R^2	0.9634	0.9888	0.9768	0.9472	0.9387	0.933	0.960	0.933	0.960	0.954
Pseudo first order	Slope	–0.0657	–0.0839	–0.0541	–0.0418	–0.04	–0.0405	–0.0695	–0.0541	–0.0472	–0.0571
	Intercept	1.2949	1.8176	1.588	1.6464	1.6785	–0.6042	0.7642	0.7422	0.8798	0.7376
	k_1 (min^{-1})	0.0657	0.0839	0.0541	0.0418	0.04	0.0405	0.0695	0.0541	0.0472	0.0571
	$q_{e(cal)}$ (mg/g)	3.65	6.16	4.89	5.19	5.36	0.55	2.15	2.10	2.41	2.09
	$q_{e(exp)}$ (mg/g)	36.76	47.50	57.35	63.68	75.29	7.76	15.02	22.17	28.20	33.64
	D (%)	–90.07	–87.04	–91.47	–91.85	–92.88	–92.96	–85.70	–90.52	–91.45	–93.78
	R^2	0.9195	0.9972	0.9842	0.9853	0.9924	0.9854	0.974	0.9005	0.9886	0.9288
Pseudo second order	Slope	0.0269	0.0206	0.0171	0.0155	0.0131	0.126	0.065	0.044	0.035	0.029
	Intercept	0.0173	0.0166	0.0135	0.119	0.0089	0.097	0.058	0.032	0.024	0.014
	k_2 (g mg^{-1} min^{-1})	0.0418	0.0255	0.0217	0.0202	0.204	0.1636	0.0728	0.0605	0.0510	0.0600
	$q_{e(cal)}$ (mg/g)	37.17	48.54	58.48	64.52	76.34	7.94	15.38	22.73	28.57	34.48
	$q_{e(exp)}$ (mg/g)	36.76	47.50	57.35	63.68	75.29	7.76	15.02	22.17	28.20	33.64
	D (%)	1.13	2.20	1.97	1.31	1.39	2.27	2.43	2.51	1.32	2.20
	R^2	0.9999	0.9999	0.9999	0.9998	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999

Elovich model was not being followed for the biosorption of both the metal ions by FR.

The biosorption data fits a pseudo-second order (PSO) better than a pseudo-first order (PFO) model. For instance, if biosorption is directly proportional to the number of freely available sites onto the biomass, then the process would follow a PFO. In such a case,we observe a straight line with negative slope when plotting ln(q_e – q_t)against time, t. The difference (D%) between calculated and experimental q_e values is significantly high (Table 4). Since the experimental data ($q_{e(exp)}$) did not match the modelled data ($q_{e(cal)}$), it could be inferred that PFO ddid not explain the kinetics of Pb(II) and Cd(II) ions by biomass from *F. religiosa*. Rather, when we plotted t/q_t against t (Fig. 3), the straight line with

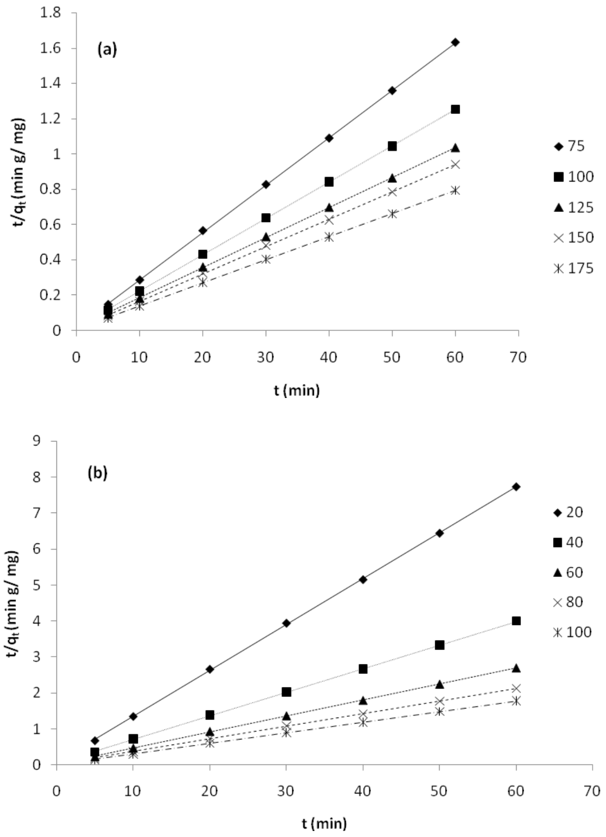

Fig. 3. Pseudo second order plots for biosorption of (a) Pb(II) and (b) Cd(II) ions by FR leaves.

positive slope and intercept obtained would suggest biosorption follows a PSO mechanism. This also reveals that biosorption is proportional to square of number of freely available binding sites. In that context, $R^2 > 0.98$ for both Cd(II) and Pb(II) onto FR and smaller D% values, inferred that pseudo-second-order model was suitable to describe the kinetics of the biosorption process. This fact is in accordance with the reported studies that mostly metal cations biosorbed following PSO model (Tables 2 and 3).

3.3. Effect of pH on biosorption of Pb(II) and Cd(II) ions

The pH of medium also affects the metal speciation in solution. Mostly, metal ions precipitate out in basic medium, forming hydroxides [25]. The precipitation is not required for biosorption as metal ions are not 'available' for attachment with the material. Hence, a solution pH less than the precipitating point is desirable.

pH of aqueous solution affected the biosorption of Pb(II) ions more than it did Cd(II) ions (Fig. 4). A large q_e (47.20 mg/g) and turbidity were observed as the pH neared pH 7, indicating Pb(II) ions precipitated out forming hydroxides. A similar trend was observed in case of Cd(II) ions, though the change in q_e value was not that large. The optimum pH was found to be 6 for both of the studied ions. This value is in accordance with the studies reported in literature for these metal ions by various biosorbent (Tables 2 and 3).

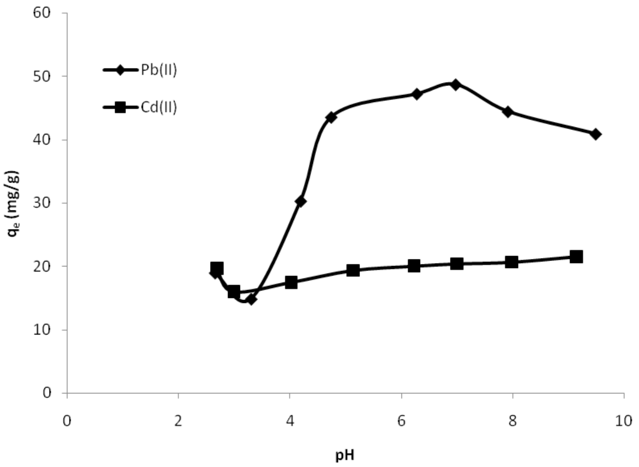

Fig. 4. Effect of pH of solution on the biosorption of Pb(II) and Cd(II) ions by FR (50 mg/L, 50 mL, 100 mg, 125 rpm, 20 min for Pb(II) and 30 min for Cd(II)).

3.4. Effect of concentration - equilibrium modeling

Fig. 5 shows the fitting of Langmuir, Freundlich and D-R models. The parameters calculated for these models are presented in Table 5. The fitting of experimental and model curves to Langmuir, Freundlich and D-R models indicated that the best fit for the Pb(II) data wa with Langmuir and D-R models. Freundlich model curve showed a greater deviation from the experimental values. The fitting was favored for Langmuir model compared to that for D-R model. However, RMSE values pointed to a different inference. RMSE was minimum for D-R model, indicating that biosorption of Pb(II) ions followed D-R model compared to Langmuir model. The biosorption capacity from D-R model (87.11 mg/g) was relatively close to that from Langmuir model (91.74 mg/g). The energy of adsorption of for Pb(II) ions was calculated to be 9.13 kJ/mol. This indicated a dominating ion-exchange process compared to physical adsorption on a homogeneous surface forming a monolayer. In case of Cd(II) ions, the model curve fitting and RMSE data suggest that biosorption followed the Langmuir model. As per D-R model, the energy of adsorption was 4.08 kJ/mol indicating a physical adsorption process of Cd(II) on the homogeneous surface of biomass forming a monolayer. The q_m values for Pb(II) and Cd(II) ions were determined to be 91.74 and 76.29 mg/g. This value is higher than a number of reported biosorbents (Tables 2 and 3), further supporting the potential of FR biomass as a biosorbent for Pb(II) and Cd(II) ions. Hence, FRS biomass was a potential biosorbent for the biosorptive removal of Pb(II) and Cd(II) ions from their aqueous solutions.

3.5. Effect of temperature on biosorption of Pb(II) and Cd(II) ions

Temperature is a very important factor/parameter affecting the biosorption process/equilibrium by varying the kinetic energy of the metal ions (sorbate) and the vibrations of the functional groups present in the biosorbent. Thus a variation in the extent of biosorption is expected to be observed with a change in temperature.

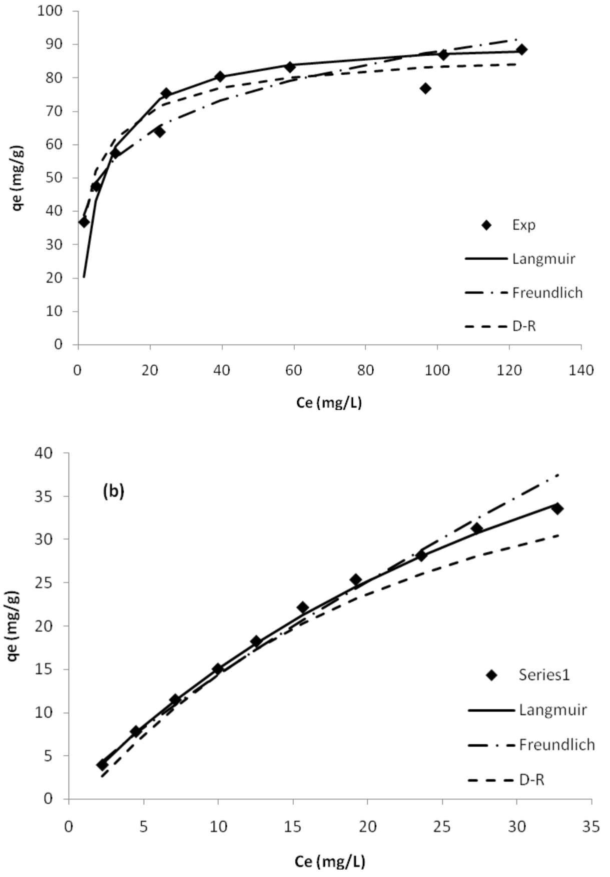

Fig. 5. Effect of variation in concentration of metal ions and the fitting of equilibrium models (a) Pb(II) ions and (b) Cd(II) ions (50 mL, 100 mg, 125 rpm, 60 min for both metal ions).

Table 5
Equilibrium models for the biosorption of Pb(II) and Cd(II) ions by FR

Model	Parameters	Pb(II)	Cd(II)
Langmuir	K_L (L/mg)	0.1766	0.0247
	q_m (mg/g)	91.74	76.29
	R_L	0.0185–0.0702	0.2881–0.8019
	RMSE	7.01	0.47
Freundlich	$1/n$	0.1976	0.8066
	K_F	35.39	2.25
	RMSE	5.26	1.46
Dubinin-Radushkevich	β	6×10^{-9}	3×10^{-8}
	q_D (mg/g)	87.11	45.71
	E (kJ/mol)	9.13	4.08
	RMSE	4.47	1.99

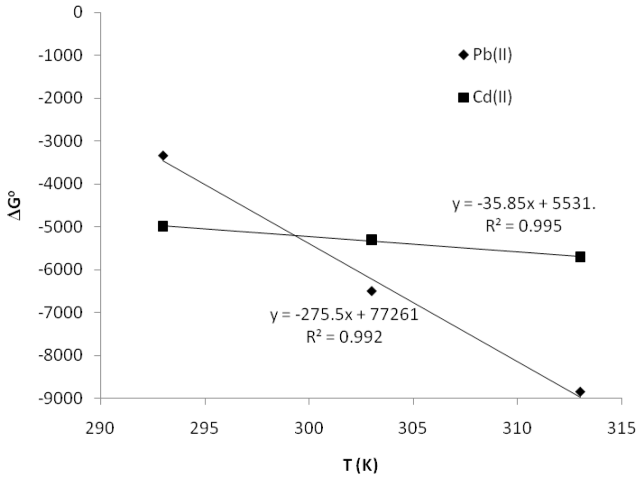

Fig. 6. Thermodynamic modeling for biosorption of Pb(II) and Cd(II) ions by FR biomass.

Effect of change in temperature was explored in terms of the changes to Gibbs' free energy (Fig. 6) and in terms of thermodynamic parameters (Table 6). It was observed that temperature affected the biosorption of Pb(II) ions greater than that of Cd(II) ions. An increase in the q_e value with temperature showed a greater feasibility of biosorption at higher temperatures.

A decrease in the Δ*G*° value was observed with increase in temperature indicating a greater feasibility of the process at higher temperatures. The change in standard enthalpy (Δ*H*°) was found to be positive indicating an endothermic process for the binding of metal ions (Pb(II) and Cd(II)). The positive value of change in standard entropy (Δ*S*°) indicated that the randomness increased at solid-liquid interface and that the equilibrium was established for the process [25].

An endothermic biosorption process, more feasible at relatively higher temperature, is advantageous for the treatment of industrial effluents as these are often disposed-off at a relatively higher temperature. Hence, the biosorbent can be a potential candidate for the biosorptive removal of Pb(II) and Cd(II) ions from industrial wastewaters.

4. Conclusion

Dried material (powdered branches) from locally available *Ficus religiosa* were used as a biosorbent material for the removal of toxic Pb(II) and Cd(II) metal ions from their aqueous solutions using batch mode. The bulk density (1.0047 g/cm^3), ash content (11.6%) moisture content (0.4%), BET surface area (653.515 m^2/g) and point of zero charge pH (pH$_{pzc}$) value was found to be 7.73. FTIR indicated a number of oxygen and nitrogen containing functional groups. The optimum time of contact for both metal ions i.e., Pb(II) and Cd(II) ions was found to be 40 min. An increase in the concentration of metal ions resulted in increase of the equilibrium biosorption capacity (q_e) till the enrichment of the binding sites of the material. Pb(II)-biosorbent and Cd(II)-biosorbent systems followed Langmuir model with q_{max} of 91.74 mg/g and 76.21 mg/g respectively. The process was found to follow the pseudo-second-order kinetics for Pb(II) and Cd(II) ions. The negative values of Δ*G*° indicated that process was feasible under the studied conditions. The positive Δ*H*° values indicated that the process was endothermic.

The results of the present studies indicated that the biomass from *Ficus religiosa* could be used for the removal of

Table 6
Thermodynamic parameters for the biosorption of Pb(II) and Cd(II) ions by FRS

Metal Ion	T (K)	K_d	q (mg/g)	ΔG° (J/mol)	Slope	Intercept	ΔH° (kJ/mol)	ΔS° (J/molK)
Pb(II)	293	3.9275	39.85	–3332.48	–275.52	77261	77.261	275.52
	303	13.1667	46.47	–6493.56				
	313	29.9090	48.38	–8842.98				
Cd(II)	293	7.7542	22.14	–4989.51	–35.859	5531.1	5.531	35.859
	303	8.2198	22.29	–5306.71				
	313	8.9617	22.49	–5706.7				

Pb(II) and Cd(II) ions from their aqueous solutions. The high q_{max} values suggest that the material can be used as alternative to other costly adsorbent materials for the biosorptive removal of these metal ions in an effective manner.

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