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Biosorption of Pb(II) and Cd(II) Ions from Aqueous Solution by Chemically Modified *Syzygium cumini* Leaves and its Equilibrium, Kinetic and Thermodynamic Studies

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Abstract. The removal of Pb (II) and Cd (II) ions from aqueous solution by a novel low-cost biosorbent; chemically modified *Syzygium cumini* leaves (CMSCL) was studied. The effects of biomass dosage, pH, concentration, temperature and contact time were investigated. Characterization of CMSCL was carried out by FT-IR spectroscopy, pore size, and surface area analyzer. The maximum biosorption capability of CMSCL for Pb (II) and Cd (II) ions was 104 and 50 mg/g at optimum conditions of pH 6 and 7, biomass dosage of 5 g/L, contact time of 120 and 90 min and temperature of 50 and 40 °C, respectively. The experimental data was analyzed using pseudo-first order and pseudo-second order kinetics models. The biosorption of Pb (II) and Cd (II) followed pseudo-second order model. Langmuir, Freundlich and Temkin adsorption isotherm models were applied to explain the removal of heavy metal ions by CMSCL biosorbent. Langmuir isotherm model fitted better than other isotherm models. Thermodynamics parameters such as $\Delta H°$, $\Delta G°$ and $\Delta S°$ showed that the biosorption of Pb (II) and Cd (II) ions onto CMSCL was spontaneous, exothermic and feasible under examined conditions. The occurrence of various functional groups and change in the absorption frequency after metal uptake indicates that complexation was the main mechanism involved in the process of biosorption. Based on the present investigation, it was proved that CMSCL is an effective, alternative and economical biosorbent for the removal of Pb (II) and Cd (II) ions.

Keywords: *Syzygium cumini*, biosorption, lead, cadmium

Introduction

The occurrence of heavy metals like Pb, Cd, Cr, etc. has caused serious environmental problem for the aquatic system. These contaminants are not decomposed by living organisms and can accumulate in their body tissues. The occurrence of heavy metals in the aqueous system and their influences on the living organism is a problem of concern since a long time ago. Pb (II) and Cd (II) are very toxic metals of high atomic masses (Reddy *et al*., 2010b). Industries of ceramic glass, matches, pigments, mining, storage batteries, smelting, metal plating, ammunition, oil refining, and painting are the main sources which discharge Pb (II) and Cd (II) ions into the aquatic system (Schneegurt *et al*., 2001). The maximum permissible limit of Pb (II) ions in drinking water is 0.05 ppm given by the US environmental protection agency (USEPA) and WHO (Agency, 2002; Organization, 1996). Higher concentration of Pb (II) ions than the permissible limit causes a serious threat to brain, kidney, reproductive system, liver, and nervous system (Soliman *et al*., 2016). Heavy metals are non-biodegradable and their removal from the aquatic medium is necessary before they contaminate the drinking water and accumulate in the body.

The conventional methods used to remove Pb (II) and Cd (II) ions include precipitation, ion exchange, membrane filtration, oxidation and reduction and adsorption by activated carbon (Wang *et al*., 2003). However, these methods are expensive and produce chemical sludge which creates serious problem when disposed of and also fail to remove metal ions below 100 ppm. Therefore, nowadays it is a challenge to

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explore more efficient and economical methods to treat the heavy metals ions.

The biosorption method is a very simple and economical process. The chemically modified *Syzygium cumini* leaves (CMSCL) bind metals of high atomic masses on their surface if present in aqueous medium and waste water (Yang and Volesky, 1999). The important application of CMSCL as agriculture biomass, where toxic metals of high atomic masses can effectively be removed. The plant based biosorbent is cheap, easily regenerated and can be reused and metals of high atomic masses can be easily eliminated. Previously many plant leaves have been successfully utilized to eliminate heavy metal ions, including; *Diceriocaryum eriocarpum* leaves, (Edokpayi *et al*., 2015) and *Melia azedarach* leaves (Khokhar and Siddique, 2015) and *Phytolacca americana* leaves (Wang *et al*., 2018) and *Salvia moorcroftiana* leaves (Salman *et al*., 2019) and *Leucaena leucocephala* residues (Cima-Mukul *et al*., 2019) and mango leaves (Adelaja *et al*., 2019) and *Aloe barbadensis* leaves (Gupta *et al*., 2019) and peel of *Artocarpus nobilis* (Priyantha and Kotabewatta, 2019).

Tree leaves are efficient adsorbents which successfully remove toxic metals of high atomic masses from aqueous solution in which functional groups hydroxyl, carbonyl, amino and ether group may be present which are important binding sites for heavy metals. *Syzygium cumini* is well known tropical tree native from Indian subcontinent, but widely cultivated in many countries in south America, Africa and Asia (Chagas *et al*., 2015). The Pb (II) and Cd (II) ions can be removed by using leaves of *Syzygium cumini* as adsorbent. Chemical modification of tree leaves enhances their adsorption capacity of heavy metal ions (Ngah and Hanafiah, 2008) therefore, selected leaves were chemically modified.

The aim of the present study was pretreatment and modification of biosorbent to improve its sorption capacity. The prospective application of biosorbent and biosorption of Pb (II) and Cd (II) ions in the aquatic system was discussed. The effects of different parameters such as pH, initial metals ions concentration, biomass dosage, contact time and temperature were studied. Moreover, the kinetic, thermodynamic and isothermal studies were also conducted.

Materials and Methods

Preparation and chemical modification of *Syzygium cumini* leaves. The leaves of *Syzygium cumini* were collected, extensively washed and shadow dried. The dried leaves were kept in an electric oven for 24 h at 40 °C to remove the vapours. The brittle dried leaves were ground into powder by the electrical grinder. 45 mish size particles were selected and soaked in 0.1 M nitric acid which was kept for 24 h. The solution having nitric acid treated *Syzygium cumini* leaves were filtered and washed with double distilled water to remove excess HNO_3. The nitric acid treated *Syzygium cumini* leaves was first dried in the open air and after in oven at 100 °C. 50 g acid treated *Syzygium cumini* leaves treated with 0.1 M $CaCl_2$ solution for 24 h. The excess $CaCl_2$ was removed from the chemically modified *Syzygium cumini* leaves (CMSCL) by filtration and washing with double distilled water. The CMSCL was dried at room temperature and put in the vacuum oven at 105 °C for complete removal of moisture. The CMSCL was treated with acid to remove the impurities and metals ions present on its surface. Moreover, biosorbent was treated with calcium chloride to load calcium metal on biosorbent surface which work as ion exchanger for the removal toxic metals.

Chemicals, solutions and instruments. All chemicals and reagents analytical standard were purchased from Sigma Aldrich, Merck and Fisher companies. The solutions of Pb (II) and Cd (II) ions were prepared by dissolving 1.0 g/L Pb $(NO_3)_2$ and $CdCl_2$ in doubled distilled water.

Atomic absorption spectrophotometer of Z-2000 series was used for the determination of the metal concentrations. Mettler balance was used for weighing various chemicals and chemically modified *Syzygium cumini* leaves (CMSCL) powder. Fourier transformed infrared spectrophotometer (Prestige-21) from Shimadzu Japan was used for the functional group's identification. NOVA, 2200e, USA was used for surface morphology, surface area and pore size analyses. To determine the pH of the solution a digital Mettler Delta 320 hydrogen ion concentration meter was used. The variable speed shaker from (40-400 rpm) having a temperature controller up to 70 °C was used.

Characterization of chemically modified *Syzygium cumini* leaves (CMSCL). The removal of heavy metal ions is linked with the nature of biosorbent. The functional groups present in the CMSCL were identified by using FTIR spectrophotometer. This technique also helps to understand the mechanism of biosorption. 0.05 g sample of biomass was pressed from 3 to 5 barometric pressure. Frequency ranging from 400-4000/cm was used for spectral analysis. Pores size and surface area are the important parameters of the biosorbent. Biosorption capacity increases by raising the surface area of the biosorbent. The good biosorbent is that which has a greater number of small pores size surface area, pore volume and pore diameter were investigated by using the analyzer (NOVAS200e, Quantachrome, USA).

Batch biosorption experiment. Batch biosorption was performed to determine the removal of Pb (II) and Cd (II) ions in the aqueous system of 100 mL volume that was selected for all experiments. 5 g biosorbent was used to determine the biosorbent concentration effect. For biosorption experiments, the shaking speed was kept constant at 180 rpm. The pH was adjusted from 2.0 to 7.0 using 0.1 M solution of HCl and 0.1 M solution of NaOH. Similarly, a solution concentration of 100 ppm was used in the experiment. The metal adsorption capacity of CMSCL for Pb (II) and Cd (II) ions were determined by using the given formula:

$$qe = V \times \frac{(C_o - C_e)}{m} \quad \text{..............................} \quad (1)$$

where:

q_e is the metal quantity adsorbed (mg/g) for the (CMSCL), C_o is the initial equilibrium concentration (mg/L) and C_e is the final equilibrium concentration (mg/L) of the metal ions in the aqueous solution, m is mass in grams (g) of the CMSCL used in the process and V is the volume (dm^3) of the solution.

Results and Discussion

Biosorbent and its characterization. Surface area was analyzed by Barrett-Joyner-Halenda (BJH), pore volume and pore diameters were calculated by using Brunauer-Emmett-Teller (BET) shown in Table 1. The results reveal that CMSCL has the greater surface area and very high porosity making it a good biosorbent.

FTIR analysis of biomass. FT-IR spectra of chemically modified *Syzygium cumini* leaves, Pb loaded CMSCL and Cd loaded CMSCL are shown in Fig. 1a-c, respectively. The FTIR spectra of Pb (II) and Cd (II) unloaded CMSCL showed the presence of various functional groups. The absorption at 2928/cm shows the stretching vibration of C-H in C=C-H and $-CH_2$ groups. The peak located at 1322/cm exhibits -NH functional group. The peak at 1159/cm represents the CN stretching. CO and C-OH stretching vibration showed peaks in the 1080/cm and 1035/cm region respectively (Anayurt *et al*., 2009a).

Table 1. Surface area, pore volume and pore diameter of CMSCL biomass

Biosorbent	BET surface area m^2/g	BJH surface area m^2/g	Pore volume cm^3/ g	Pore diameter Å
CMSCL	72.68	293.26	0.96	133.00

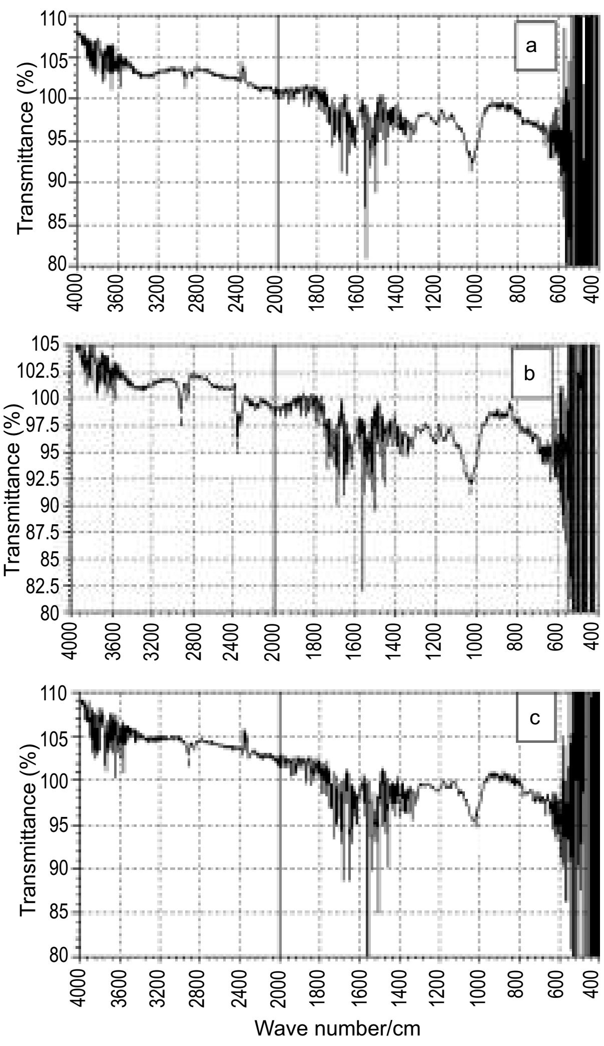

Fig. 1. FT-IR spectra of (a) the biosorbent of CMSCL (b) biomass treated with Pb (II) solution, (c) biomass treated with Cd (II) solution.

The Pb (II) loaded FTIR spectra of CMSCL showed wavenumber shift of many functional groups. Meanwhile, the wave number of absorption peaks were moved from 2927/cm, 1153/cm and 1035/cm to 2918/cm, 1153/cm and 1028/cm, respectively. The FTIR data clearly indicates the involvement of C=O, OH and CN groups in Pb biosorption. FTIR spectra of Cd loaded CMSCL indicates the involvement of C=O and -OH groups for Cd (II) biosorption, due to shifting of the absorption peaks from 2928/cm and 1036/cm to 2918/cm and 1019/cm, respectively (Yu *et al*., 2007).

Batch biosorption experimental works. ***pH effect.*** pH effect is the important parameter for the biosorption of Pb (II) and Cd (II) ions onto CMSCL. Biosorption was performed by changing pH values from 2-7 and the experimental data is shown in Fig. 2. The maximum elimination for Pb (II) and Cd (II) ions was achieved at pH 6.0 and 7.0. respectively. It was noted that when the concentration of hydrogen ions increases the removal of metal ions also increases and maximum removal of Pb (II) and Cd (II) ions onto CMSCL biosorbent was obtained at pH 6.0 and pH 7.0, respectively. Figure 2 showed that at low pH the binding places become saturated with hydrogen ions and compete for the positive Pb (II) and Cd (II) ions to be adsorbed (Amegrissi *et al*., 2013). Beyond optimum pH, biosorption decreases and the biosorption sites at higher pH do not get activated. Ionic precipitation of metal hydroxides occurs at higher pH value given in Fig. 2.

Biosorbent dose effect. The biosorbent dose variation was studied for the removal of Pb (II) and Cd (II) ions. To study the influence of CMSCL, dose was changed from 1.0 g/L to 30 g/ L and is shown in Fig. 3. The experimental data explained that the percent removal of metal biosorption has linear relationship with raising the amount of CMSCL. Beyond 15 g/L up to 30 g/L the percent biosorption was negligible. It was concluded that dosage of CMSCL of 5 g/L was further used as an optimum amount for maximum removal of Pb (II) and Cd (II) ions. The experimental result clearly elaborates that biosorption increases by raising biomass sites. The biosorption capability becomes nearly remain same above the optimum dose value which is due to high biosorbent dose resulted in the biosorbent aggregation. The interference phenomenon may be happening between active binding sites at higher biosorbent dose or insufficient heavy metal ions in the aqueous system with respect to available active binding sites. It is known that hydrogen ions will react with heavy metal ions and therefore decreases the interactive relationship of Pb (II) and Cd (II) ions with the biomass (Hanafiah *et al*., 2009). Moreover similar reports were achieved for the removal of Cd (II) ions from aqueous system by *Saccharomyces cerevisiae*. Therefore, the optimal amount of biosorbent was taken as 5 g/L for further research.

Study of initial metal ions concentration. Initial metal concentration is considered to be a necessary parameters of the biosorption study. The initial metal concentration was studied for Pb (II) and Cd (II) ions varied from 20 to 700 ppm. The CMSCL was taken 5 g/L by keeping constant other parameters. Figure 4 shows that the metal absorption capability on CMSCL increases when percent

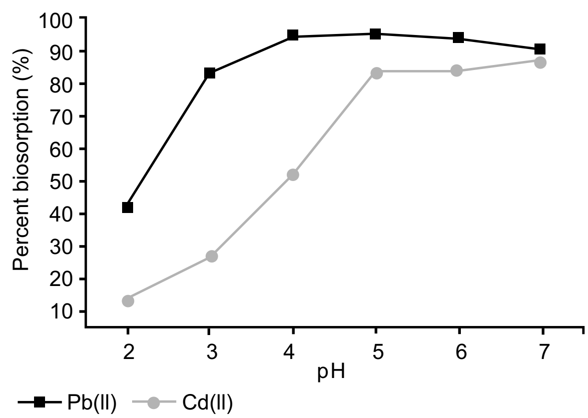

Fig. 2. Ionic precipitation of metal hydroxides occurs at higher pH value.

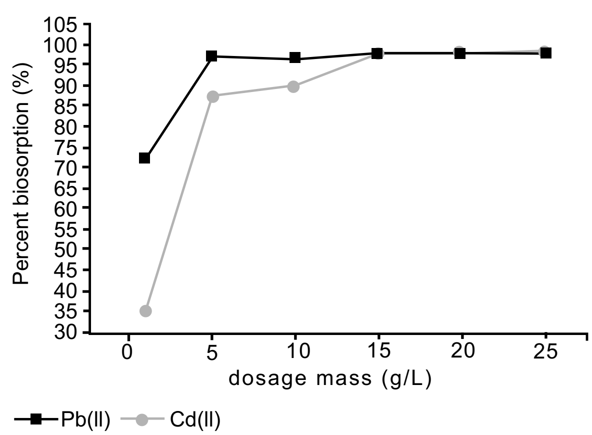

Fig. 3. Biomass dose for the removal of Pb (II) and Cd (II) ions onto CMSCL.

biosorption decreases with the increasing initial concentration of Pb (II) and Cd (II) ions. Biosorption capacity Increase were due to increasing in concentration (Rao *et al*., 2011). Biosorbent ability of CMSCL leaves increases by raising the metal ion concentration. At lower concentration of heavy metal ions, it is observed that biosorption reached up to near hundred percent.

Effect of initial concentration on the biosorption of Pb (II) and Cd (II) ions onto CMSCL (experimental parameters for Pb (II) and Cd (II): pH 6.0 and 7.0, contact time 120 and 60 min, solution 100 mL, biomass 0.5 g, temperature 50 and 40 °C, shaking speed 180 rpm) shows in Fig. 4.

Study of contact time. Contact time is considered to be the crucial parameter for the study of heavy metals biosorption by CMSCL biomass. When the contact time increases the metal biosorption also increases linearly shown in Fig. 5. Initially rapid removal of Pb (II) and Cd (II) ions occur in which maximum absorption occurs and becomes slow and continued until equilibrium was attained. The first step was fast due to the maximum available spaces on biosorbent surface. The process becomes slower in the second step when the surface of chemically modified *Syzygium cumini* leaves (CMSCL) was deposited by metal ions. Therefore, the optimum time for Pb (II) and Cd (II) ions biosorption was considered as 120 min and 60 min respectively for further research (Rao *et al*., 2011).

Temperature effect. Temperature is an important parameter studied for the removal of Pb (II) and Cd (II) ions. It was varied from 298 to 348 K, while all other parameters remain unchanged. Figure 6 shows when the temperature increases the nature of biomass changes and biosorption capacity increases and reaches to further minimum change at 348 K. The relationship of temperature and biosorption of metal ions is given in Fig. 6 which shows a decrease in the removal of Pb (II) and

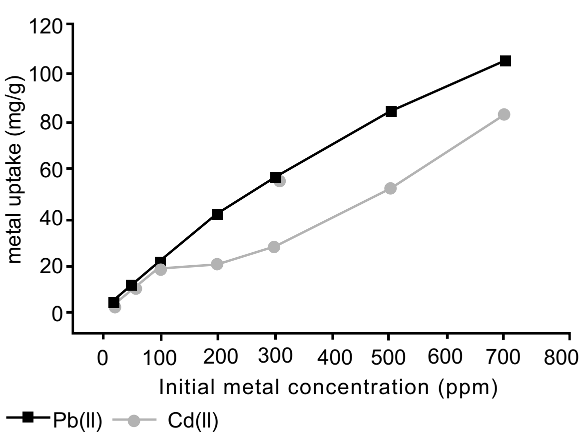

Fig. 4. Effect of initial concentration on the biosorption of Pb (II) and Cd (II) ions onto CMSCL.

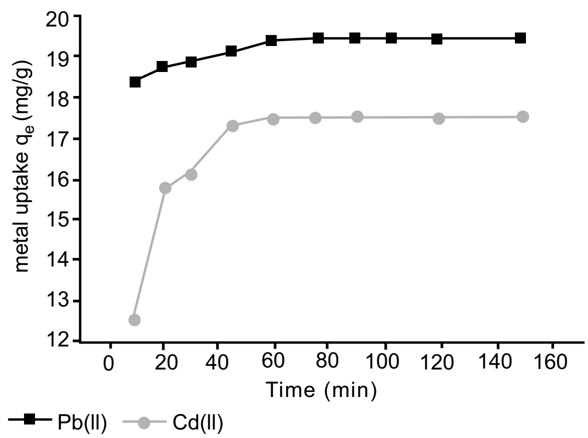

Fig. 5. Contact time study on the removal of Pb (II) and Cd (II) ions onto CMSCL (experimental parameters for Pb (II) and Cd (II): pH 6.0 and 7.0, biomass 0.5 g, solution 100 mL, initial con. 100 mg/L, temperature 50 and 40 °C, shaking speed 180 rpm).

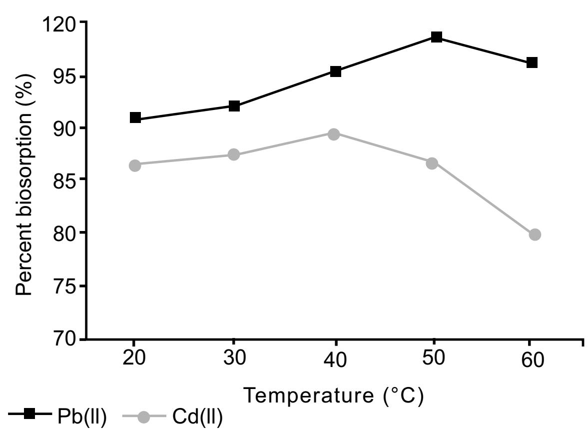

Fig. 6. Temperature study on the removal of Pb (II) and Cd (II) ions onto CMSCL (experimental parameters for Pb (II) and Cd (II): pH 6.0 and 7.0, biomass 0.5 g, solution 100 mL, initial con. 100 mg/L, contact time 120 and 60 min and shaking speed 180 rpm).

Cd (II) ions with the regular increase in temperature which may be due to the destruction of active sites in the surface of biosorbent. The optimum temperature for the removal of Pb (II) and Cd (II) ions was 50 °C and 40 °C, respectively (Sari and Tuzen, 2009).

Biosorption kinetics. Kinetics studies is important for the evaluation of batch biosorption process. It is necessary to get fundamental information about the rate by which absorption occurs on the CMSCL biomass. To study the chemical kinetics for biosorption for Pb (II) and Cd (II) ions, the pseudo-first order (Ho, 2009) and pseudo-second order kinetics models Amegrissi *et al*. (2013) were applied on the experimentally obtained data.

The pseudo-first order kinetic model was presented by Lagergren in 1898.

$$d_q/d_t = k_1 (q_e - q_t) \text{ .... } (2)$$
$$q_t = q_e (1-e^{-K1t}) \text{ .... } (3)$$

The q_e (mg/g) is for metal ion concentrations at equilibrium and q_t (mg/g) is metal ion concentration at any time t. The k_1/min is the rate constant for 1st order.

Lagergren pseudo-first order models are not suitable for the biosorption kinetics study.

The pseudo-second order kinetic models presented by Ho for the biosorption in the equation form is given below:

$$dq_t/d_t = k_2 (q_e - q_t)^2 \text{ .... } (4)$$
$$q_t = q_e \quad q_eK_2t/1+q_eK_2t \text{ .... } (5)$$

where:

K_2 is the second order kinetic equilibrium rate constant (g/mg/min). The q_t (mg/g) and q_e (mg/g) for the biosorption at time "t" and the biosorption at equilibrium.

The equilibrium capacity q_e, rate constant k_2 and correlation coefficient (R^2) are given in Table 2. The comparison of the experimental work with kinetic model's data confirmed a good correlation coefficient (R^2) and was greater than 0.999. The value of q_e obtained is in close agreement with pseudo-second order kinetics model. The kinetic model is more suitable to predict kinetic nature with chemical biosorption being occur in the rate determining step. It was concluded on the bases of correlation coefficient (R^2) that the removal of Pb (II) and Cd (II) ions by using CMSCL was chemisorption and followed pseudo second kinetics model.

Table 2. Kinetic study of pseudo second order for removal of Pb(II) and Cd(II) ions

Metals	Pseudo second order			
	C_0 (mg/L)	K_2 (g/mg/min)	q_e mg/g	R_2
Pb (II)	100	0.01968	12.269	0.999
Cd (II)	100	0.01776	13.960	0.999

Adsorption isotherms at equilibrium. At the same temperature and equilibrium condition biosorption explains the relationship between per unit mass of the adsorbent and the amount of the adsorbate adsorbed. The equilibrium system at constant temperature is established to check the batch biosorption process in batch dynamics. Important information were obtained from adsorption isotherm that reveals the occurrence of absorption. The sorbent and sorbate interaction determine its distribution between liquid and solid phases.

According to Langmuir adsorption isotherm, "a fixed number of specific homogenous places are available at the surface of adsorbent on which reversible monolayer adsorption takes place without the lateral interaction among the adsorbate species" (Sari and Tuzen, 2009).

Langmuir equation at constant temperature is given as:

$$q_e = q_{max}\, b\, C_e/1+ b\, C_e \text{ .... } (6)$$

After solving we get the linear equation as:

$$C_e/q_e = 1/q_{max}\, b + C_e/q_{max} \text{ .... } (7)$$

At equilibrium, the quantity of adsorbate adsorbed per unit weight of biomass is given by q_e (adsorbate in mg/adsorbent in g). At equilibrium condition the adsorbate present in the aqueous solution after the process of biosorption is given by C_e (mg/L). The q_{max} (mg/g) shows highest adsorption ability of the adsorbent while b (L/mg) shows the experimental Langmuir constant for adsorption. The b (L/mg) is also relationship of ability and free energy of binding places available. The Langmuir adsorption isotherm perfectly describes the present biosorption data.

According to Freundlich adsorption isotherm "adsorption of molecules on available active places assumes a multilayer sorption" (Sari and Tuzen, 2009) Mathematically, Freundlich adsorption isotherm equation is given as:

$$q_e = k_F (C_e)^{1/n} \text{ .... } (8)$$

Linear equation of above equation can be expressed as:

$$\ln q_e = 1/n \ln C_e + \ln k_F \text{ .... } (9)$$

where:

C_e (mg/L) is the equilibrium concentration of adsorbate in the aqueous solution. At equilibrium, the q_e (mg/g) is the amount of adsorbate adsorbed per unit mass of biosorbent. The K_F is adsorption coefficient which shows the biosorption ability and n is associated with the amount of biosorption. High values of n and K_F and lower value of R^2 showed that Freundlich isotherm does not applicable to the present research data given in Table 3.

Adsorption thermodynamics. Biosorption of Pb (II) and Cd (II) ions are generally written by the following reversible process:

Metal (II) ions in aqueous solution ← →
metal (II) ions-biomass

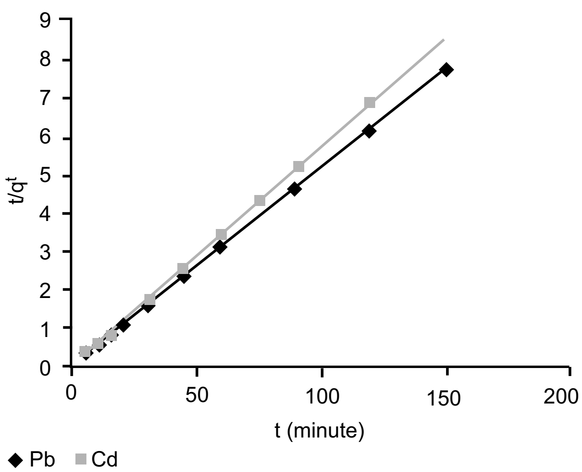

Fig. 7. Pseudo-second order kinetics plot for the removal of Pb (II) and Cd (II) ions by using CMSCL.

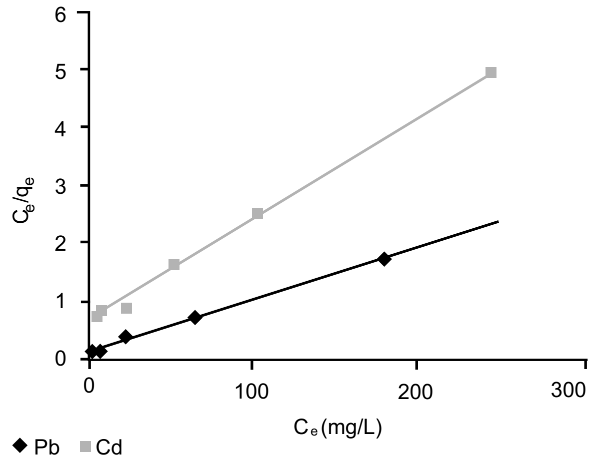

Fig. 8. Langmuir plot for the removal of Pb (II) and Cd (II) ions onto CMSCL.

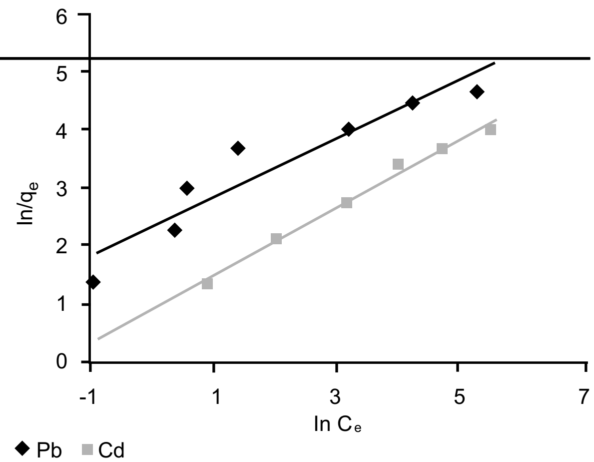

Fig. 9. Freundlich plot for the removal of Pb (II) and Cd (II) ions onto CMSCL.

Thermodynamic parameters are used to study the physical or chemical nature and feasibility of the biosorption process. It is also important to investigate whether the process is exothermic or endothermic. The changes in enthalpy (ΔH°), Gibbs free energy (G°) and

Table 3. Langmuir, Freundlich and Temkin isotherm correlation coefficients and constants for the removal Pb (II) and Cd (II) ions by CMSCL

Metals		Langmuir model			Freundlich model			Temkin model		
	C_0 (mg/L)	q_{max} (mg/g)	b (mg/L)	R^2	n (g/L)	K_F (g/L)	R^2	K_T (g/L)	b_T (J/mol)	R^2
Pb (II)	100	109.89	0.0760	0.9931	1.956	213.45	0.8879	1.958	144.44	0.9693
Cd (II)	100	57.14	57.14	0.9956	1.699	7.80	0.9695	0.366	239.65	0.9577

entropy (ΔS°) were determined by applying the Van't Hoff's equations:

$$K_D = q_e / C_e \quad (10)$$

$$\Delta G^0 = -RT\ln K_D \quad (11)$$

$$\ln K_D = \Delta S°/ R - \Delta H°/RT \quad (12)$$

K_D of Van't Hoff's plot is a function of 1/T gives a straight line shown in Fig. 11. The ΔS° and ΔH° were calculated from intercept and slope respectively.

The calculated Gibbs free energy (ΔG°) are -2.138, -2.174, -2.245, -2.316 KJ/mol for Pb (II) ions and -0.325, -0.334, -0.345, -0.356 KJ/mol for Cd (II) ions removal at 298 K, 303 K, 313 K, 323 K, respectively.

Table 4. Thermodynamics conditions for removal of Pb (II) and Cd (II) ions onto CMSCL

Metals	ΔH (Kj/mol)	ΔS (Kj/mol)	ΔG (Kj/mol)			
			298K	303K	313K	323K
Pb (II)	-12.158	7.136	-2.138	-2.174	-2.245	-2.316
Cd (II)	-2.100	1.0964	-0.325	-0.334	-0.345	-0.356

The Table 4 shows the values of ΔH°, ΔS and ΔG°. The parameter ΔH° was found to be -12.157 KJ/mol and -2.100 KJ/mol for the removal Pb (II) and Cd (II) ions, respectively. The negative value of ΔH° exhibits that the Pb (II) and Cd (II) ions removal on to CMSCL was exothermic in nature. The was achieved value for ΔS° was 7.135 J/mol K for the removal of Pb (II) ions and 1.0964 J/mol K for of Cd (II) ions removal. The positive value of ΔS° suggest that biosorption mechanism was favourable (Singh *et al*., 2006). The negative values of ΔG° shows the decline in biosorption feasibility with increases in temperature, nature of chemical biosorption and spontaneous nature of biosorption process (Krishna and Venkateswarlu, 2011).

Comparative biosorption capacity. As shown in Table 5, CMSCL is a cheap and abundantly available alternative chemically modified *Syzygium cumini* leaves which has higher biosorption capability than many other biomasses.

Table 5. Comparative study of maximum biosorption capability of CMSCL with other low-cost biomasses

Biomass	q_{max} (mg/g) for Pb (II) ions	q_{max} (mg/g) for Cd (II) ions	References
Ulva lactuca	34.7	29.2	(Krishnani *et al*., 2008)
Phanerochaete chrysosporium	69.8	23.0	(Jiemtaweeboon *et al*., 2007
Lactarius scrobiculatus	56.2	53.1	(Anayurt *et al*., 2009b)
Peels of Banana	2.18	5.71	(Anwar *et al*., 2010b)
Amanita rubescens	38.4	27.3	(Sari and Tuzen, 2009)
Mucor rouxii	-	20.3	(Saltali *et al*., 2007)
Phanerochaete chrysosporium	-	15.2	(Shohreh *et al*., 2016)
Rhizopus Arrhizus	-	26.8	(Alimohamadi *et al*., 2005)
Streptomyces noursei	-	3.4	(Mattuschka and Straube, 2010)
Mucor rouxii	-	20.3	(Yan and Viraraghavan, 2010)
Moringa oleifera tree leaves	209.40	-	(Reddy *et al*., 2010a)
Ulmus carpinifolia leaves	201.10	-	(Sangi *et al*., 2008)
Fraxinus excelsior leaves	172.00	-	(Sangi *et al*., 2011)
Xanthat rubber leaf powder	166.70	-	(Khalir *et al*., 2011)
Sludge of rose petals	87.70	-	(Nasir *et al*., 2007
Tea waste	65.00	-	(Amarasinghe and Williams, 2007)
Rubber leaf powder	46.70	-	(Hanafiah *et al*., 2006)
Sago waste	46.60	-	(Auldry *et al*., 2009)
Tree fern	40.00	-	(Driscoll *et al*., 2003)
Ficus religiosa leaves	37.45	-	(Kazmi *et al*., 2015)
Groundnut hull	31.54	-	(Qaiser *et al*., 2009)
Rice husk ash	12.60	-	(Feng *et al*., 2004)
Lalang leaf powder	5.89	-	(Abdus-Salam, 2012)
Tobacco stem	5.54	-	(Wei *et al*., 2008)
CMSCL	109.89	57.14	This study

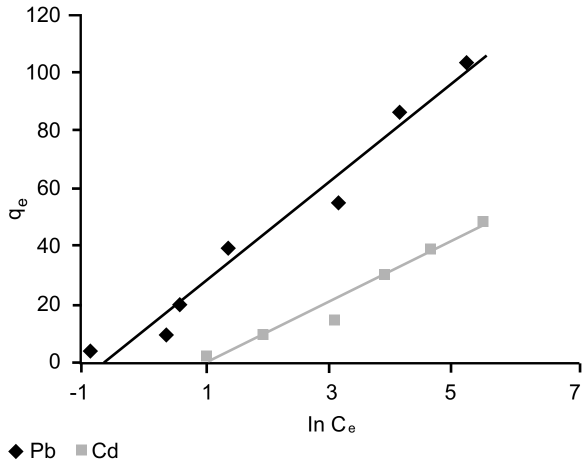

Fig. 10. Temkin plot for the removal of Pb (II) and Cd (II) ions onto CMSCL.

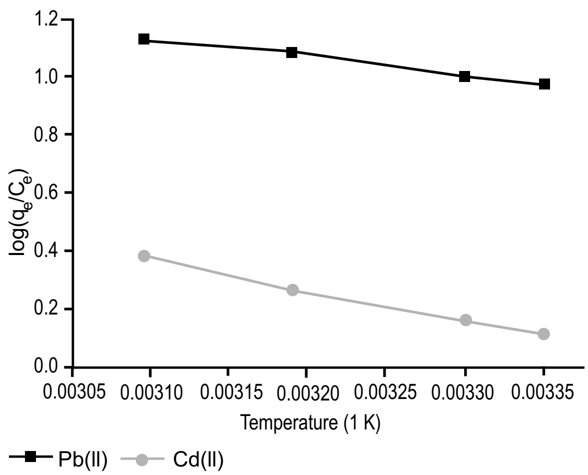

Fig. 11. The Van't Hoff's plot for the removal of Pb (II) and Cd (II) ions onto CMSCL (experimental parameters for Pb and Cd (II) ions: pH 6.0 and 7.0, biomass 0.5 g, solution 100 mL, initial con. 100 mg/L, contact time 120 and 60 min and Agitation speed 180 rpm).

Conclusion

The present study proved that CMSCL could be efficiently used as an effective and alternative biosorbent for the removal of Pb (II) and Cd (II) ions from aqueous solution. The operating conditions, pH of the solution, biosorbent dosage, initial metal concentration, temperature and contact time were thoroughly studied for biosorption efficiency. The maximum removal capacity of Pb (II) and Cd (II) ions was 109.89 mg/g and 57.14 mg/g at optimum pH 6.0 and pH 7.0, contact time of 120 min and 60 min and temperature 50 °C and 40 °C, respectively. The kinetic studies declared the biosorption of Pb (II) and Cd (II) ions onto CMSCL biomass properly followed the pseudo-second order kinetic model. Thermodynamic data exhibits that the process of biosorption of Pb (II) and Cd (II) ions onto CMSCL was spontaneous, feasible and exothermic. Langmuir isotherm successfully interpreted the process of biosorption. Taking into evaluation of the present works, it can be concluded that CMSCL is good biomass having a high capacity for removal of Pb (II) and Cd (II) ions from aqueous solution and industrial effluents. Furthermore, it can be considered as low-cost alternative biomass for the biosorption of Pb (II) and Cd (II) ions containing wastewater.

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Conflict of Interest. The authors declare have no conflict of interest.

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