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A Simple and Effective Bio-adsorbent Generated from the Stems of *Momordica charantia* Plant for the Simultaneous Removal of Lead and Cadmium Ions from Wastewater

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Sulphuric acid generated activated carbon from the stems of *Momordica charantia* (MCSAC) was identified to adsorb lead(II) and cadmium(II) ions from water. Extraction conditions were optimized. At pH: 6, both the ions can be simultaneous removed by 2.0 mg/L of MCSAC after an equilibration period of 90 min at room temperate (30 ± 2 ºC). The sorption capacities were observed to be 21.0 mg/g for Pb^{2+} and 18.9 mg/g for Cd^{2+}. MCSAC was characterized by conventional methods and also by surface morphology assessing techniques such as XRD, FTIR and FESEM. The sorption mechanism was investigated by evaluating thermodynamic parameters and by adopting various kinetic and isothermal models. High ΔH values of 29.399 KJ/mol for Pb^{2+} and 33.222 KJ/mol for Cd^{2+}, indicated that the mechanism of sorption is ion exchange and /or complex formation between Pb^{2+}/Cd^{2+} ions and surface functional groups present in MCSAC. Further, high positive ΔS values imply the presence of disorder at solid-liquid interface, favouring the metal ions to overcome the surface barrier and get adsorbed. The negative ΔG values indicates the spontaneity of sorption process. Spent MCSAC can be regenerated and reused for three cycles. The procedure developed using MCSAC as sorbent was successfully applied to treat real effluents samples collected from several industrial effluents. The novelty of the present investigation is that a simple biosorbent is developed for the effective simultaneous removal of highly toxic Pb^{2+} and Cd^{2+} from contaminated water.

Keywords: Biosorbent, *Momordica charantia*, Adsorption, Lead(II), Cadmium(II), Thermodynamic parameters, Applications.

INTRODUCTION

Lead and cadmium ions are highly toxic and their presence in water, effects aquatic life and human health [1-3]. They cause diseases such as malfunctioning of kidneys, neurological problems, neonatal deaths, *etc*. [4-6]. Hence, the contamination of water with these ions is highly objectionable and these ions are termed as carcinogens by USEPA [7]. As per WHO, the maximum permissible limits in drinking water are 0.01 mg/L for Pb^{2+} and 0.003 mg/L for Cd^{2+} [7].

The metallic lead and cadmium and their salts are basic ingredients of many industries *viz.* alloying, electroplating, batteries, electronics, plastics, *etc*. The effluents of industries contain substantial amounts of Pb^{2+} and Cd^{2+} ions. Before disposing, the effluents are to be treated for the complete removal of these two toxic ions or otherwise, the ions enter into aquatic systems and turn natural water unsuitable for human consumption [8-10]. So, water remediation methods for the extraction of Pb^{2+} and Cd^{2+} ions from water assumes importance [11].

Many investigations reported in literature are based on the reverse osmosis, ion-exchange, electrocoagulation, adsorption, membrane-filtration, *etc*. [11,12]. Methods based on the adsorption are simple and effective [13,14]. Investigating plant materials or their derivates as sorbents in the extraction of lead and cadmium from water, is increasingly interesting as this method is proving to be simple, effective, eco-friendly and based on easily and abundantly available biomaterial [13-15]. Several reported bioadsorbents *viz.* activated carbons prepared from *Typha angustifolia* and *Salix matsudana* [16] and African palm fruit [17], oily sludge derived char [18], *Enteromorpha prolifera* biochar modified with different chemical reagents [19], NaOH treated pineapple waste [20], activated biocarbon [21], calcium alginate beads doped with hydrazine sulphate-activated red mud [22], magnetic acid-treated activated carbon nanocomposite [23] are successfully applied in the treatment of effluents.

Activated carbon of *Caryota urens* seeds and its embedded calcium alginate beads [24], olive stone activated carbon [25], polyphenolic bioactive Indian curry leaf (*Murraya koengii*) powder [26] and nanofibrous sheet of activated polyacrylonitrile [27] are also investigated as adsorbents for the successful removal of some heavy metal ions. Granular activated carbon and activated clay [28], activated carbon from black cumin seeds [29] and bamboo charcoal [30] are also reported as adsorbents for the removal of lead(II) and cadmium(II) ions.

The methods so far reported are mainly aimed to remove either lead(II) and cadmium(II) and not both at a time. Hence, in this investigation, we tried to identify and develop bioadsorbents for the simultaneous removal of lead(II) and cadmium(II) ions from wastewater. Through this investigation, it is identified that active carbon generated from the stems of *Momordica charantia* plant has shown remarkable affinity for both Pb^{2+} and Cd^{2+} at pH 6. This common pH has facilitated this investigation for developing a method for the simultaneous removal of the above said ions.

EXPERIMENTAL

Preparation of asorbent: *Momordica charantia* plant stems were cut to small pieces, washed with distilled water and dried under sunlight for a day. The biomaterial was immersed in sufficient amount of conc. H_2SO_4 and kept aside for overnight for complete carbonization. The material was washed with distilled water thoroughly for neutrality, oven dried at 105 ºC for 1 h and preserved in air-tight brown bottle. The product was termed as MCSAC.

Batch extractions: The metal(II) salts ($M = Pb^{2+}$ or Cd^{2+}) stock solutions were prepared using double distilled water. Batch extraction were performed in a glass reactor of 250 mL capacity equipped with a six-bladed (pitched blade) glass turbine for agitation [9,10]. To 100 mL each of Pb^{2+}/Cd^{2+} (15 mg/L) solutions taken 250 mL stoppered flasks, weighed quantities of MCSAC, was added and initial solutions pH 2-12 were adjusted using dil. HCl/dil. NaOH. The solutions were agitated for desired time at 350 rpm and at room temperature 30 ± 2 ºC and filtered. The filtrate was assayed for the unextracted amounts of Pb^{2+}/Cd^{2+} by adopting AAS methods (240-AAFS, Agilent, USA) [7].

Sorption capacities of MCSAC and % removal of Pb^{2+} or Cd^{2+} ions were evaluated using the equations:

$$q_e = \frac{(C_i - C_e)}{m} V$$

$$\text{Removal } (\%) = \frac{(C_i - C_e)}{C_i} \times 100$$

where C_i = initial concentration of Pb^{2+}/Cd^{2+}; C_e = equilibrium Pb^{2+}/Cd^{2+} concentration of Pb^{2+}/Cd^{2+}; V = simulated solution volume (L); m = sorbent mass (g).

RESULTS AND DISCUSSION

Physico-chemical parameters: The physico-chemical characteristics of sulphuric acid generated activated carbon from the stems *Momordica charantia* (MCSAC) were evaluated per the standard methods [31-35] and the findings are shown in Table-1. The decrease in surface area signifies the sorption of Pb^{2+} and Cd^{2+} by MCSAC.

TABLE-1
PHYSICO-CHEMICAL CHARACTERISTICS OF MCSAC [31-35]

Parameter	Value
Moisture content (%)	5.4
Ash content (%)	3.90
Iodine number (mg/g)	546
Particle size (μ)	54.4
Apparent density (g/mL)	0.276
BET analysis surface area (m^2/g)	Before adsorption: 368.6 After adsorption: 278.8

XRD studies: XRD spectra of MCSAC was noted before and after sorption of Pb^{2+} and Cd^{2+} ions. The XRD spectra is presented in Fig. 1. In before sorption, a broad peak is observed at 2θ = 15-30º and another less broaden peak around 44.5º. There are no sharp peaks, which indicate more amorphous region in the active carbon with high porosity. This is an ideal condition for sorption process to take place. In contrast to these features, the spectrum taken after adsorption of Pb^{2+} and Cd^{2+}, has sharp peaks at 2θ = 26.6º, 31.0º, 37.2º, 41.5º. The appearance of these peaks may be due to the crystalline order brought by the interaction of Pb^{2+} and Cd^{2+} with the functions groups prevailing on the sorbent surface.

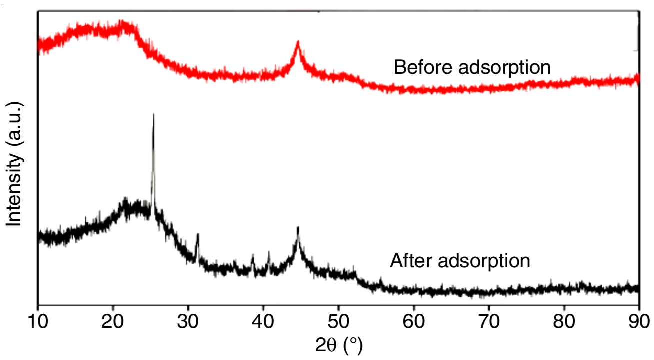

Fig. 1. XRD spectra of MCSAC taken before (a) and after (b) adsorption of Pb^{2+} and Cd^{2+}

FTIR studies: Spectral features of MCSAC recorded 'before and after' adsorption of Pb^{2+} and Cd^{2+} are presented in Fig. 2. Marked differences in some peaks positions and intensities were observed and in addition, some new peaks also appeared. The broad peak of stretching of -OH in before spectrum appeared between 3520-3000 cm^{-1} was narrowed after adsorption. The less broad C=N peak at 2050 cm^{-1} was shifted to 2080 cm^{-1} after sorption. A C=O stretching peak at 1732 cm^{-1} was disappeared after adsorption. The observed ester peaks at 1630 cm^{-1} and 1414 cm^{-1} in the before sorption were moved to 1620 cm^{-1} and 1400 cm^{-1} after adsorption. A small broad peak at 1290 cm^{-1} due to $-SO_3H$ group (generated while treating biomass with conc. H_2SO_4) presented in before sorption spectrum was almost completely disappeared in the after adsorption spectrum due to the sorption of adsorbate ions. Two new peaks

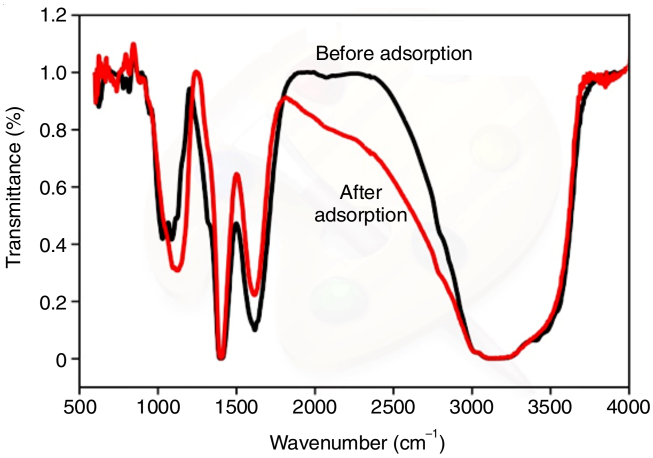

Fig. 2. FTIR Spectra of MCSAC (a) before adsorption and (b) after adsorption

at 1015 cm^{-1} and 1068 cm^{-1} were observed in the spectrum of after adsorption. They may be due a short of bond formation of M–O (M= Pb/Cd). New frequencies at 890 cm^{-1} (small, sharp), 790 cm^{-1} (sharp, intensified) and 630 cm^{-1} (sharp frequency with shoulder) were observed after the adsorption of Pb^{2+} and Cd^{2+} ions. These changes in features of FTIR spectrum of MCSAC confirmed the adsorption of Pb^{2+} and Cd^{2+} by MCSAC.

FESEM studies: Surface morphological evidence for the sorption of Pb^{2+} and Cd^{2+} by MCSAC could be provided by the FESEM images taken before and after sorption. MCSAC was observed to have more amorphous nature as evident from the existence of big pores and voids in the image taken before adsorption (Fig 3a). The pores and voids were disappeared or reduced and thereby, resulting a smooth surface in the image taken after sorption of Pb^{2+} and Cd^{2+} (Fig 3b). These morphological changes proves the binding of Pb^{2+} and Cd^{2+} ions to the surface of MCSAC.

Optimization of extraction conditions

Initial pH: The equilibrating solution pH was observed to have profound influence on the extraction of Pb^{2+} and Cd^{2+} (Fig. 4). The maximum adsorption was observed at pH 6 for both the adsorbates *viz*. 76% for Pb^{2+} and 71% for Cd^{2+}. Increasing or decreasing this pH value, the % removal decreases. Comparatively, the decrease was less marked with Pb^{2+} than Cd^{2+} ions. The pH_{zpc} value for MCSAC was evaluated and found to be 6.0 (Fig. 5). At this pH value, the surface of MCSAC is neutral. If the equilibrating solution pH is below this value, the surface of MCSAC is positively charged due to the protonation of functional groups (-OH/-COOH), while the surface of MCSAC acquires negative charge due to dissociation of functional groups, if the solution pH is more than pH_{zpc} (6.0) [36].

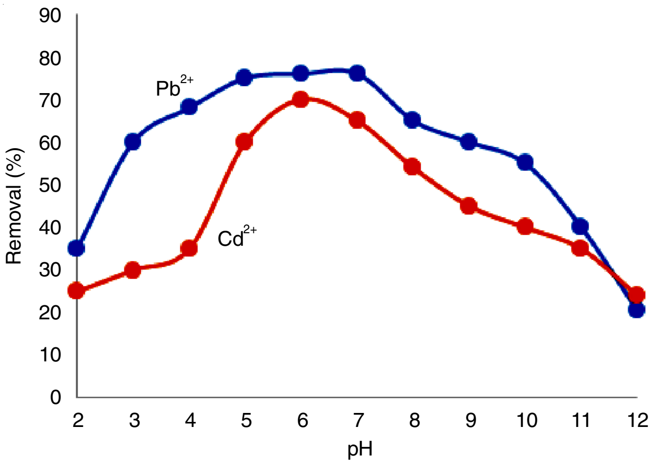

Fig. 4. pH *vs*. % removal of Pb^{2+} and Cd^{2+} (conc. of Pb^{2+}/Cd^{2+}: 15 mg/L)

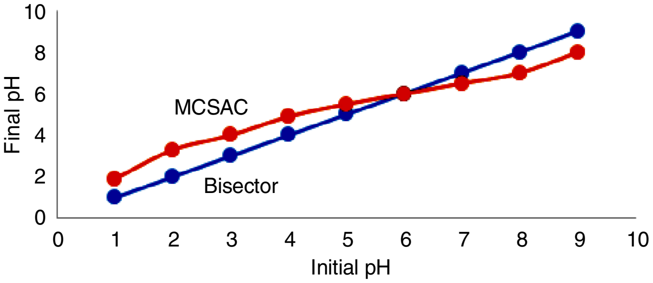

Fig. 5. Evaluation of pHzpc

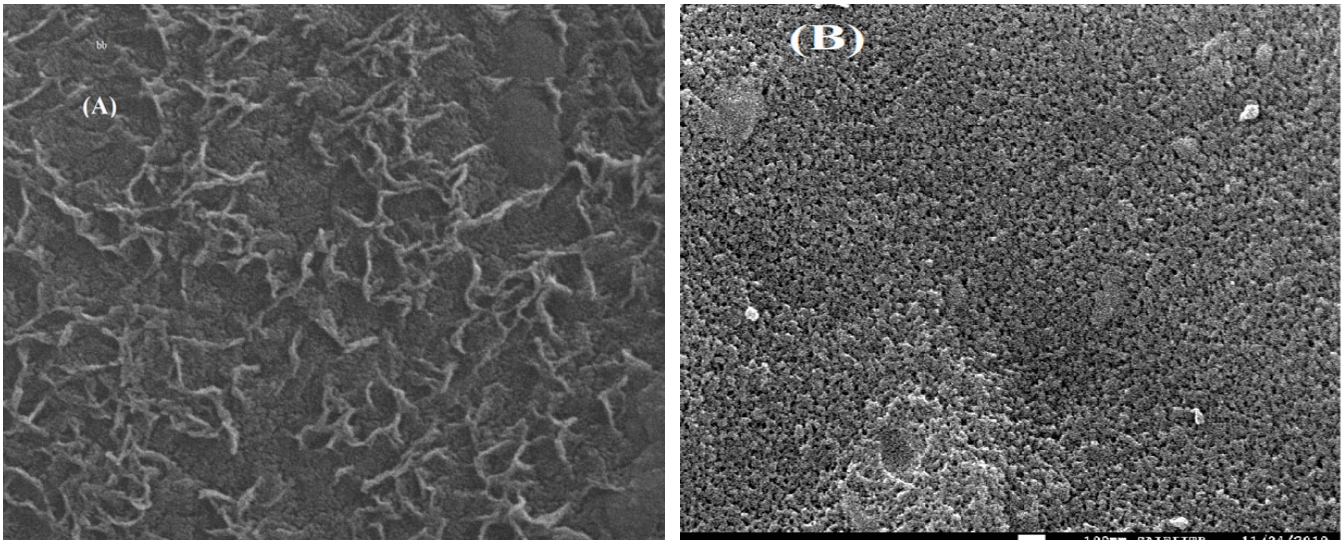

Fig. 3. FESEM images: (a) MCSAC -before adsorption and (b) MCSAC-after adsorption - of Pb^{2+} and Cd^{2+}

At pH 6, both lead and cadmium exist as cationic species in solution as $Pb^{2+}/PbOH^{+}$ and $Cd^{2+}/CdOH^{+}$, respectively. So, for good electrostatic interactions and subsequent removal, the surface of the sorbent must be negative. However from Fig. 4, it is inferred that maximum sorption is noted at pH_{zpc}, when the surface of the sorbent is neutral. An interesting result indicates that the forces biding the adsorbates to the surface of MCSAC are not electrostatic interactions but may be due to surface complex formation and/or ion-exchange [36].

Sorbent dosage: The optimum sorbent, MCSAC, concentration was evaluated by changing the concentration from 0.25 g/L to 2.5 g/L (Fig. 6). With increase in concentrations of MCSAC, proportional increase in the % removal of Pb^{2+} and Cd^{2+} were observed at low concentrations of MCSAC upto 1.0 g/L for Pb^{2+} and 1.5 g/L for Cd^{2+}. Above these values, there was only marginal increase and then a steady state was achieved. At low concentrations, the sorption sites are proportionally increased with the increase of dosage but at high concentrations, the proportionality was lost because of overlapping and/or blocking of active sites and thereby, curtailing the pathways for Pb^{2+} and Cd^{2+} ions to reach the inner laying active sites of MCSAC [37].

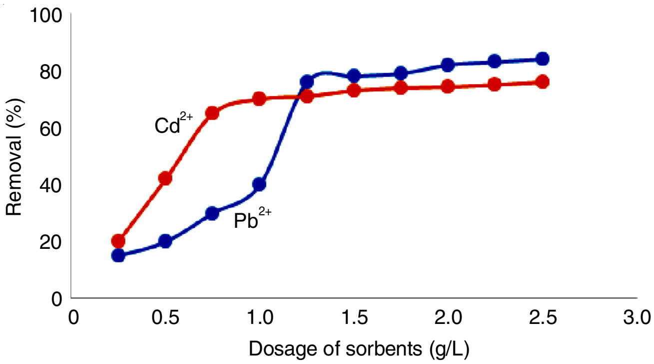

Fig. 6. Effect of dosage of MCSAC (initial concentration of Pb^{2+}/Cd^{2+}: 15 ppm)

Contact time: The optimum duration needed for MCSAC to extract maximum possible amount of Pb^{2+}/Cd^{2+} was investigated. It was observed that a minimum time of 60 and 90 min are required for the maximum extraction of Pb^{2+} and Cd^{2+}, respectively (Fig. 7). With progress of equilibration time, % removal was increased more initially, slow down with time and a steady state was reached after 60 min for Pb^{2+} and 90 min for Cd^{2+}. With more contact time, Pb^{2+} and Cd^{2+} ions have sufficient time to penetrate deeper into the matrix of MCSAC to reach the inner laying active sites. Hence, % of extraction is increased with time. As MCSAC dosage was fixed at 1.5 g/L for Pb^{2+} and 1.00 g/L for Cd^{2+}, only a limited active-sites were available. So, after certain time of equilibration, all active site were used up, resulting a steady state wherein the rate of sorption and desorption of metal ions are equal [36,37].

Initial concentrations of Pb^{2+}/Cd^{2+}: The effect of initial concentration on the sorption nature of MCSAC was also investigated. With the increase in initial concentration of Pb^{2+} and Cd^{2+} percentage removal was decreasing (Fig. 8) but adsorption capacity of MCSAC for Pb^{2+}/Cd^{2+} was increasing (Fig. 9). With increase in Pb^{2+} or Cd^{2+} concentrtion, the active sites needed for sorption also increases. But as the dosage of MCSAC was fixed (1.5 g/L for Pb^{2+} and 1.00 g/L for Cd^{2+}) only a fixed number of active sites are available. So, sufficient number of active sites are not available as per the demand and hence, decrease in the removal percentage.

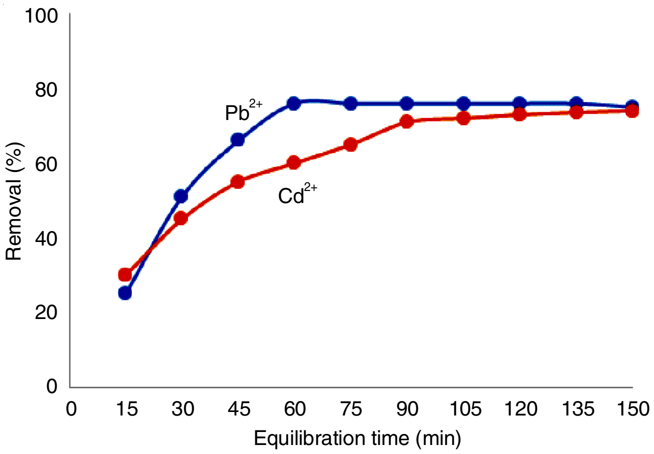

Fig. 7. Effect of equilibration time on % removal of Pb^{2+}/Cd^{2+} (initial concentration of Pb^{2+}/Cd^{2+}: 15.0 mg/L)

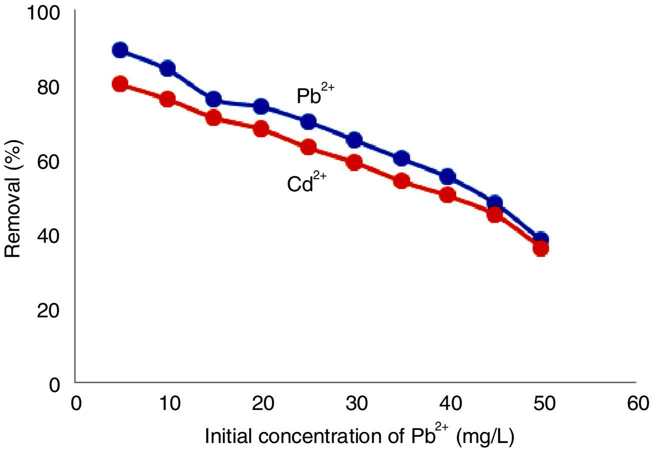

Fig. 8. Initial conc. Pb^{2+}/Cd^{2+} *vs.* Pb^{2+}/Cd^{2+}removal

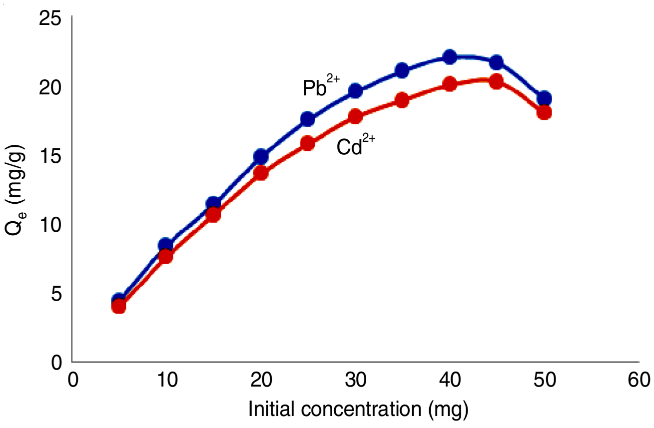

Fig. 9. Initial concentration *vs.* sorption capaity (Q_e)

It is interesting to note an increase in sorption capacities with increase in initial concentration of Pb^{2+}/Cd^{2+}. With increase in initial concentration of adsorbates, Pb^{2+}/Cd^{2+}, the difference in concentrations of the adsorbates at the surface of sorbent and in the bulk of the solution also increases. This causes the Pb^{2+}/Cd^{2+} to diffuse more towards the surface of sorbent, resulting the increase in sorption capacity [37,38].

Interference of co-ions: The effect of the common co-ions (in two-fold excess) naturally present in water was investigated, Figs. 10 and 11. It may be inferred that the % of extractions of Pb^{2+} and Cd^{2+} are marginally effected due to the presence of co-ions.

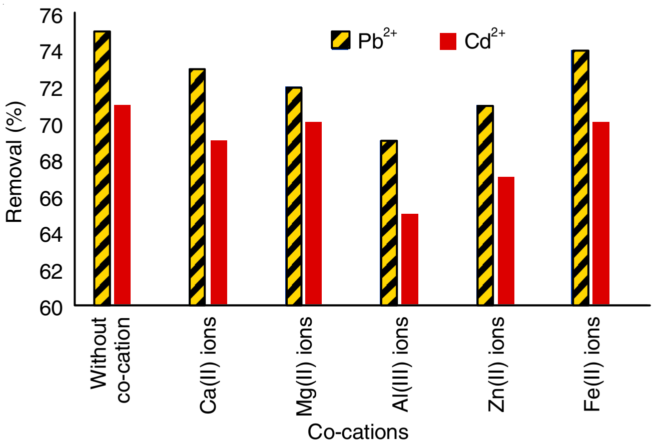

Fig . 10. Interference of Co-cations

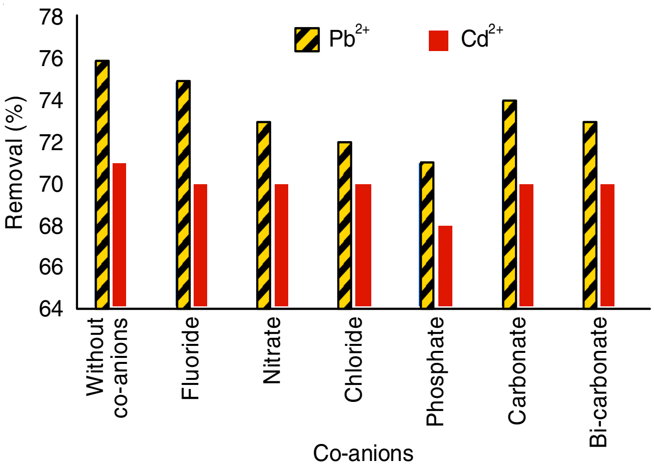

Fig. 11. Interference of coanions

Simultaneous removal of lead and cadmium: From the above investigations, the optimum conditions of extraction for the removal of Pb^{2+} or Cd^{2+} with the simulated individual solutions of the said ions using MCSAC as sorbent were also optimized. It was observed that both the ions show maximum extraction at pH 6. This fact help us to investigate further the possibility of simultaneous extraction of both the ions at pH 6. It was observed that the simultaneous removal of Pb^{2+} and Cd^{2+} was possible at the pH 6 with sorbent dosage of 2.0 g/L, equilibration time: 90 min, rpm: 350 and temperature: 30 ± 2 ºC. The results are presented in Table-2.

TABLE-2
SIMULTANEOUS REMOVAL LEAD AND CADMIUM IONS WITH MCSAC AS SORBENT
(Conditions: pH: 6.0; dosage: 2.0 g/L; Contact time: 90 min; rpm: 350; Temp.: 30 ± 2 °C)

Samples	Compositions (mg/L)		After treatment (mg/L)		Removal (%)	
	Pb^{2+}	Cd^{2+}	Pb^{2+}	Cd^{2+}	Pb^{2+}	Cd^{2+}
1	9.0	1.0	0	0	100	100
2	8.0	2.0	0	0	100	100
3	7.0	3.0	0	0	100	100
4	6.0	4.0	0	0	100	100
5	5.0	5.0	0	0	100	100
6	4.0	6.0	0	0	100	100
7	3.0	7.0	0	0	100	100
8	2.0	8.0	0	0	100	100
9	1.0	9.0	0	0	100	100

*The values are average of five estimations; SD: ± 0.14

Thermodynamic parameters: The influence of temperature of the solution on the extraction of Pb^{2+} and Cd^{2+} was investigated in the temperature range 303 to 333 K. With raise in temperature, the adsoptivity was increasing, which confirmed the endothermic nature of sorption. With increase in solution temperature, the kinetic energy of Pb^{2+} or Cd^{2+} ions, increases and simultaneously, the surface layers of the sorbent are more open for allowing the ions to reach the underlaying active sites, resulting increase in adsorptivity.

Various tthermodynamic factors, ΔGº, ΔHº and ΔSº were evaluated using the equations [39-42].

$$\Delta G^\circ = -RT \ln K_d$$

$$\ln K_d = \frac{\Delta S^\circ}{R} - \frac{\Delta H^\circ}{RT}$$

$$K_d = \frac{q_e}{C_e}$$

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$

where q_e = sorbed quantities of Pb^{2+}/Cd^{2+}; K_d = distribution coefficient; C_e = equilibrium Pb^{2+}/Cd^{2+} concentrations; R = gas constant; T = temperature (K). The results are presented in Table-3.

The high ΔH values of 29.399 kJ/mol for Pb^{2+} and 33.222 kJ/mol for Cd^{2+} suggested the binding of the said adsorbates to the surface of MCSAC is *via* ion-exchange and/or complex formation. This fact can also be inferred from the FTIR data. The ΔS values are positive with high magnitudes, indicating

TABLE-3
THERMODYNAMIC CHARACTERISTIC PARAMETERS OF THE SORPTION PROCESS

Adsorbate	ΔH (kJ/mol)	ΔS (J/mol	ΔG (kJ/mol)			R^2
			303 K	313 K	323 K	
Pb^{2+}	29.399	105.89	-2.685	-3.744	-4.800	0.9997
Cd^{2+}	33.222	116.91	-2.207	-3.371	-4.539	0.9914

TABLE-4
ADSORPTION ISOTHERMS PARAMETERS

Adsorbate	Parameter	Temkin	Freundlich	Dubinin-Radushkevich	Langmuir isotherm
Pb^{2+}	Slope	1.342	0.192	-1.33	0.0767
	Intercept	9.24	2.20	2.5	0.062
	R^2	0.9690	0.9742	0.777	0.9991
		B = 1.386	1/n = 0.177	E = 7.32 kJ/mol	R_L = 0.027
Cd^{2+}	Slope	1.71	0.1691	-9.56	0.061
	Intercept	10.04	2.344	2.23	0.048
	R^2	0.9670	0.9652	0.8814	0.9945
		B = 1.24	1/n = 0.155	E = 2.223 kJ/mol	R_L = 0.0543

much disorder at the interface of sorbent and solution. This creates a conducive condition for Pb^{2+}/Cd^{2+} ions to cross-barrier at the interface and thereby enhancing adsorption [39,42].

Adsorption isotherms: Freundlich, Langmuir, Temkin, Dubinin and Radushkevich adsorption models were used to assess the better fit model to explain the mode of sorption onto MCSAC as per the standard equations [43-46]. The results are shown in Table-4.

Langmuir model with high R^2 values is relatively better fit model. This indicates that the surface of MCSAC is uniform and the adsorbates (Pb^{2+} and Cd^{2+}) are held to the surface of MCSAC in monolayer [43-46]. The R_L values for Pb^{2+} and Cd^{2+} sorption onto MCSAC were 0.027 and 0.0543, respectively, indicating favourability of sorption as per Hal *et al.* [47]. The evaluated E and B values using Temkin and Dubinin-Radushkevich equations are given in Table-4.

Adsorption kinetics: Different kinetic models were analyzed as per literature [48-52] to understand the mechanism of kinetics. The evaluated parameters are presented in Table-5. With high R^2 values (0.992 for Pb^{2+} and 0.990 for Cd^{2+}), pseudo 2nd order model is relatively better fit.

TABLE-5
KINETIC PARAMETERS

Models	Parameters	Pb^{2+} removal	Cd^{2+} removal
Pseudo-first order model	R^2	0.980	0.938
	Intercept	0.034	0.018
	Slope	1.30	1.41
Pseudo-second-order	R^2	0.992	0.990
	Intercept	0.082	1.3
	Slope	0.51	0.991
Elovich model	R^2	0.930	0.981
	Intercept	4.68	5.56
	Slope	8.18	8.0
Bangham's pore diffusion	R^2	0.713	0.949
	Intercept	0.39	0.37
	Slope	2.0	2.10

Regeneration of spent MCSAC and reuse: Different acids, bases and salt solutions of varying concentrations were investigated for the regeneration of spent MCSAC. Fig. 12 indicate that 0.1 N HCl was effective. Spent MCSAC was treated with 0.1N HCl, filtered and dried at 102 ºC for 1 h [52]. It also inferred from Fig. 12 that upto three cycles of regeneration-cum-reuse, moreover, it was found that MCSAC is robust and retain sorption nature with marginal loss of capacity.

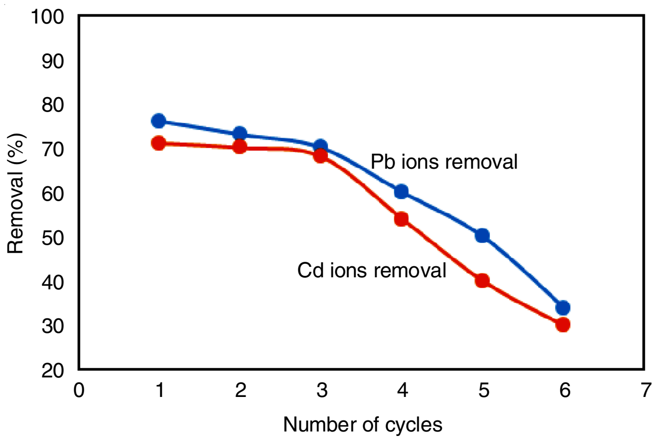

Fig. 12. Regeneration of spent MCSAC and reuse

Applications: The developed method using MCSAC as sorbent were applied for treating samples collected from the effluents of industries in Hyderabad, India. The samples were assessed for the actual concentrations of lead and cadmium. Then they were treated for 90 min at room temperature 303 K with MCSAC (2.0 g/L) at pH 6.0. The results are shown in Table-6. It may be inferred that MCSAC can be successfully remove Pb^{2+} and Cd^{2+} ions from polluted industrial effluents at the established extraction conditions.

Comparison with previous works: The present developed MCSAC was compared with the sorbents hitherto reported to the literature (Table-7). In fact, the majority of previous studies are devoted to extract either Pb^{2+} or Cd^{2+}. The significance of the present study using MCSAC as sorbents is that Pb^{2+} and Cd^{2+} can be simultaneously removed at pH 6.

Conclusion

Biochar generated from the stems of *Momordica charantia* by treating with conc. H_2SO_4 (MCSAC) exhibited a strong adsorption for lead(II) and cadmium(II) ions at pH 6. Extraction conditions were optimized for the simultaneous removal of Pb^{2+} and Cd^{2+} ions from polluted water. The adsorbent (MCSAC) was characterized by conventional methods and also by surface morphology assessing techniques such as XRD, FTIR and FESEM. The sorption mechanism was investigated thermodynamically and by employing different kinetic and isothermal models. High ΔH positive values and infrared analysis suggested the mechanism of sorption as ion exchange and/or complex formation between Pb^{2+}/Cd^{2+} ions and surface functional groups. The positive ΔS values also confirmed the disorder at the boundary of solid/liquid, while the negative ΔG values supports

TABLE-6
APPLICATIONS OF PREPARED BIOADSORBENTS FROM THE STEMS OF *M. charantia* FOR SIMULTANEOUS REMOVAL OF Pb(II) AND Cd(II) IONS

Sample	C_i	Lead removal				Cadmium removal			
		C_e*	Removal (%)	C_e*	Extraction (%)	C_e*	Removal (%)	C_e*	Extraction (%)
(a) Battery industries effluents									
1	4.6	0	100	0	2.5	0	100	0	100
2	5.8	0	100	0	3.1	0	100	0	100
3	6.9	0	100	0	3.9	0	100	0	100
4	7.4	0	100	0	4.3	0	100	0	100
5	8.0	0	100	0	5.0	0	100	0	100
(b) Electroplating industries effluents									
1	3.2	0	100	0	0.7	0	100	0	100
2	3.8	0	100	0	1.9	0	100	0	100
3	4.3	0	100	0	3.0	0	100	0	100
4	5.6	0	100	0	3.8	0	100	0	100
5	6.9	0	100	0	5.0	0	100	0	100

*C_i = initial Pb^{2+}/Cd^{2+} concentration; C_e = equilibrium Pb^{2+}/Cd^{2+} concentration; *Mean of four determinations; SD: ± 0.19

TABLE-7
COMPARISON DATA OF THE EFFICIENCIES OF DIFFERENT REPORTED ADSORBENTS TOWARDS LEAD AND CADMIUM IONS

Sorbent	pH	Pollutant	Adsorbent capacity (mg/g)	Ref.
Granular activated carbon	5.3	Lead	2.89	[53]
Activated carbon from black cumin seeds	9.0	Lead	17.98	[29]
Activated carbon prepared from African palm fruit	8.0	Cadmium	1.82	[17]
Natural biosorbent and activated carbon	4.0	Cadmium	0.08	[54]
Biochars and its applications	6.8	Lead	1.7	[55]
Activated polyacrylonitrile	5.0	Lead	12.7	[27]
Microwaved olive stone activated carbon activated	5.0	Cadmium	11.7	[25]
Granular activated carbon and activated clay	6.0	Cadmium	9.65	[28]
Polyphenolic bioactive Indian curry leaf (*Murraya koengii*) powder	4.5	Lead	13.62	[26]
New low-cost adsorbent bamboo charcoal	8.0	Cadmium	12.08	[30]
MCSAC	6.5	Lead	21.0	Present work
MCSAC	6.5	Cadmium	18.9	

the spontaneity of the adsorption process. Spent MCSAC can be regenerated-cum-reused upto the three cycles and successfully applied to treat effluents samples from the industrial effluents. The merit of the present investigation is that a simple and effective biosorbent was developed for the simultaneous removal of toxic Pb^{2+} and Cd^{2+} at nearly neutral pH conditions.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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