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Review Article

Adsorption phenomenon and its application in removal of lead from waste water: a review

Abstract

Increased urbanisation and industrialisation has led to a situation of higher quantities of lead in waste water which has become a serious problem. Lead is toxic and is not essential for body. Its presence in body bears serious implications. Various technologies have been employed for the removal of lead ions from waste water. Adsorption with low cost adsorbents has been recognised as one of the cost effective and efficient techniques for this. Natural minerals, industrial waste, agricultural and forest waste are used as low cost adsorbents. This paper presents an overview of adsorption equilibria, kinetics and mechanisms. Effect of pH, metal ion concentration, adsorbent dose and temperature on adsorption capacity and percentage removal of lead from aqueous solutions using low cost adsorbents has been presented in this paper. The experimental data analysed statistically to verify the validity of the data is also reviewed in this paper.

Keywords: Adsorption equilibria, Kinetics, Mechanism, Heavy metals, Adsorption, Low cost adsorbents

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Introduction

Lead is a heavy metal toxic for body. It is among the major pollutants responsible for soil, water and atmospheric pollution.[1] For decades, unchecked release of industrial effluents has worsen the environment. Release of lead in environment can be a man-made activity such as mining, automobile emissions, sewage discharge, combustion of fossil fuel or effluent discharge from industries or can result from natural activity such as urban and agricultural runoff, dry deposition, precipitation, sea spray, forest fires, volcanic eruptions etc,.[2–4] Lead is non-biodegradable and is harmful to both man and other living organisms. It has an ability to enter the food chain, get accumulated and absorbed in body tissues.[5,6] It has been reported that adults absorb 5-15% of lead and retain about 5% of it. Presence of lead more than 0.5-0.8µg /ml into blood causes various abnormalities such as mental retardation, hepatitis, reduction in the production of haemoglobin. It interferes with body metabolism, causes reduced I.Q. levels in children and has been classified by the IARC as a 2B carcinogen.[7–10] Because of its toxicity, measurement, monitoring and removal of lead from the waste water prior to discharge is must. World Health Organization has recommended that the levels of lead in water must be within the allowable concentration limits. As per water quality standards, quantity of lead in water should be between 0.05-0.1mg/L.[11,12] According to the Indian Standard Institution, the tolerance limit of presence of lead for drinking water is 0.05 mg/L and for surface waters is 0.1mg/L (ISI, 1982). For decades, various physical and chemical methods employed for the removal of lead ions from effluent discharge are chemical precipitation, liquid membrane separation, electrochemical reduction, ion exchange, fixation and cementation, solvent extraction and adsorption.[13–16] The choice of method for treatment depends on

a. Effluent characteristics such as concentration of lead ions, pH, temperature, BOD and flow rate.
b. Economic feasibility of the process.
c. Standards set by the government agencies.[17]

Some of the above methods generate toxic sludge, disposal of which is an additional environmental problem, which affect the techno-economic feasibility of the treatment process.[18] Adsorption has been found to be meritorious over other methods and is preferred in the removal of lead and other heavy metal ions. Use of commercial adsorbents such as activated carbon, zeolites, activated alumina, bone char, silica gel, synthetic polymers[19–23] is very popular even today. Significant efforts have been made to enhance their efficiency by chemical activation or through heat treatment. Adsorption using nanoparticles is has shown significant metal removal efficiency and are commonly used these days.[24] These efforts are expensive and regeneration of modified adsorbents is difficult and sometimes not possible. Emphasis was laid on the use of low cost adsorbents as they show good results in lowering the concentration of heavy metal ions.

These are called as low cost adsorbents because they

a. Require little processing.
b. Are abundant in nature.
c. Are easily available.
d. Are of low cost.
e. Do not require complicated regeneration process because of their low cost and high availability.23

In the present study, performance of low cost adsorbents in terms of sorption capacity and % removal of lead ions with respect to pH, temperature, initial lead ion concentration, adsorbent dose has been reviewed.

Adsorption Equilibria

Adsorption equilibria is attained when the rate of adsorption of a molecule on a surface becomes equal to the rate of desorption. Types of adsorption equilibria are Table 1 shows

a. C is the concentration of the adsorbate in the fluid state

b. C_s is the concentration of the adsorbate in the solid phase

c. T is the temperature of the system.

The basic concept of adsorption is the adsorption isotherm, the equilibrium relationship between the amount of the material adsorbed and concentration of the fluid phase in bulk at constant temperature.

Adsorption isotherms models used to study the relation between adsorbent and the adsorbent in Table 2.

Table 1 Types of adsorption equilibria

Adsorption isotherm	plot between C and C ,T constant
Adsorption isostere	plot of C vs T, Cs constant
Adsorption isobar	plot between Cs vs T, C constant

Table 2 Types of adsorption isotherms

Isotherm	Equation	Significance	Reference
Single component adsorption	$C_s = Ka\ C$	For very low concentrations	65
Langmuir isotherm	$q^0 = QK_{L.c.} / (1 + K_{L.c})$	For homogeneous surfaces where interaction between adsorbed molecules are negligible	66
Brunauer- Emmett-Teller (BET) isotherm	$q^0 = Q.K_L.\mathrm{p}/\ [\ 1\ + K_L p\ +\ \left(\mathrm{p}/\ \mathrm{P}\right)][1 - (\mathrm{p}/\ \mathrm{P})]$	For gas- solid systems where condensation is approached	67
Freundlich isotherm	$C = k_F[v(C_0 - C)]^n$	For dilute solutions, over a small concentration range	68
Gibbs isotherm	$d\Gamma = (n_s / A_s)\ RT\ d\ (l_n P)$	Based on the assumption that the adsorbed molecules move freely like liquid film over the adsorbent surface	65
Temkin Isotherm	$q_e = (RT / B_T) ln(A_T C_e)$	Based on the adsorbent–adsorbate interactions	69 70
Dubinin–Radushkevich (DRK) isotherm	$q_e = q_s exp\ (-k_{ad}\varepsilon^2)$	Describes adsorption with a Gaussian energy distribution onto a heterogeneous surface	71 72
Kisliuk isotherm	$d\theta / dt = R_K \left(1 - \theta\right)\left(1 + k_E\theta\right)$	Adsorption occurs around the gas molecules that are already present on the solid surface	73
The Flory –Huggins model	$Log\ \left(\theta / C\right) = log\ K_{FH} + \alpha_{FH} log\ \left(1 - \theta\right); \theta = \left(1 - C_e / C_o\right)$	It accounts for the extent of surface coverage as characteristics of the adsorbate on the adsorbent	74 75
Jovanovic isotherm model	$q_e = q_n[\ 1 - exp(-K_J C_e)]$	Jovanovic model considers the possibility of some mechanical contacts between the adsorbing and desorbing molecules	69–77
Redlich–Peterson isotherm	$q_e = K_R Ce /\ (1 + a_R Ce^g)$	It can be applied either in homogeneous or heterogeneous systems	78
Hill isotherm	$q_e = \left(q_H Ce^{\eta}{}_H\right) / \left(K_D + Ce^{\eta}{}_H\right)$	It explains the binding of various species onto homogeneous substrates	79
Koble-Corrigan isotherm	$q_e = AC_e{}^D / \left(1 + BC_e{}^D\right)$	It is usually used with heterogeneous adsorption surfaces.	80
Combination of Langmuir and Jovanovic model	$q_e = \left[rC_e / \left(1 + C_e\right)\right] / [1 + exp\left(-pC_e{}^Z\right)$	It is a new model with less error in comparison to other models	76

Adsorption Kinetics

Adsorption kinetic modelling is studied to determine the rate of adsorption and rate expressions for a given reaction.

Pseudo first order kinetic: The pseudo first order kinetic equation is given by

$$dN_t\ /\ dt\ =\ k_{ad}\left(N_e - N_t\right) \qquad (1)$$

N_e and N_t are the amounts of metal ions adsorbed at equilibrium time and at any instant of time t respectively. k_{ad} is the rate constant.[25]

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Pseudo second order kinetics: The pseudo second order kinetics are given by the equation;

$$dN_t \;/\; dt \;=\; k_2\left(N_e - N_t\right)^2 \qquad (2)$$

k_2 is the rate constant for the second order equation.[26–28]

Mechanism of adsorption

Molecules have a natural tendency to diffuse from the bulk of a turbulent phase through a laminar layer around the solid particle to the bulk of another phase through its extreme surface due to concentration gradients given by four diffusion mechanisms:[29]

1. Diffusion of adsorbate on molecular scale from the bulk of one phase to the liquid film surrounding the adsorbent molecule.
2. Film diffusion i.e. the diffusion of adsorbate from the liquid film to the surface sites on the adsorbent molecule.
3. Pore diffusion i.e. intraparticle diffusion of adsorbate within the interstices of the adsorbent. 4. Adsorption of adsorbate on the internal surface sites of the adsorbent.

Diffusion of adsorbate at internal surface sites ((Table 3) & (Table 6)) is very rapid and thus resistance to mass transfer in these steps is negligible. Thus these steps are not considered the rate-limiting steps in the process. For steps 2 and 3 in the adsorption mechanism, three cases may occur:

I. External transport > internal transport.

II. External transport < internal transport.

III. External transport ≈ internal transport.

In cases I and II, film and pore diffusion are the rate controlling steps. In case III, the rate of transport of molecules to the boundary may be insignificant, causing formation of a liquid film around the adsorbent particles, thus creating a concentration gradient.[30]

Table 3 Natural materials used as adsorbents for the removal of lead from aqueous solutions

S.No.	Adsorbent	Maximum uptake capacity Mg/G	Maximum % removal	Optimum ph	Sorbent dose G/L	Concentration Mg/L	Temperature Oc	References
1	Natural sand particles		91.5	6	24.9			81
2	Natural goethite		100	4.5-6.0	100	5-750 ppm	30	82
3	Natural bentonite clay	83.02			1g/50ml	100-5000	ambient	83
4	Acid activated bentonite clay	92.85			1g/50ml	100-5000	ambient	83
5	Agbani clay	0.65		6	2g/20ml	20-100	45	43
6	Natural clay		84.8	4.46	0.2-2g/ 50ml	200-300		44
7	Iron coated sand			2.5-7.5 (study range)	2.5g/50ml	0.01M	283-333K (Study Range)	84
8	Talc surface		>98	6	0.1g	5-500ppm	20	85
9	Peat moss		96	5.5-6.0	0.2g/100ml	15-Feb		86
10	Sphagnum peat moss		98	6	0.125-1.0g	34-507		87

Table 4 Industrials by products used as adsorbents for the removal of lead from aqueous solutions

S. No.	Adsorbent	Uptake capacity Mg/G	Maximum% removal	Optimum ph	Sorbent dose G/L	Concentration Mg/L	Temperature Oc	References
1	Iron slag	95.24		3.5-8.5	2	200		88
2	Steel slag	32.26		5.2-8.5	2	200		88
3	Fly ash baggasse	2.5	95-96	6	10	5.0-7.0	30	89
4	Fly ash modified, activated	98 mmol/100g	98	5	0.5-2	0.0027 mol/l	25	90
5	Waste beer yeast	2.34	96.35	1.0-5.0	0.5-2	25-100		91
6	Sludge from steel industry	2.74		5±0.1	5g	0.15-10 g/lt	20-80	92

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Table Continued....

S. No.	Adsorbent	Uptake capacity Mg/G	Maximum% removal	Optimum ph	Sorbent dose G/L	Concentration Mg/L	Temperature Oc	References
7	Coal fly ash		90.37		0.5-1.5	100		93
8	Sawdust waste generated in the timber industry	0.646 mmol/g	88.6	6.5	1	0.5 mmol/dm3	30	94
9	Saw dust activated carbon	0.223 mmol/g	90.1	5	2	0.5 mmol/l	30±2	95
10	Low grade manganese ore	67 mg/g		2-5.25	6-Jan	50-500	27	96

Pore diffusion: The phenomenon pore diffusion or Knudson diffusion occurs because at low pressure conditions, the mean free path of the molecules may be larger than the pore diameter of the molecules. Pore diffusivity for liquids is expressed as:

$$D_{pore} = D_f \chi / \tau \tag{3}$$

χ = internal porosity of the particles and τ = Tortuisity (Usually between 2 and 6).[31]

Intraparticle diffusion model: This model suggests that the molecular diffusion the controlling step, because the speed of diffusion of the adsorbate molecule towards the adsorbent surface determines the rate of adsorption.

$$Q_e = k_i t^{1/2} + I \tag{4}$$

K_i = intra particle diffusion rate constant (g/mg/min), I = Intercept from plot of Q_e vs $t^{1/2}$.[32,33]

Statistical Analysis

Hypotheses are the assumptions, concise statements or formal questions for the available data, which can be tested for their validity and can be accepted or rejected.[34] Various hypothesis tests for the analysis of experimental data are classified as

1. Parametric tests, the standard tests, include z-test, t-test, F-test and χ^2-test.
2. Non-parametric tests, the distribution-free tests of hypotheses, do not dependent on assumptions based on the characteristics of the parent population.

The ***z-test*** is used to judge the significance of mean for large samples (n>30) by comparing the sample mean with some hypothesised value of the population mean.

$z = \left(\bar{X} - \mu_{Ho}\right) / \left(\sigma_p / \sqrt{n}\right)$ H_a may be one sided or two sided. (5)

The **t-test** is based on t-distribution and is used to judge the significance of the difference between the two sample means for small sample size (n<30). H_a is chosen to be one sided or two sided.

$t = \left(\bar{X} - \mu_{Ho}\right) / \left(\sigma_s / \sqrt{n}\right)$ for (n-1) degree of freedoms. (6)

The ***F-test*** is based on the F-distribution and is used to compare the variance of two samples.

$$F = \sigma_{s1}^{\;2} / \sigma_{s2}^{\;2} \tag{7}$$

The ***χ^2-test*** is a statistical technique used to test the goodness of fit, independence and significance of population variance.

$$\chi^2 = \Sigma\{(O_i - E_i)^2 / E_i\} \tag{8}$$

ANOVA, Analysis of variance is used when there are multiple sample cases at the same time. With ANOVA, it is possible to analyse the differences among sample means of different populations by making estimates for population variance:

a. Based on between sample variance.
b. Based on within sample variance. The ratio of these two called F-ratio is compared with the F-limit value for given degrees of freedom.

F-ratio = MS between/MS within.[35,36] (9)

Low cost adsorbents

Low cost materials can be broadly categorized into four classes:

- Natural minerals such as sand, coal, moss, peat, clays etc.
- Industrial wastes such as biogas slurry, industrial by products, sludge, furnace slag, fly ash, waste from smelters etc.
- Agricultural wastes such as fruits and vegetable peels, nuts, shells, pulps, stones etc
- Forest wastes such as barks, roots, leaves and sawdust etc.[23]

Natural minerals: Natural minerals are rich and excellent sources of adsorbents available naturally, abundantly easily for the adsorption of heavy metals. Moss (Claymperes delessertti) was used for removal for copper from aqueous solutions.[37] Soil, clay and slow sand filters have shown significant potential towards the removal of heavy metals from aqueous solutions laden with heavy metals.[38–42] Agbani clay obtained from Nigeria was used for the removal of lead ions using batch techniques.[43] Results showed that the Freundlich isotherm fitted the best followed by the Temkin isotherm and the Langmuir isotherm fitted the least. Adsorption of lead on natural clay was studied batch wise.[44] Results showed that adsorption was very fast in the beginning but slowed down gradually. Natural minerals studied for the removal of lead from waste waters are summarized in Table 3.

Industrial by-products: Industrial by-products are cheap and abundantly available adsorbents used for the removal of heavy metals from waste water. They can be chemically modified to enhance their metal ion removal efficiency.

Red mud, obtained as a residue during alkaline leaching of bauxite ore in the Bayer process, has been found to remove fluoride, Cr(VI),

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dyes, nitrates, and phosphate from aqueous solution. It has also been used for the removal of Pb ions.[45,46] studied the adsorption of Cu, Pb, Zn and Cd using Tourmaline, obtained from Chifenf mine of China and noted that the optimum value of process temperature was 55^0C, pH was 7 for the metal ion concentration between 10-500 mg/l. Removal was 78.76 mg/g for Cu II, 154.08mg/g for Pb II, 67.25 mg/g for Zn II and 66.67 mg/g for Cd II.[47] The study of removal of lead by fly ash showed that lead ions were retained in the pores and onto the surface for pH higher than 5.5 and through adsorption for pH less than 5.5. Adsorbed ions were not released in the pH range 3.5-10.0.[48] Studied bagasse fly ash for the removal of lead ions using batch adsorption studies. 50-65% lead ions were removed at pH 3.0 in the first hour.[49] At other values of pH, % removal was lesser. It decreased with increase in temperature. % removal of lead ions was 100% for an adsorbent dose of 10 g/l, average particle size of 150-200 mesh at lower concentrations of the adsorbate and 50-70% at higher concentrations. Industrial products studied for the removal of lead from waste water are summarized in Table 2.

Agricultural waste: Agricultural waste is widely used low cost adsorbent available abundantly and does not require significant processing.[50] They comprise of hydrocarbons, carbohydrates, cellulose and hemicelluloses, starch, lignin, lipids, proteins and various functional groups.[51] They have the ability to bind heavy metal ions by donating a pair of electrons and to form complexes with metal ions through reactions, by chemisorptions, diffusion through pores, complexation and adsorption on surface. Orange peel was used to remove Ni (II) from synthetic samples.[52] Metal adsorption capacity was 158mg/g at 323K. % removal was maximum at pH 6.0. Peanut hulls were studied for the removal Ni (II) and Cu (II) from synthetic solutions. Maximum removal of Ni (II) was 53.65mg/g was observed in the pH range 4- 5 and Cu (II) was 65.57mg/g in the pH range 6-10 in the column study.[53] Cu (II) removal of 10.17 mg/g was observed in the batch study.[54] In batch studies, the concentration gradient decreased with time. Where as in the column, the adsorbent was in continuous contact with the fresh feed of the adsorbent resulting in higher removal of Cu (II) Zn (II) removal was studied by[24–55] with the help of mango tree leaves as adsorbent. Experimental data was analysed statistically. Hypotheses were tested to verify the validity of the test results and the data was found to be within the accepted regions of the statistical charts. Adsorbents activated by heating or chemically are expensive, but the cost incurred in processing is compensated by better adsorption capacity.[51-56] Also it prevents the elution of tannin compounds which stain the treated water and increase the COD of water to a great extent.[57] Rice hull modified with ethylenediamine studied for Cr (VI) removal from simulated solution was reported to give maximum metal ion adsorption of 23.4mg/g at pH 2. The surface of rice hull contains carboxylic and hydroxyl groups which act as electron donors in the solution. Due to these, Cr (VI) oxyanion reduces to Cr (III) ions by proton consumption in the acidic solution resulting in Cr (VI) removal.[58] Soybean hull and modified soybean hull extracted with NaOH and with citric acid were used for the Cu (II) removal. Metal removal efficiency was 24.76mg/g for natural soybean hull and was increased to 154.9mg/g after modified chemically. Possibly, pre-treatment increased the number of carboxyl groups and negative charge on the soybean hull increasing the efficiency.[59] Chemically modified potato peel (PP)where used for the adsorption of malachite green with 100 ml of 100 ppm dye solution with 0.250gm dose.[60,61] Langmuir, Freundlich and Temkin isotherms were studied. PP favoured the Freundlich isotherm. Potato peel worked efficiently when treated with HCHO. The percentage removal of lead ions for PP and APP (activated potato peel) was 92.2% and 82.7% respectively. Various agricultural products studied for the removal of lead summarized in Table 5.

Forest waste: Shedding of leaves and bark natural phenomenon of trees. Tree barks and saw dust are produced at saw mills in large quantities as a solid waste. Febrifuga bark studies for the removal of lead showed that maximum removal was 98.42%, optimum pH was 4.0, and equilibrium time was 6 hours. Adsorption decreased with increase in temperature.[62] Neem Bark (NB) and activated neem bark (ANB) used to study adsorption of malachite green dye[60] showed 92.7% and 94.4% removal respectively. Pinus bark was used to carry out the adsorption studies of lead ions at pH 5.0 and 7.0 with an average particle size≤60 mesh. % removal of lead ions 98.61% at pH=5.0 and 98.83% at pH=7.0.[63,64] Studied the adsorption of lead ions by Ficus Religiosa leaves for the removal of lead ions from waste water. 80% removal was observed in first 15 minutes and after 45 minutes concentrations became almost constant. Equilibrium was attained in 1 hour. Forest wastes studied for the removal of lead from waste waters are summarized in Table 6.

Table 5 Agricultural waste used as adsorbents for the removal of lead from aqueous solutions[23]

S. No.	Adsorbent	Uptake capacity Mg/G	Maximum % removal	Optimum ph	Sorbent dose G	Concentration Mg/L	Temperature Oc	References
1	Activated bamboo charcoal	53.76	83.01	5	0.1	50-90	29	97
2	Almond	8.08	68	7-Jun	0.5	0.001mol/l	25±1	98
3	Dust of bamboo	2.151	66.73	7.2	28	600		99
4	Peels of banana	72.79		5	1	200	25±2	100
5	Peels of banana	2.18	85.3	5	2	30-80	25	101
6	Coconut	4.38	60	4	6	100	60	102
7	Coconut shell	26.5	75	4.5		50mg/50ml		103
8	Coir	0.127	86.98	4.9	1	0.56mmol / dm3	30	104
9	Shells of groundnut	0.106 mmol/g	82.81	4.9	1		30	104

Table Continued....

S. No.	Adsorbent	Uptake capacity Mg/G	Maximum % removal	Optimum ph	Sorbent dose G	Concentration Mg/L	Temperature Oc	References
10	Shells of hazelnut	28.18	90	7-Jun	0.5	0.001mol/l	25±1	98
11	Okra waste	5	99	5		240	25	105
12	Formaldehyde treated orange peel,		99	5	0.12			106
13	Natural orange peel	46.61	99	5	0.12	150		106
14	Peach stone	2.33 mg/kg	97.64	8-Jul	2	200		4
15	Peanut hulls	69.75		5	1	200	25±2	100
16	Modified peanut shells	0.63 mmol/g		4.6-5.0				107
17	Onion skins	200	93	6	0.15	25-200	30	108
18	Rice husk	5.69		5	2	50	60	109
19	Rice husk	31.13		5	1	200	25±2	100
20	Ash of rice husk	10.86		5.6-5.8	2	40	15	88
21	Ash of rice husk	91.74	99.3	5	5	3-100	30	110
22	Chemically modified rose petals	118.4		5	0.1	100	30	111
23	Sun flower waste	33.2		4		10		112
24	Tea waste	73	96	5	0.5	5-100	30	113
25	Discarded tea leaves	35.89		5	1	200	25±2	100
26	Wheat bran	86.96		7-Apr	0.5	200-500	20	114
27	Acid treated wheat bran	79.37	82.8	6	0.1	100	25	115

Table 6 Forest waste used as adsorbents for the removal of lead from aqueous solutions

S. No	Adsorbent	Uptake capacity Mg/G	Maximum % removal	Optimum ph	Sorbent dose G/L	Concentration Mg/L	Temperature Oc	References
1	Pinus Elliottii Bark		98.61	5	500 mg	100		63
			98.83	7				
2	Pongamia Pinnatta Bark			5.5	10	5- 50 ppm	30	116
3	Ficus Religiosa Leaves	16.95±0.75	80	4	10	10-1000	20-50	64
4	Aliathus Excelsa Bark		70	4.5	1	10		117
5	Bael Tree Leaf		90.07	5	20-May	25-100	30	17
6	Pinus Nigra Tree Bark	12.6	90	8		35		57
7	Streblus Asper leaves		71.9	8	400mg	1.598 g/l	25	118
8	Mango tree leaves	31.54		4	1	200	25±2	100
9	Neem tree leaves		41.45	5	1	20	25	119
10	Peepul tree leaves	127.34		4	1	200	25±2	100

Discussion and conclusion

Drying and crushing of adsorbents increase the surface area to facilitate the adsorption. Chemical activation or modification of adsorbents increases active surfaces for adsorption and prevent the elution of tannin compounds. The sorption capacity was observed to

a. Increase with increase in Ph.

b. Decrease with increase in metal ion concentration because at a given equilibrium concentration, biomass adsorbs more metal ions than at higher loading.

c. Increase with increase in adsorbent dose as the number active sites available for adsorption increase.

d. Decreases with increase in temperature because the texture of biomass changes at higher temperature.

However, some exceptions were also observed.

- For tourmaline, sorption capacity increased with increase in metal ion concentration. This could be attributed to an increase in electrostatic interactions relative to covalent interactions, because an electrostatic field exists around the particles.
- For Ficus religiosa tree leaves and Pinus Ellioti tree bark, sorption capacity decreased at higher pH, because lead ions precipitated due to formation of hydroxides.
- For streblus as per tree leaves, sorption capacity increased with temperature indicating an exothermic reaction.

From the above study it has been concluded that the process of adsorption using low cost adsorbents is a simple, cost effective and an eco-friendly technique for the treatment of waste water containing lead ions. Efficiency of the process depends not only on the physical and chemical properties of the material used as adsorbent, but also on the various process variables like pH, adsorbent dose, metal ion concentration, temperature, contact time etc. These parameters have to be optimized to make the process more efficient and economical.

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Conflict of interest

The Authors declare no conflict of interest.

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