Adsorptive Removal of Copper Ions from Polluted Water Using Sorbents Derived from *Cordia dichotoma*, *Albizia thompsonii* and *Polyalthia cerasoides* Plants

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Three different activated carbons as effective adsorbents were prepared by digesting the stems of *Cordia dichotoma, Albizia thompsonii* and *Polyalthia cerasoides* plants in conc. H$_2$SO$_4$ for Cu^{2+} removal from wastewater. The sorption natures of these sorbents are optimized with respect to various physico-chemical characteristics for the maximum Cu^{2+} removal using simulated waters. *Cordia dichotoma* (CDAC), *Albizia thompsonii* (ATAC) and *Polyalthia cerasoides* (PCAC) activated carbons show good sorption capacities of values: 97.0, 76.8 and 66.7 mg/g, respectively in a wide pH ranges. Unlike that of other two activated carbons, *Cordia dichotoma* activated carbon is effective even in acid conditions, indicting its direct applicability to Cu-based industrial effluents which are generally acidic in nature. Interference of two fold excess of co-ions is minimal. The established extraction conditions for the removal of more than 95.0% from 10 ppm Cu^{2+} solution at room temperature (303 K) using CDAC as sorbent are: pH: 3-9; time of equilibration: 1 h; sorbent dosage: 0.100 g/100 mL; with ATAC: pH: 6-9; time of equilibration: 1.5 h and sorbent dosage: 0.125 g/100 mL; and with PCAC: pH: 6-9; time of equilibration: 2.0 h and sorbent dosage 0.50 g/100 mL. Spent adsorbents can be regenerated and reused until four cycles with minimal loss of adoption capacities. Thermodynamic studies revealed that the sorption is spontaneous and endothermic in nature. Further, the ΔH value for CDAC is 30.156 KJ/mol; it indicates the strong chemisorption and may be through reduction to Cu$^+$/Cu and/or complex formation between Cu^{2+} and functional groups of the adsorbent. The ΔH values of other two activated carbons, ATAC and PCAC, indicated that the sorption is mainly physical with strong inclination towards chemical nature. Positive ΔS values of all the three sorbents, emphasizes the disorder or randomness at the solid-liquid interface and hence favourable conditions for more penetration of Cu^{2+} into the surface layers of the adsorbent and hence, more removal of Cu^{2+} ions. The negative ΔG values indicate that the sorption forces are good enough to cross the potential barrier at the solid-liquid interface and hence the process is spontaneous. The prepared three activated carbons were also successfully applied to industrial effluent and polluted lake samples.

Keywords: Copper ions, Thermodynamic analysis, *Cordia dichotoma*, *Albizia thompsonii*, *Polyalthia cerasoides*.

INTRODUCTION

The presence of copper ions even in trace quantities in drinking waters is highly toxic to human beings [1,2]. Liver problems, neurological and gastroenterological complications, are some noted ailments related to the intake of Cu^{2+}. Even minute amounts of Cu^{2+} ions in water bodies disturb the aquatic life and eco-systems in ponds [1-5]. The maximum allowed limit of copper ions in drinking waters is 2.0 ppm as per WHO [2,3,6].

The main sources of copper contamination of water are the industries based on copper and its ores/compounds [2,3,7,8]. Examples are: electroplating, metal finishing, plastics and manufacturing of various copper compounds having wide utility [3]. Even if copper ions are in trace quantities, they get get accumulated in water bodies due to bio-amplication and more so, as they are non-degradable. Further, excessive use of copper sulphate solution in agriculture fields as fungicide, is another important source of manmade contamination of natural waters with copper ions.

So the developing method for the treatment of industrial effluents and contaminated water bodies for the removal of Cu^{2+} is an important aspect of pollution control research [3]. Cementation [9,10], membrane filtration [11,12], electro-flotation [13], electrodialysis [14,15], photocatalysis [16,17] and reverse osmosis [3] are investigated. Though they produce

good Cu-free water, the methods are costly and involve more technical expertise.

In this contest, methods based on biomaterials as adsorbents are encouraging as they are based on renewable eco-friendly sources. Further, these methods are proving to be effective and simple. Activated carbons prepared from *Phaseolus aureus* hulls [18], peanut hull [19], *Ceiba pentandra* hulls [20], green vegetable waste [21] and rice husk [22] are investigated. Barks of *Limonia acidissima* plant [4], stems of *Hibiscus cannabinus* plant [4], peels of potato and banana [23], sugar beet pulp [24], dehydrated wheat bran [25] and coffee waste [26], are also reported for their adsorptive nature. Modified fly ash [27], waste slurry [28], HCl-treated clay [29], treated fly ash with NaOH solution [30], spirogyra (green alga) [31], iron oxide coated eggshell [32], rose waste biomas [33], chitosan [34] and cross-linked chitosan [35] are also employed.

Copper has two oxidation states: cupric and cuprous and of these, Cu^{2+} is more stable. The species in acidic solutions is Cu^{2+} and with the raise of pH, hydroxo-species: $Cu(OH)^+$, $Cu(OH)_2$, $[Cu(OH)_3]^-$ and $[Cu(OH)_4]^{2-}$ are gradually formed [36,37]. These hydroxo-species are less soluble in water. The solubility of Cu^{2+} ions depends upon pH and also on the nature of anions. Though in neutral solutions, Cu^{2+} is less soluble and forms hydrated species, still micro-amounts of Cu^{2+} ions are present in water and they are to be removed as such amounts are also hazardous and further, they are more difficult to be removed at such low concentrations. Removal of Cu^{2+} from acidic solutions is one of the challenging aspects and beneficial to industries, as most of the industrial effluents are acidic. To develop strategies for the removal of Cu^{2+} ions based on bio-adsorbents, advantage may be taken from the fact that the reduction potential Cu^{2+}/Cu^+ is: 0.153 V and that of Cu^{2+}/Cu is: 0.337 V and even mild reducing agents can reduce Cu^{2+} to Cu^+ or to Cu [38]. As cuprous (Cu^+) salts are less soluble even in slight acidic solutions, they can be removed easily. If the reduction is upto elemental Cu, it is easily separated. Hence, methods may be developed with an aim to reduce Cu^{2+} to Cu^+/ Cu or to complex the Cu^{2+} ions with the surface functional groups of an adsorbent. Activated carbons having diverse functional groups and even mild reduction nature, may serve this purpose. In this work, many activated carbons derived from various routes and different classes of plants, have been investigated. Thus, in present work, the adsorptive parameters of activated carbons synthesized by digesting the stems of *Cordia dichotoma, Albizia thompsonii* and *Polyalthia cerasoides* plants for Cu^{2+} ions have been investigated.

EXPERIMENTAL

Analytical grade chemicals procured from the different sources were used throughout the experiments. All solutions were prepared using double-distilled water.

Plants description: *Cordia dichotoma* plant belongs to *Borage* family of plant kingdom and it is well grown in tropical regions. *Albizia thompsonii* tree belongs to *Leguminosae* family and its biomaterials are used in local medicines. *Polyalthia cerasoides* plant is a species of *Annonaceae* family and it grows to a height of nearly 20 m.

Synthesis of activated carbons: Stems of *Cordia dichotoma*, *Albizia thompsonii* and *Polyalthia cerasoides* plants were cut to pieces and washed separately with distilled water and half-dried under sunlight. Then these biomaterials were immersed in conc. H_2SO_4 and allowed to be digested for 2 days at room temperature (303 K). The materials with conc. H_2SO_4 were then digested in round bottomed flasks for 2 h adopting cond-enser setup. This procedure ensured the total carbonization of biomaterials. The materials in the flask were diluted with water, filtered and the biochar was washed with distilled water until the washing become neutral. The materials were allowed to dry in hot air over at 105 °C, cooled and grinded in a mortar and pestle to reduce size of the particles. The particles were sieved through a mesh of size: 75 μm (ASTM) and the fine powder was preserved in air-tight brown bottles. Thus synthesized sulphuric acid mediated activated carbons from stems of *Cordia dichotoma*, *Albizia thompsonii* and *Polyalthia cerasoides* are named as CDAC, ATAC and PCAC, respectively.

Adsorption experiments: Investigations were carried out using batch modes of extractions [39-41]. Simulated Cu^{2+} solutions of known Cu^{2+} concentrations were prepared.

General procedure: To 100 mL of Cu^{2+} solution taken in 250 mL stoppered iodine flasks, known amounts of CDAC/ ATAC/PCAC were added. Initial pHs of solutions were adjusted to desired values using dil. HCl/NaOH. Then the flasks were placed in mechanical shaker and agitated for desired period at 300 rpm. Then the solution was filtered and analyzed for the remaining Cu^{2+} content by atomic adsorption spectroscopic method using AA 500 instrument [2].

Contact time: The effect of time of equilibration on Cu^{2+} sorption abilities of CDAC, ATAC and PCAC were investigated. For this, 100 mL of 10 ppm Cu^{2+} solution was equilibrated with 0.1 g for CDAC/0.125 g for ATAC/0.150 g PCAC at pH 3 for CDAC/6.0 for ATAC/7.0 for ATAC, for different periods ranging from 15 to 150 min at 300 rpm and 303 K.

Dosage of sorbents: By changing the concentration of CDAC, ATAC and PCACs from 0.25 g to 2.00 g/L and keepng the other parameters optimized, removal percentage was investigated. For this, 0.025 g to 0.20 g of the adsorbent was added to 100 mL of 10 ppm Cu^{2+} solution. Then pH was adjusted to 3 for CDAC, 6.0 for ATAC and 7.0 for PCAC. The solutions were equilibrated for a time of 60 min for CDAC, 90 min for ATAC and 120 min for PCAC, at rpm 300 and temperature 303 K.

Initial concentration: The effect of initial concentration of Cu^{2+} on sorption capacities of CDAC, ATAC and PCAC were studied. A 100 mL of Cu^{2+} solutions of different concentrations ranging from 25 ppm to 200 ppm were taken into 250 mL iodine flasks and for each of the flask, 0.100 g of CDAC or 0.125 g of ATAC or 0.150 g of PCAC were added. The solutions then were adjusted to pH 3 for CDAC, 6.0 for ATAC and 7.0 for PCTAC. The solutions were equilibrated for an optimum period of 60 min for CDAC, 90 min for ATAC and 120 min for PCAC. Then the solutions were filtered and the filtrates were analyzed for residual copper(II) ions.

The influence of individual parameter on the extraction of Cu^{2+} was studied by gradually changing the levels of parameter

but maintaining constant the other parameters at optimum levels. Regeneration of the spent CDAC, ATAC and PCAC were also investigated for evaluating their reuse. The developed methods were applied to industrial effluent samples and polluted lake samples.

Effect of temperature: The extraction studies were made by taking Cu^{2+} solution of initial concentration: 40 ppm. 100 mL of Cu^{2+} solution was taken into a 250 mL iodine flask. To it, 0.100 g of CDAC or 0.125 g of ATAC or 0.150 g of PCAC was added and then pH was adjusted to 3 in the case of CDAC; pH 6 for ATAC; pH 7 for PCAC. The solution was then equilibrated in shaking machines for optimum periods: 1 h for CDAC, 1.5 h for ATAC and 2.0 h for PCAC. And finally filtered the solutions and the filtrates were assayed for residual Cu^{2+} ions.

RESULTS AND DISCUSSION

Effect of pH: The pH has remarkable effect on the removal of Cu^{2+}. Among the studied adsorbents *viz.* CDAC, ATAC and PCAC, it is interesting to observe that CDAC has shown substantial amounts of Cu^{2+} removal (more than 90%) from water in a wide rage of pH 2 to 10 (Fig. 1).
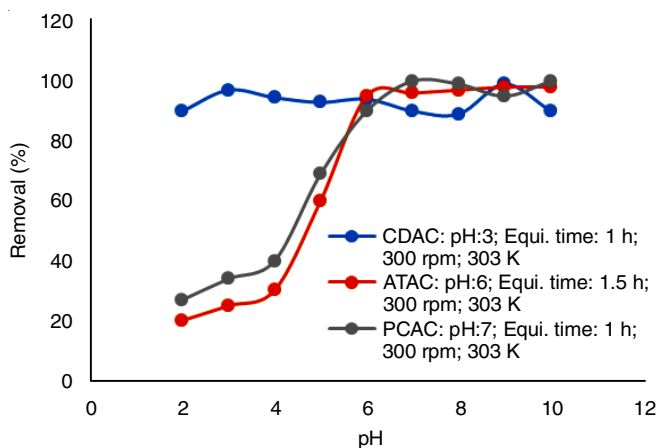

Fig. 1. pH *vs.* % removal of Cu^{2+} conc. of Cu^{2+}: 10 ppm

Thus, CDAC as adsorbent is effective in acidic, neutral and also in moderately basic solutions. This finding may be applied to remove Cu^{2+} even for acidic solutions because most of the industrial effluents are acidic in nature. This behaviour of CDAC differ from the other two investigated adsorbents (ATAC and PCAC). Good adsorption is noted for these two adsorbents (not less than 90%) above pH: 6 while at pH below 6, the removal% has fallen markedly. So ATAC and PCAC are effective above pH 6. The CDAC extracted maximum of 97% from 10 ppm Cu^{2+} solution at pH 6. Extraction of 96% was observed with ATAC at pH 6 and 100% with PCAC at pH 7.

The pH_{ZPC} for CDAC, ATAC and PCAC were found to be 5.0, 5.5 and 6.0 (Fig. 2). So, at these pHs, the surface of the sorbents are neutral having balancing the negative and active sites [42]. Above these values, the surface of the studied sorbents assumes negative charge due to dissociation of functional groups (-NH_2, -COOH, -OH). Below these values, the dissociation is less favoured and at sufficiently acidic conditions, protonation
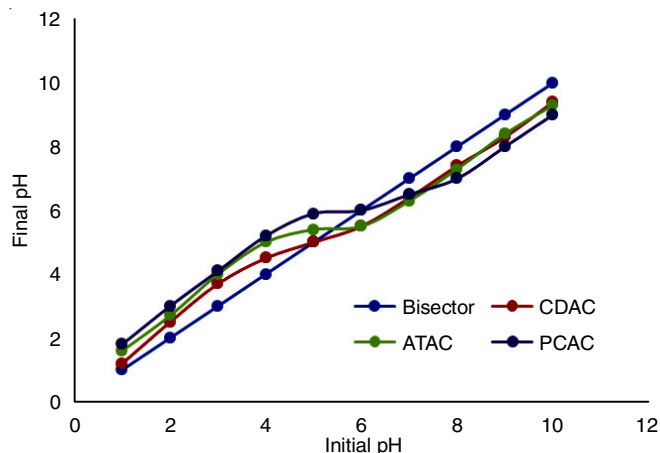

Fig. 2. Evaluation of pH_{zpc} of CDAC, ATCA and PCCA

of functional groups may occur imparting positive charge to the surface [42,43]. As already discussed earlier, the main species of Cu(II) ions were Cu^{2+} (below pH 3); $Cu(OH)^+$ (pH 3-6); $Cu(OH)_2$ (pH 6-11) and $[Cu(OH)_3]^-$ & $[Cu(OH)_4]^{2-}$ (above 11). In case of CDAC, maximum adsorption is noted at pH 3. This may be due to the exchange H^+ of functional groups with Cu^{2+} and may also be due to the reduction of Cu^{2+} to Cu^+ or even to Cu by CDAC because of the small redox potential values: Cu^{2+}/Cu^+: 0.153 V and Cu^{2+}/Cu: 0.337 V. Cuprous salts as well as metallic Cu are insoluble in water and hence easy to remove. The other two adsorbents showed less affinity at low pHs. If the mechanism is ion-exchange only, these adsorbents must show good sorption at pH 3 as that of CDAC, but the case is not true and hence, the most probable mechanism of adsorption at pH 3 in the case of CDAC is reduction. When the pH is increased above the pH_{zpc}, the hydroxylated species show more attraction towards the functional groups of sorbent surface and may be due to the formation of hydrogen bridges such as: -O-H····O–Cu^{2+}. Further, at high pH values, hydroxyl species are relatively insoluble, resulting aggregates. The cumulative result is the high adsorption of Cu^{2+}.

At pH above 10, there is a decrease in the removal percentage, since the surface of the adsorbents becomes negatively charged and also some negative Cu(II) species *viz.* $[Cu(OH)_3]^-$ and $[Cu(OH)_4]^{2-}$ exist, causing repulsions between the surface and Cu(II) species.

Contact time: Initially, the removal is progressively increased almost linearly with the increase in contact time. But latter, the sorption is slowdown and after certain time of interval, a steady state has been resulted (Fig. 3). For CDAC, the sorption was observed at 30% at 15 min; 61% at 30 min; 74% at 45 min; 97% at 60 min or above. In case of ATAC, the extraction was achieved at 25% at 15 min; 51% at 30 min; 74% at 45 min; 85% at 60 min; 90% at 75 min; 96% at 90 min; 97% at 105 min or above. Using PCAC, the removal percentage was achieved 15% at 15 min; 41% at 30 min; 61% at 45 min; 70% at 60 min; 82% at 75 min; 94% at 90 min; 97% at 105 min and 100% at 120 min or above.

These observations may be explained from the fact that initially, active sites are more and hence removal percentage is more [44]. But with time, when all the sites available are engaged with the sorption of Cu^{2+} ions, a steady line is resulted.
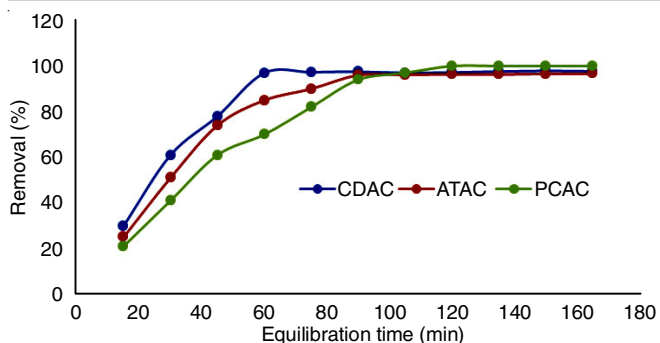
Fig. 3. Effect of equilibration time on % removal of Cu^{2+}

Dosage of sorbents: As observed from Fig. 4 that optimum minimum dosages needed for the maximum removal of Cu^{2+} are 0.1 g/100 mL for CDAC; 0.125 g/100 mL for ATAC and 0.150 g/100 mL for PCAC.
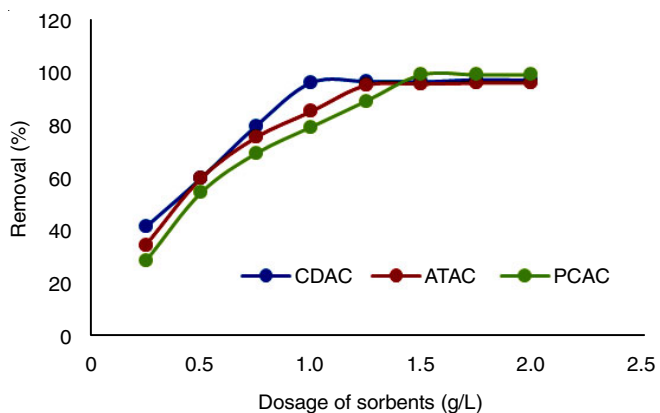

Fig. 4. Effect of dosage of adsorbents

Initial concentration: Fig. 5 shows that the maximum removal is observed for Cu^{2+} solution of initial concentration up to 25 ppm for CDAC and ATAC and 30 ppm for PCAC. Beyond these concentrations, removal percentage is decreased. Fig. 6 emphasizes the relation between adsorption capacity (q_e) and initial concentration of Cu^{2+} (C_i). As observed, with raise in initial concentration, there is a linear (nearly) increase in q_e. But after certain initial concentration, the intake capacity almost came to stand still. These observations are as per expected lines [45]. With the increase in concentration of Cu^{2+} ions,
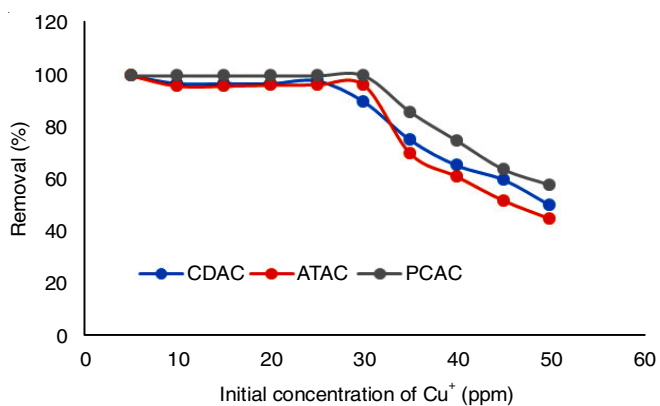
Fig. 5. Effect of initial concentration of Cu^{2+} on % removal of Cu^{2+}
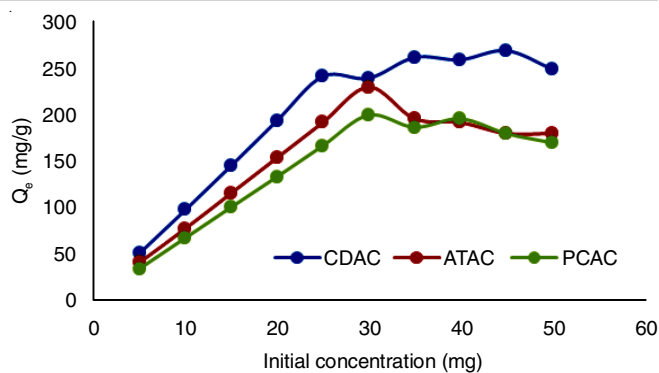
Fig. 6. Initial concentration *vs.* sorption capacity (q_e)

removal percentage decreases but adsorption capacity increases. With the increase in Cu^{2+} concentration, more ions are diffused towards sorbent surface due to concentration gradient and this results in the enhancement of adsorption capacity [45]. But as the amount of sorbent is fixed, active sites for the sorption process are also fixed. Proportional number of active sites are not available with the increase in concentration of Cu^{2+} and so removal percentage of Cu^{2+} also decreased.

Effect of Co-ions: Interference caused by two-fold excess of co-ions were investigated with synthetic simulated samples using CDAC, ATAC and PCAC at the optimum extraction conditions. It can be inferred from Figs. 7 and 8 that the anions except fluoride, did not show any interference to the adsorption process and even the interference caused by fluoride ion is also marginal. But few cations *viz.* Al^{3+}, Fe^{2+} and Zn^{2+} have interfered to some extent.
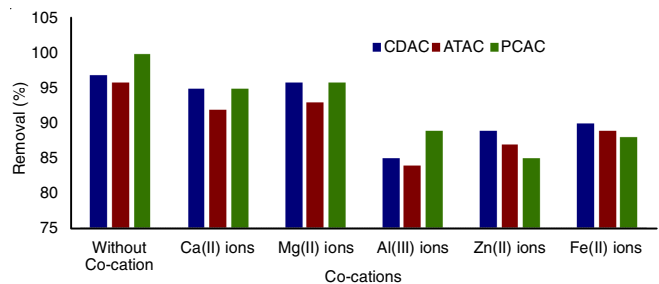
Fig. 7. Interference of Co-cations on the % removal of Cu^{2+}
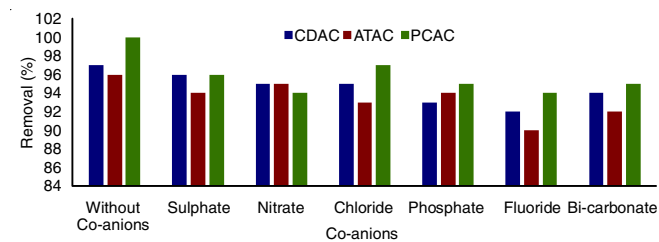
Fig. 8. Effect of Co-anions on the % removal of Cu^{2+}

Thermodynamic studies: The effect of temperature on the sorption of Cu^{2+} on CDAC, ATAC and PCAC were investigated. It is observed that as the temperature increases, the adsorption also increases (Figs. 9 and 10). The reason is attributed due to the fact that the surface functional groups are subjected to greater vibrational motion at high temperature and as a result, the thickness of surface layers of activated
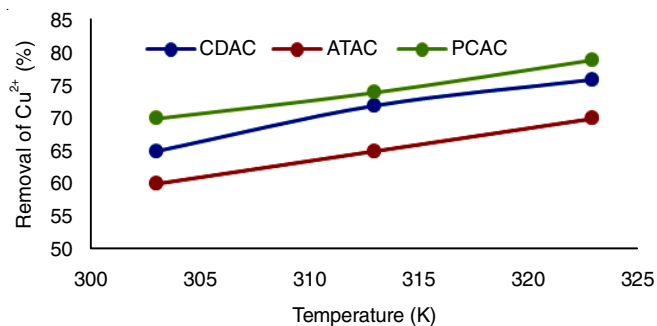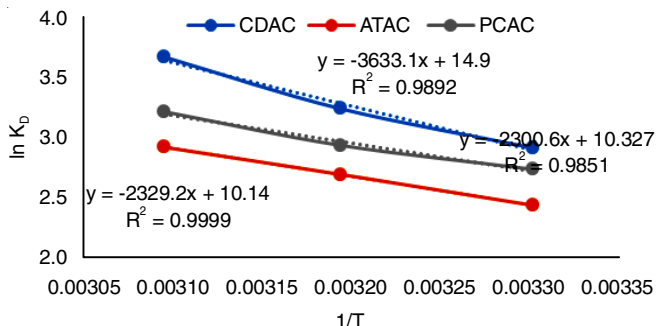
Fig. 9. Effect of temperature on % removal of Cu^{2+}

Fig. 10. I/T *vs.* ln K_D

carbons decreased [46]. Moreover, kinetic energy of Cu^{2+} ions is also increased and hence, penetrate deeper into the activated carbon surface layers. The net effect is the more adsorption of Cu^{2+} ions. Furthermore, the thermodynamic parameters *viz.* change in free energy ($\Delta G°$, kJ/mol), enthalpy ($\Delta H°$, kJ/mol) and entropy ($\Delta S°$, J/K mol) were also evaluated and the values are shown in Table-1.

Based on the values obtained in Table-1, one can conclude that the in present work, (i) adsorption is endothermic in nature for all the three sorbents since ΔH values are positive; (ii) as the value for CDAC is more than 30 KJ/mol, it indicates the strong chemisorption [47]. If the ΔH values lie between 2.1 to 20.9 KJ/mol, physical adsorption and between 20.9 to 418.4 KJ/mol, chemical adsorption may be presumed. From the values, CDAC sorption is mainly chemical in nature while with others, the sorption is mainly physical with strong inclination towards chemical nature. This further confirms that pH plays an important part and the main mechanism of adsorption for CDAC is reduction and/or complexation while with others (ATAC and PCAC), agglomeration of hydroxide species of Cu^{2+}:$Cu(OH)^+$, $Cu(OH)_2$, $Cu(OH)^-$ and $Cu(OH)_4^{2-}$ is dominant; (iii) since ΔS values of the three sorbents are also positive, the disorder or randomness is emphasized at the solid-liquid interface [48], which is a favourable condition for more penetration of Cu^{2+} into the surface layers of the adsorbent and hence, more

removal of Cu^{2+} ions caused; and finally (iv) the ΔG values are negative for all the sorbents. This indicates that the sorption process is spontaneous and sorption forces are good enough to cross the potential barrier at the solid-liquid interface [48].

Regeneration of spent adsorbents: The spent adsorbents were investigated for their regeneration and reuse. For this, various acids, bases and salts at varying concentration were employed. CDAC was successfully regenerated by digesting the adsorbent with 0.1 N HCl solution for 1 h on a water both.

ATAC and PCAC were regenerated by digesting them on water baths with 0.5 N HCl for 1 h. Thus treated activated carbons were washed with distilled water until the washings become neutral. Then the activated carbons were dried at 105 ºC for 1 h in hot air oven. Then they were cooled to room temperature and reused. This regeneration and reuse were repeated until 7 cycles. It may be inferred from Fig. 11 that until four cycles, the loss of adsorption capacity of all the three adsorbents is marginal.
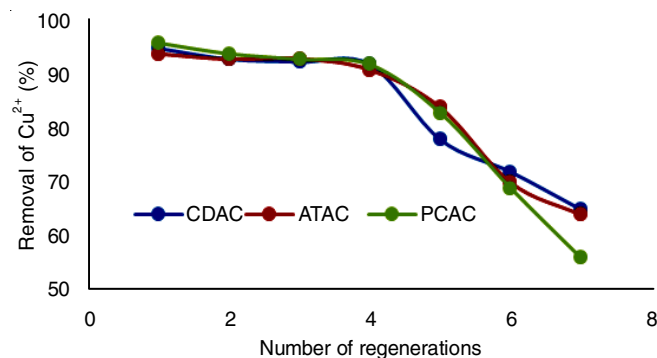

Fig. 11. Regeneration and reuse of spent sorbent

Applications: The developed methods with CDAC, ATAC and PCAC as sorbents were applied to real polluted waters collected from effluents of industries and lake waters polluted with over utilization of copper salts in agricultural fields. At the optimum extraction conditions, the samples were extracted with CDAC, ATAC and PCAC. It can be inferred from the Table-2 that the three sorbents developed namely, CDAC, ATAC and PCAC, are very effective in the removal of Cu^{2+} ions from polluted waters.

Comparison with previous works: The sorbents developed are also compared with other sorbents reported to literature with respect to pH and sorption capacity. It may be inferred from Table-3 that the sorbents developed in the present work have good sorption capacities. The CDAC is effective in a wide pH range 3-9 and its good sorption even in acidic solution is noteworthy because most of the industrial effluent from Cu-based industries are generally acidic in nature.

TABLE-1
THERMODYNAMIC PARAMETERS: ADSORPTION OF Cu^{2+} ONTO CDAC, ATAC AND PCAC

Adsorbent	ΔH (KJ/mol)	ΔS (J/mol)	ΔG (KJ/mol)			R^2
			303 K	313K	323K	
CDAC	30.156	123.7	-7.113	-8.56	-9.80	0.9892
ATAC	19.366	84.309	-7.022	-6.18	-7.87	0.9999
PCAC	19.13	85.86	-8.55	-7.74	-8.6	0.9851

TABLE-2
APPLICATIONS OF DEVELOPED ADSORBENTS (DCAC, ATAC AND PCAC) FOR TREATING REAL WATER SAMPLES

Water samples	Adsorbents								
	DCAC*: Concentration of Cu^{2+}			ATAC*: Concentration of Cu^{2+}			PCAC*: Concentration of Cu^{2+}		
	C_i (ppm)	C_e (ppm)	Removal (%)	C_i (ppm)	C_e (ppm)	Removal (%)	C_i (ppm)	C_e (ppm)	Removal (%)
Effluent samples from industries									
Sample 1	8.5	0	100	8.5	0	100	8.5	0	100
Sample 2	9.5	0.1	98.9	9.5	0.2	97.9	9.5	0	100
Sample 3	10.5	0.75	92.9	10.5	0.60	94.3	10.5	0.1	99.0
Water samples from polluted lakes due to over utilization of copper salts									
Sample 1	3.5	0	100	3.5	0	100	3.5	0	100
Sample 2	4.5	0	100	4.5	0	100	4.5	0	100
Sample 3	5.2	0	100	5.2	0	100	5.2	0	100

@Mean of four values; SD: ± 0.12

TABLE-3
COMPARISON OF COPPER UPTAKE CAPACITY OF DEVELOPED ADSORBENTS
(CDAC, ATAC AND PCAC) WITH OTHER REPORTED ADSORBENTS

Adsorbent	pH	Cu^{2+} sorption capacity (mg/g)	Ref.
Barks of *Limonia acidissima* plant	4.0	13.5	[4]
Stems of *Hibiscus cannabinus* plant	4.0	15.0	[4]
Activated carbon prepared from *Phaseolus aureus* hulls	7.0	20.0	[18]
Activated carbon prepared from *Ceiba pentandra* hulls	7.0	21.0	[20]
Modified fly ash	7.0	21.50	[27]
Waste slurry	3.0	20.97	[28]
HCl-treated clay	5.0	83.30	[29]
Treated fly ash with NaOH solution	6.2	64.00	[30]
Spirogyra (green alga)	5.0	133.00	[31]
Iron oxide coated eggshell powder	6.0	44.00	[32]
Rose waste biomass	5.0	56.00	[33]
Chitosan	4.5	88.43	[34]
Crosslinked chitosan	5.0-6.0	200.00	[35]
Cordia dichotoma activated carbon (CDAC)	3.0-9.0	97.00	Present work
Albizia thompsonii activated carbon (ATAC)	6.0-9.0	76.80	Present work
Polyalthia cerasoides activated carbon (PCAC)	7.0-9.0	66.70	Present work

Conclusion

In this work, three effective activated carbons were synthesized by digesting the stems of *Cordia dichotoma*, *Albizia thompsonii* and *Polyalthia cerasoides* plants in conc. H_2SO_4 for Cu^{2+} removal from wastewater. The adsorption capacity of all the adsorbents towards Cu^{2+} ions was investigated through batch extraction method using simulated waters. The extraction parameters were optimized for the maximum Cu^{2+} removal. Unlike that of other two activated carbons, *Cordia dichotoma* activated carbon (CDAC) is effective even in acid conditions, indicating its direct applicability to copper based industrial effluents which are generally acidic in nature. Moreover, the interference caused by two-fold excess of co-ions was minimal. The reusability of the studied adsorbents can be utilized till four cycles with minimal loss of adoption capacities. Thermodynamic studies revealed that the sorption process was spontaneous and endothermic in nature and all the three active carbons were successfully applied to industrial effluents and polluted lake water samples.

CONFLICT OF INTEREST

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

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