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Research Article

Studies on the Removal of Pb(II) from Aqueous Solutions by Adsorption with *E. Globulus* Leaf Powder through Response Surface Methodology

Hymavathi D and Prabhakar G*
Department of Chemical Engineering, S.V. University College of Engineering, Tirupati, Andhra Pradesh, India

***Corresponding author:** Garimella Prabhakar, Department of Chemical Engineering, S.V. University College of Engineering, Tirupati, Andhra Pradesh, India

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Abstract

An exhaustive batch experimental investigation to treat lead-laden waters by adsorption using leaf powder of Eucalyptus globulus is reported. Based on full factorial approach, optimum conditions to yield a removal of 96.58% are identified as initial ion concentration of 20mg/L, sorbent dosage 25g/L at a pH of 5.0 and a temperature of 303K. Freundlich model adequately represents the equilibrium and the maximum adsorption capacity is found to be 6.803mg/g. The process is endothermic and spontaneous. Adsorption follows second order kinetics. The adsorption process compares well with other similar studies.

Keywords: Pb(II) removal; Adsorption; E. globules; Equilibrium; Kinetics; RSM

Nomenclature

C_o: Initial Concentration of Pb(II) solution (mg/L); C_e: Equilibrium Concentratin of Pb(II) solution (mg/L); q_e: Amount Sorbed Per Unit Weight Of Biosorbent At Equilibrium (mg/g); q_{et}: Equilibrium Metal Uptake Capacity At Time (mg/g); q_{max}: Maximum Metal Uptake Capacity (mg/g); q_t: Metal Uptake Capacity At Time t (mg/g); K_{diff}: Intra-Particle Diffusion Rate Constant; c: Thickness Of Boundary Layer; m: Mass Of Adsorbent (g); w: Adsorbent Dosage (g/L); V: Volume of the Pb(II) solution (L); b=k_L: Affinity Constant Or Energy To Biosorption (L/g); n: number(dimensionless); K_f : Freundlich coefficient (mg/g); K_1 : First Order Equilibrium Rate Constant (1/min); K_2: Second Order Equilibrium Rate Constant (g/mg.min); A_T: Temkin Adsorption Intensity, (L/g); A_E: Elovich constant; B_E: Initial Adsorption Rate; E: Mean Free Energy Of Sorption Per Of The Molecule Of Sorbate; b_T: Heat Of Adsorption Constant

Abbreviations

R: Universal Gas Constant (8.314mol-1K-1); X_1: Initial Concentrations of Pb(II) (mg/L); X_2: pH(dimensionless); X_3: Adsorbent Dosage (g/L); X_4: Absolute Temperature (K); RSM: Response Surface Methodology; ANOVA: Analysis Of Variance; Max: Maximum Metal Uptake Capacity; Diff: Intra-Particle Diffusion Rate Constant

Introduction

Water contamination is mainly due to the accumulation of heavy metals, from different industries like metallurgical, battery, electroplating and metal finishing industries, chemical manufacturing and tanneries [1,2]. Among heavy metals viz., Co, Cr, Zn, Cd, Cu, Pb, Hg, As, Al and Ni, Pb(II) is one of the most toxic ion causing serious health issues related to liver damage, nervous system, kidneys, reproductive system, neurological activity and also causes high hypertension [3,4]. Maximum allowable concentration for Pb(II) ion limit value of 0.01mg/L in drinking water recommended by World Health Organization [5] and the permissible level of Pb(II) in wastewater is 0.05mg/L given by the Environmental Protection Agency (EPA) [6]. Conventional methods - chemical precipitation [7], reverse osmosis [8], ion exchange [9], coagulation [10], electro dialysis [11] and ultra filtration [12] were studied earlier. These methods were found to be not so promising due to incomplete metal removal, high reagent and high energy requirements.

Adsorptive treatment of lead waters was probed with different types of waste materials and a few of them are as follows. Nile rose plant [13], chaff [14], rice husk [15], coir fiber waste [16], banana stems [17], wheat bran[18], coffee grounds [19], tree ferns [20], palm kernel fibres [21], crop milling waste-black gram husk [22], pomegranate peels [23] , peanut skins [24], cone biomass of Pinus sylvestris [25], carbon derived from agricultural waste[26], almond shell [27], native and chemically treated olive stone [28], residue of all spice [29], ceder leaf ash [30], cashew nut shell [31], Peanut shell [32], native and chemically treated olive tree pruning [33], pine cone shell [34] and rapeseed biomass [35] were used in the studies and Eucalyptus globulus , leaf powder of cheap and widely available which is preferred as a natural antimicrobial agent, industrial solvent, and deodorant, is tried for the removal of lead from aqueous systems [36,37].

In present work, E. globules L., used as an adsorbent for removal of Pb(II) from aqueous solution and E. glubulus belongs to the family of myrtaceae. Eucalyptus bark was used for the removal of chromium [38] and mercury [39]. Till –to- date, non literature is available on *E. globulus* leaf powder for removal of Pb(II).

Materials and Methods

Preparation of stock solution

All chemical compounds used are of analytical grade (Merck).

A Stock solution of 500ppm Pb(II) is prepared by dissolving

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Table 1: Result from CCD for Pb(II) Adsorption by *E. globulus* L.

Run	X_1(Co)	X_2(pH)	X_3 (w)	X_4(T)	% Adsorption of Pb(II)	
					Experimental	Predicted
1	-2	0	0	0	94.42	94.4391
2	1	-1	1	1	95.34	95.3214
3	-1	-1	-1	1	96.01	95.9773
4	0	0	-2	0	95.7	95.733
5	0	0	0	-2	94.42	94.4155
6	-1	1	-1	1	92.42	92.4071
7	-1	1	1	-1	94.77	94.7846
8	0	0	0	0	96	96
9	-1	-1	1	1	95.881	95.8978
10	-1	1	-1	-1	93.158	93.1381
11	0	0	2	0	96.58	96.6018
12	1	1	-1	-1	93.634	93.601
13	1	1	-1	1	93.43	93.4143
14	0	0	0	0	96	96
15	1	1	1	-1	94.555	94.5493
16	0	-2	0	0	95.53	95.5361
17	0	0	0	0	96	96
18	0	2	0	0	92.36	92.4086
19	-1	-1	-1	-1	96.19	96.2035
20	1	-1	-1	1	96.13	96.0991
21	1	-1	-1	-1	95.77	95.7811
22	0	0	0	0	96	96
23	0	0	0	2	94.84	94.8993
24	2	0	0	0	94.29	94.3256
25	-1	-1	1	-1	95.25	95.2273
26	-1	1	1	1	95	94.9504
27	1	-1	1	-1	94.11	94.1066
28	0	0	0	0	96	96
29	1	1	1	1	95.289	95.2593
30	0	0	0	0	96	96

0.4055mg of 98.5% pure $Pb(NO_3)_2$ in 500ml of distilled water. It is diluted to different levels, appropriate to the study. pH of the solution is adjusted using 0.1N NaOH and 0.1N H_2SO_4. Final Pb(II) ion concentration is obtained by Inductively Coupled Plasma Optical Emission Spectroscope (Perkin Elmer model Optima 8000). FTIR (ALPHA interferometer (ECO-ATR)), Bruker, Germany) in the range of 4000 – 500 cm^{-1} is employed to identify the functional groups that are involved in adsorption. Elemental composition is recorded by Scanning Electron Microscope, (SEM–EVO MA 15) with Electron Dispersive X- Ray Spectroscope of OXFORD INSTRUMENTS (Inca Penta FET x3).

Preparation and activation of biosorbent

E. globulus leaves are collected in the University Campus, water washed thoroughly to clear the surface impurities, and is then sun dried. They are grounded into a fine powder and 63µm – size particles are collected. The particles are further washed with water to remove coloring agents, dried at room temperature and are stored in air tight bottles for further studies.

Biosorption studies

Sufficient numbers of flasks, each containing 50ml solution of 20mg/L Pb(II) are taken and the solution pH adjusted. A known quantity of adsorbent is added and the flasks are agitated at constant speed on a shaker at room temperature, Flasks are withdrawn at suitable time intervals, the content filtered and Pb(II) estimation in the liquid sample is made. Similarly, the procedure is repeated with different quantities of adsorbent and other parameters to make the study complete. Percentage removal Pb(II) is calculated using the formula

$$\frac{C_o - C_e}{C_o} * 100 \quad (1)$$

The equilibrium metal uptake capacity is estimated by using

$$q_e = \frac{C_o - C_e}{C_o} * V \quad (2)$$

Response surface methodology (C.C.D) and optimization of Pb(II) removal

RSM is a group of mathematical and statistical techniques for modeling and analysis of problems in which the response of a model is influenced by several variables [40]. A 24 full-factorial design, 6 center points and 8 axial points leading to 30 experimental runs is performed to study the effect of the four contributing parameters using statistical software, Design expert 10.0.03 (Ease state, USA). Central Composite Design (CCD) consists of 2n factorial runs with 2*n axial runs and the minimum number of experiments that need be conducted is provided by equation 3.

No of experiments (N) = 2^n+2n+6 (center points) = 2*4+2*4+6=30 (3)

Each variable is investigated at two levels and as the number of factors/operating variables increases, then the number of experimental runs for complete picture also increases.

Y=f (X1, X2, X3 …Xn) (4)

In the present case, four factors - initial metal ion concentration (X_1), initial solution pH (X_2), adsorbent dosage (X_3) and temperature of solution (X_4) are selected as independent variables in equation 4 and by fixing the contact time and size of the adsorbent, the percentage removal of Pb(II) is obtained. Percentage adsorption (%Y) is considered as the dependent variable and the experimental design made with range and levels (-2, -1, 0, 1, 2) of independent variables. In the optimization process, the response can be related to the independent variables by quadratic (second degree) equation and the model equation is given in equation 5.

$$\%(y) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 +$$

$$\beta_{14} X_1 X_4 + \beta_{23} X_2 X_3 + \beta_{24} X_2 X_4 + \beta_{34} X_3 X_4 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{33} X_3^2 + \beta_{44} X_4^2 \quad (5)$$

where Y is estimate response of the system, β_0 is constant coefficient, β_1, β_2, β_3 and β_4 are linear coefficients, β_{12}, β_{13}, β_{14}, β_{23}, β_{24} and β_{34} are interaction coefficients among the four factors, β_{11}, β_{22}, β_{33} and β_{44} are quadratic coefficients, X_1, X_2, X_3 and X_4 are independent variables. A

Table 2: Levels of different process variables in coded and uncoded form for Adsorption of Pb (II) using *E. globulus* L. leaf powder.

Variable	Name	Range and level				
		-2	-1	0	1	2
X_1	Initial concentration(C_o) mg/L	10	15	20	25	30
X_2	pH of the solution	3	4	5	6	7
X_3	Biosorbent dosage(w), g/L	5	10	15	20	25
X_4	Temperature(T), K	283	293	303	313	323

Table 3: ANOVA and estimated regression coefficients for the Pb (II) biosorption onto *E. globulus* L.

	Sum of Squares	df	Mean Square	F-value	p-value Prob > F	significant
Model	38.15	14	2.72	2256.97	< 0.0001	
X_1-Initial Conc.	0.019	1	0.019	16	0.0012	
X_2-pH	14.67	1	14.67	12152.03	< 0.0001	
X_3-dosage	1.13	1	1.13	937.84	< 0.0001	
X_4-Temp.	0.35	1	0.35	290.83	< 0.0001	
$X_1 X_2$	0.78	1	0.78	649.07	< 0.0001	
$X_1 X_3$	0.49	1	0.49	403.82	< 0.0001	
$X_1 X_4$	0.3	1	0.3	245.34	< 0.0001	
$X_2 X_3$	6.88	1	6.88	5697.4	< 0.0001	
$X_2 X_4$	0.25	1	0.25	211.02	< 0.0001	
$X_3 X_4$	0.8	1	0.8	666.05	< 0.0001	
X_1^2	4.49	1	4.49	3715.37	< 0.0001	
X_2^2	7.05	1	7.05	5837.42	< 0.0001	
X_3^2	0.048	1	0.048	39.78	< 0.0001	
X_4^2	3.09	1	3.09	2559.5	< 0.0001	
Residual	0.018	15	0.06			
Lack of Fit	0.018	10	0.09			
Pure Error	0	5	0			
Cor Total	38.17	29				

R^2 (Adj) = 0.9991 and R^2 (Pred) = 0.9973

multiple regression analysis is then performed to obtain the values of the coefficients. A total of 30 experiments are needed to estimate the biosorption of Pb(II) on to *E. globulus* L. The responses and corresponding parameters are modeled and optimized using analysis of variance (ANOVA) and by the correlation coefficient (R^2). The R^2 value shows a measure of how variability in the observed response values can be simplified by experimental factors and their interactions [41].

Results and Discussion

Optimization using response surface methodology (RSM)

It is pointed out that six factors are critical in adsorption. The smaller the particle, the higher is the surface available for transfer and the higher the transfer. However, post adsorption separation puts a limit on the particle size. In the present study a particle of 63µm is used. The time progress of adsorption is studied first and the process has taken 60 minutes to reach equilibrium, Thus, keeping 63µm particle size and 60 minutes of contact time fixed, the effect of other vital parameters, namely, Pb(II) ion concentration, initial solution pH, sorbent dosage and temperature is studied. A total of 30 experimental runs are conducted and the results of the experimentation are in (Table 1). Levels of different process variables in coded and uncoded form for adsorption of Pb(II) using *E. globulus* L. leaf powder in

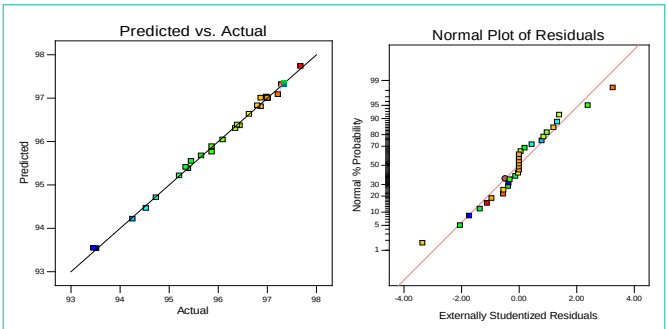

Figure 1(i): A comparison of predicted values and the percentage removal (Actual values) and the normal plot for Residual for Pb(II) onto *E. globulus*. L.

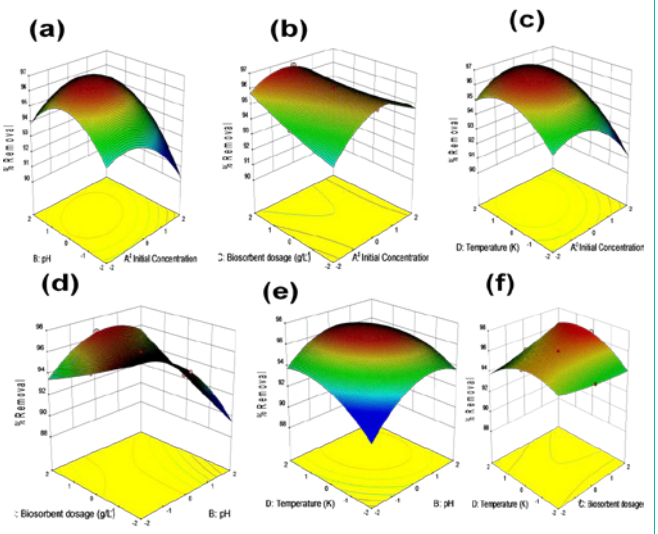

Figure 1(ii): Surface contour plots, (a). pH -Initial conc –% Removal, (b). Initial conc– dosage – % Removal, (c). Temp. – Initial conc –% Removal, (d). pH- dosage -% Removal, (e). pH – Temp. – % Removal, (f). Temp. Dosage – % Removal.

(Table 2). Thus, 96.58% removal of Pb(II) could be achieved, when 20mg/L Pb(II) is treated with 25g/L *E. globulus* L. at a pH of 5.0 and temperature of 303K. The interactive contributions of the variables are further studied with model expression given as equation 3.

$$\%Y = 96 - 0.028^* X_1 - 0.78^* X_2 + 0.22^* X_3 + 0.12^* X_1X_2 - 0.17^* X_1X_3 + 0.14^* X_1X_4 + 0.66^* X_2X_3 - 0.13^* X_2X_4 + 0.22^* X_3X_4 - 0.40^* X_1^2 - 0.51^* X_2^2 + 0.042^* X_3^2 - 0.34^* X_4^2 \quad (6)$$

The equation 6 suggests that a metal ion concentration (Co) = 20.904 mg/L, pH = 5. 258, sorbent dosage (w) = 15.372g/L, and temperature (T) = 302.006K yield the highest removal 97.087% and there is good agreement between experimental values and those, calculated with the model equation. A comparison of optimal values (predicted) and the percentage removal (actual), and the normal plot for residual is in (Figure 1(i)). Interactive contributions of the four variables - Pb(II) ion concentration, initial solution pH, adsorbent dosage and temperature, are presented in surface contour plots in (Figure 1(ii)) for better understanding. The ANOVA and regression coefficient values are presented as (Table 3).

The Model F-value of 2256.97 in (Table 3) implies that the model

Table 4: Isotherm equations and constants at optimum conditions.

Isotherm Models	Equation	Parameters	R^2
Langmuir	$c_e/q_e = 0.147c_e+0.885$	q_{max}=6.803mg/g k_L=b=0.166L/g	0.9486
Freundlich	$\ln q_e = 0.5724\ln c_e + 0.047$	K_f=1.046mg/g n=1.75	0.9918
Temkin	q_e= 1.340 $\ln c_e$+1.033	b_T=1879.95 kJ/mol A_T=2.162 K L/g	0.9492
D-R model	$\ln q_e$=-3E-07ε^2+1.2743	K=3e^{-7} q_m=3.576mg/g E=13.519 kJ/mol	0.8446

is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. All the terms with F< Probability <0.05 are significant. In this case all model terms X_1, X_2, X_3, X_4, X_1*X_2, X_1*X_3, X_1*X_4, X_2*X_3, X_2*X_4, X_3 *X_4, X_1^2, X_2^2, X_3^2 X_4^2 are significant. A value greater than 0.05 indicate the model terms are not significant.

Isotherm studies

Four different standard, the two-parameter adsorption isotherm models are examined for suitability to represent equilibrium, concerning Pb(II) removal.

Langmuir isotherm model [42]

$$\frac{c_e}{q_e} = \frac{1}{q_{m^b}} + \frac{c_e}{q_m} \quad (7)$$

Feasibility of the Langmuir isotherm depends on dimensionless constant is expressed by separation factor, RL.

$$R_L = \frac{1}{1+bc_e} \quad (8)$$

In the present study the value RL is 0.913, indicates a favorable condition.

Freundlich isotherm model [43]

$$q_e = K_f C_e^{\frac{1}{n}} \quad (9)$$

Temkin isotherm model [44]

$$q_e = \frac{RT}{b_T}\ln A_T + \frac{RT}{b_T}\ln c_e \quad (10)$$

Dubinin–Radushkevich isotherm model

Sorption energy is calculated by Dubinin–Radushkevich [45] isotherm model to predict the nature of adsorption process, i.e., physical or chemical. The linear from of the model is described as.

$$q_t = \frac{1}{A_E} \ln q_e = \ln q_D - K\varepsilon^2 \quad (11)$$

The Polanyi potential [46] which is equal to,

$$\varepsilon = RT\ln\left(1+\frac{1}{c_e}\right) \quad (12)$$

The plot of lnqe against ε^2 gave a straight line from which the values of K and q_D, where q_D is the Dubinin-Radushkevich isotherm constant related to the degree of sorbate sorption by the sorbent surface. From the K value, the mean sorption energy (E) is evaluated as

$$E = \frac{1}{\sqrt{2K}} \quad (13)$$

The E (kJ/mol) value gives the information regarding type of adsorption, physical or chemical. If E < 8kJ/mol, the adsorption process is physical in nature and in the 8–16 kJ/mol range and it is chemical in nature [47]. In the present case, the adsorption is in chemical in nature. The parametric values of these models are given in (Table 4) and represent the system well at equilibrium, with Freundlich model being marginally superior to the other models.

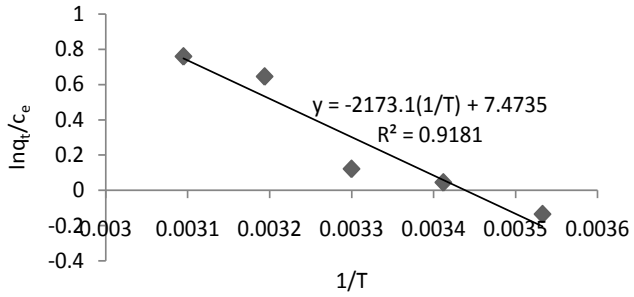

Figure 2: van't Hoff plot for biosorption of Pb(II).

Thermodynamics of adsorption

Adsorption process is temperature dependent. A plot of 1/T against the ratio of equilibrium concentrations of Pb(II) ion in liquid and solid phases is plotted on a semi logarithmic coordinate system and the plot is as shown in (Figure 2). Changes in enthalpy, Gibb's free energy and entropy are calculated to explore the nature of the adsorption, using the following equations 12 and 13.

$$\Delta G^o = -RT\ln K_c^o \quad (14)$$

$$\ln\left(\frac{q_e}{c_e}\right) = K_c^o = -\frac{\Delta H}{R}\left(\frac{1}{T}\right) + \frac{\Delta S}{R} \quad (15)$$

Thermodynamic parameters are evaluated through van't Hoff plot (Figure 2) and the values are ΔH = 18.0664kJ/mole, ΔG= (-) 0.76kJ/mole and ΔS= 62.131J/ mole -K. It is evident from the property values that the adsorption is endothermic and spontaneous.

Pb(II) sorption kinetics

Chemical interactions, between the adsorbate and the adsorbent, are described by the different kinetic expressions, in the literature and their applicability to the present case is studied.

Pseudo 1st-order model [48],

$$\log(q_e - q_t) = \log q_t - \frac{K_1}{2.303}t \quad (16)$$

Pseudo 2nd-order model [49],

$$\frac{t}{q_t} = \frac{t}{K_2 q_e^2} + \frac{1}{q_e}t \quad (17)$$

Elovich model [50]

$$q_t = \frac{1}{A_E}\ln(A_E B_E) + \frac{1}{B_E}\ln t \quad (18)$$

Intra-particle diffusion model [51]

$$q_t = K_{diff}t^{0.5} + C \quad (19)$$

A plot of log (q_e-q_t) against time (t) yielded an intercept different from experimentally determined q_e, hence, pseudo first order equation does not represent the adsorption. Pseudo second order model considers the rate-limiting step as the formation of chemisorptive and physiorption bond, involving sharing of electrons between the solute and sorbent. This pseudo-second-order kinetic model, describes the adsorption process with an R^2 of 0.997. The other three expression exhibit an inferior fit to the data, with lower R^2. The values of kinetic

Table 5: The rate equations and coefficients for adsorption of Pb (II) on to *E globulus* L.

Kinetic model	Equation	Parameters	R^2
Pseudo1st order	$\log(q_{et}-q_t) = -0.027t-0.665$	K_1=0.0306min^{-1}	0.959
Pseudo 2nd order	$(t/q_t) = 0.511 + 0.434$	K_2=0.602 g/mg.min	1
Elovich model	q_t=0.069 lnt+1.6555	A_E=14.492 B_E=1.8*10^9	0.9577
Intra-particle diffusion	q_t=0.0261$t^{1/2}$+1.8222	K_{dif}= 0.0261 C=1.7411	0.9009

Table 6: Wave number (cm^{-1}) for major peak from FT-IR analysis for Pb (II) adsorption onto *E. globulus* L.

Functional group	*E. globulus* L.		
	Before adsorption	After adsorption	Shift
Esters impurities		3826-3716	
N-H and O-H stretch (3200-3500)	3327	3336	9
strong O-H stretch	3249	3244	-5
C-H stretch	2911	2920	-9
alkyne triple bonds and nitrile triple bonds	2354	2353	-1
C=O stretch in aldehyde group	----	1718	
C=C stretch	1628	1633	5
N-O stretch in Nitro group	------	1524	
-C-H bending	1441	1441	0
C-N stretch (amide III) modes of the residual *N*-acetyl groups	1317	1320	3
C-N stretch	1221	1218	-3
C-N stretch	1153	1153	0
skeletal vibration of the C-O stretch	1046	1055	11
C-Cl stretching vibrations	771	-----	
C-Br stretch in alkylhalide	582	----	

parameters and the regression coefficient are as shown in (Table 5).

FTIR characterization

FTIR spectra to characterize the functional groups, which are responsible for adsorption process, before and after adsorption of Pb (II), are as shown in (Figure 3(a1-a2)) and as in (Table 6). As can be seen from the (Table 6), ester functional group are present after adsorption process, C-H bending and –N-H stretch are not involved in metal uptake and hence are not affected(shift is zero). Other functional groups show shifts, both on positive and negative sides, indicating their relative role in metal capture. -C-H stretch, N-H and O-H stretch and skeletal vibration of the C-O stretch is the prime functional group that is involved in metal ion loading. C=O stretch in aldehyde group are present after adsorption. C- Cl stretching vibrations and C-Br stretch in alkyl halide are not found after adsorption.

SEM with EDAX analysis

Scanning Electron Microscopy (SEM) is used to verify the morphological differences between the Pb(II) free and Pb(II) loaded *E. globulus* L. The surface character is as shown in (Figure 3(b1-b2)) and from this image *E. globulus* L. exhibits an altered surface after loading of Pb(II) a similar report is available in the literature [52].

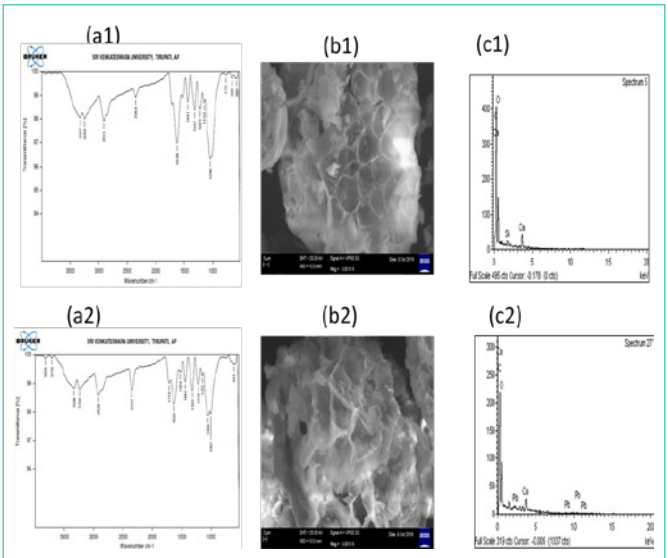

Figure 3(a1- a2): FTIR spectra, (b1- b2). SEM images and (c1- c2). EDAX spectra of the *E. globulus* L. before and after Pb(II) loading.

Table 7: Comparison of maximum biosorption capacity based on the Langmuir isotherm by different adsorbents for Pb(II) from aqueous solution.

Adsorbent	Concentration (mg/l)	Time min	pH	Metal uptake, mg/g	References
Ficus religiosa leaves	10-1000	15	4	37.45	[53]
Bael leaves (Aegle marmelos)	8.7-180.2	30	5.1	104	[54]
Cinnamomum camphora leaves	50-400	60	5	73.15,	[55]
Black cumin	20-May	60	5.1	8.08	[56]
Maize bran	100-150	100	6.5	142.86	[57]
Tephrosia purpurea	25–200	130	5.4	100	[58]
Phaseolus vulgaris L	40–80	20	5	42.68	[59]
Sargassum ilicifolium	20-200	120	3.7	195	[60]
***E.globulus* L**	**20-150**	**60**	**5**	**6.803**	**Present study**

The elemental composition of the adsorbent (before and after adsorption) is analyzed by Energy Dispersive Analysis System (EDAX). The EDAX spectrum for *E. globulus* L. powder shown in (Figure 3(c1)) indicates the presence of only O, C, Ca and Si, but no Pb(II) ions on the surface of *E. globulus* L. before adsorption. After adsorption, spectra include a characteristic peak for Pb(II) at 2.5keV, as shown in (Figure 4(c2)), confirming the metal ion loading.

Comparative study

The outcome of the present investigation compared against similar attempts is given in (Table 6) and from the table, it can be concluded that the performance of *E. globulus* L. is reasonable good.

Conclusion

E. globulus L., an agricultural byproduct and is easily available. This work demonstrates that it used as an adsorbent for the removal of Pb(II) ions from aqueous solution. Effect of operating parameters viz. metal ion concentration, initial solution pH, sorbent dosage and temperature is probed and at optimum conditions, the removal of

Pb(II) is found to be 96.58% (q_{max} 6.803mg/g). The equilibrium data fits well to the Freundlich model. The absorption is endothermic and negative values of ΔG confirm an affinity between *E. globulus* L and Pb(II).

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