# Performance of low-cost adsorbents for the removal of copper and lead

M. Rao, A. V. Parwate, A. G. Bhole and P. A. Kadu

## ABSTRACT

Bagasse and fly-ash are waste materials and have been used for the removal of copper and lead from aqueous solutions. Investigations were carried out using a batch sorption process. The efficiency of sorption of copper and lead is affected by aqueous solution pH, contact time, adsorbent dose, type and size of adsorbents and initial metal ion concentration; all of which factors were investigated. Results of the investigations were used in kinetic studies to understand the mechanism of the adsorption process. The adsorption equilibrium is well correlated by the Langmuir, Freundlich and Bhattacharya & Venkobachar models. The adsorption capacity follows the sequence of fly-ash>bagasse>PAC for Cu(II) removal, and PAC>bagasse>fly-ash for Pb(II) removal, in optimum conditions.

**Key words** | adsorption, bagasse, copper(II), fly-ash, Langmuir and Freundlich isotherms, lead(II), low-cost adsorbents

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## INTRODUCTION

The presence of heavy metals in the environment is of great concern to scientists and engineers because of their increased discharge, toxic nature and other adverse effects on receiving waters. The important toxic metals, which include Cr, Cd, Zn, Ni, Cu, Pb, etc., find their way to water bodies through industrial wastewater discharges. Industries such as metal cleaning and plating baths, pulp, paper and board mills, fertilizer production, tannery operations, chemical manufacturing, petroleum refining, mine drainage, wood preserving, battery manufacturing, and leachates from hazardous waste disposal sites containing metal ions add to heavy metal pollution (Gupta 1998; Sreenivasulu *et al*. 1998).

Lead poisoning causes diseases such as anaemia, damage to the central nervous system, mental deterioration, etc. (Mohd *et al*. 1998). Excessive copper intake leads to accumulation in the liver, hemochromotosis due to chronic copper poisoning, and gastro-intestinal catarrh. Copper is toxic to aquatic organisms even at very small concentrations (Sreenivasulu *et al*. 1998). Wastewater from plating shops may contain Pb(II) in the range of 100–250 ppm (Muthukumaram *et al*. 1995). Several mishaps due to heavy metal contamination in the aquatic environment increased the awareness of heavy metal toxicity. Among these, the Minamata tragedy in Japan due to mercury poisoning (1953–1960) and 'Itai-Itai' disease in Japan due to cadmium toxicity (1947) are well known (De & De 1994).

A number of technologies have been developed over the years for the removal of toxic metal ions from aqueous solutions *viz*. ion exchange, reverse osmosis, precipitation, adsorption, etc. Adsorption is by far the most popular and widely used process for removing heavy metals from water and wastewater. Activated carbon is commonly used as an adsorbent in the treatment of domestic and industrial wastewater. Although it is extensively used in the treatment of water and wastewater, activated carbon is an expensive material, and therefore the production of low-cost alternatives has been the focus of researchers in the last few years (Gupta 1998). Numerous experiments have been conducted by researchers to investigate the removal of metal ions, colour, organic matter, etc. using a wide

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range of adsorbents. These investigations include: the use of an electrolyte consisting of a NaCl solution for the removal of Zn, Pb, Cd, Cu and Cr from incinerator fly-ash in a marine clay (Lim *et al*. 1997); granular activated carbon for Pb (Reed *et al*. 1995); living microalgae for Al, Zn, Hg, Pb, Cu and Cd (Daniel *et al*. 2001); redox within condensed tannin gels for Cr (Yoshio *et al*. 2001); bone char for Cd (Cheung *et al*. 2001); rice husk, bark, cotton waste, coal, clay and hair for dye colours (McKay *et al*. 1987); sawdust, bone char, chitin, leather waste and sugar beet pulp for coloured organic matter (Bousher *et al*. 1997); and activated carbon for organics (Martin & Iwugo 1982).

The main objective of the present study is to investigate the adsorption behaviour of Cu(II) and Pb(II) on powdered activated carbon (PAC), fly-ash (FA) and bagasse under different operating conditions and to determine the optimum adsorption conditions of the sorbents. The sorption and speciation of Cu and Pb, under acidic and slightly alkaline conditions were studied. Experiments were conducted using a laboratory-scale batch process. The investigations were focussed on the sorption of copper and lead so as to provide an in-depth understanding of metal ions sorption mechanisms, and the mobility of heavy metal ions onto sorbents under varying environmental conditions.

## MATERIALS AND METHODS

All the reagents used were of AR grade. Metal solutions of Cu(II) and Pb(II) were prepared by dissolving copper sulphate ($CuSO_4,5H_2O$) and lead nitrate ($Pb(NO_3)_2$) separately in double distilled water in order to result in known concentrations of the metal ions required.

### Equipment

A UV-spectrophotometer (UV-2000 model) was used for the estimation of Cu(II) and Pb(II) ions in the aqueous solution as per standard methods (APHA 1992). A pH meter (Systronics digital model) and a Remi shaking machine for agitating the samples for the required period at a speed of 200 strokes/min were used. The surface area of the adsorbent particles and their porosity and density were measured by using a surface area analyser, mercury porosimetry and specific gravity bottles respectively.

### Treatment of materials

PAC of AR grade was procured from a local supplier. Fly-ash was collected from Koradi thermal power plant near Nagpur in Maharashtra State, India. Bagasse, a waste material of the sugar industry was obtained from a local sugar mill in Phubgaon, Maharashtra, India. The fly-ash was washed with double distilled water to remove dirt and other foreign matter. Bagasse was washed initially with double distilled water, sun-dried and used in the same form. It was observed that, after allowing 60 min of contact period during the study of pH, no reduction of metal ions was found and moreover some colour was released to the aqueous solution. This colour intensity increased with the increase in pH. These problems led the authors to study the adsorbent materials in detail. Finally, it was found that these problems were due to release of lignin from the raw adsorbent material (bagasse) which required some chemical treatment to remove it.

### Removal of lignin

It was observed that initially the active adsorption sites were occupied by lignin, and at higher pH it was released to the aqueous solution. Attempts were made to remove the lignin by an alkali wash followed by acid washing. Bagasse was first washed thoroughly with the distilled water to remove the dust particles and dried at 40°C for a period of 4–5 h. Dried adsorbent material (bagasse) was then soaked overnight in 0.1 M NaOH solution to remove the lignin content (Chhatre *et al*. 1996) and again washed well with double distilled water. Then it was soaked in 0.1 M $CH_3COOH$ for a period of 2–3 h to remove the traces of NaOH. Thereafter bagasse was thoroughly washed again with double distilled water until the wash water became colourless, and then sun-dried. Sorbent materials were stored separately in a vacuum desiccator to

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prevent atmospheric moisture contact until used (Rao & Bhole 2000).

## RESULTS AND DISCUSSION

### Sorption studies

Successful application of the adsorption technique demands innovation of cheap, non-toxic, easily and locally available adsorbents of known kinetic parameters and sorption characteristics. Knowledge of the optimal conditions would herald a better design and modelling process. Thus the effect of some major factors *viz*. pH, contact time, amount and particle size of adsorbent, and concentration of $Cu^{2+}$ and $Pb^{2+}$ ions on the uptake on adsorbent materials were investigated from the kinetic viewpoint. Adsorption studies were performed by batch technique to obtain the rate and equilibrium data. Experiments were carried out by shaking 1 g $l^{-1}$ of adsorbent with 50 ml of aqueous solution containing a known concentration of $Cu^{2+}$ and $Pb^{2+}$ ions and by agitating the samples on the Remi shaking machine at a speed of 200 strokes/min. Samples containing $Cu^{2+}$ and $Pb^{2+}$ ions were maintained at a desired pH by adding 0.5 N $HNO_3$ or 0.1 M NaOH. All the experiments were conducted at room temperature (32 ± 0.5°C).

### Effect of pH

The pH of the aqueous solution is an important factor in the adsorption process and thus the role of hydrogen ion concentration was examined in solutions at different pH. It was observed in these investigations that with the increase in pH of the solution, the extent of metal ions removal increased for all adsorbents (except for PAC in the case of $Pb^{2+}$ ions), but that there was a difference in the trend of the increase. The extent of removal was investigated in $Cu^{2+}$ and $Pb^{2+}$ ion concentrations of 0.5 g $l^{-1}$ and 0.1 g $l^{-1}$ respectively and the results are shown in Figure 1a and b. $Cu^{2+}$ and $Pb^{2+}$ ions are precipitated above pH 6.0 and 10.0 respectively, and hence studies were not conducted beyond these pH values. In the case of

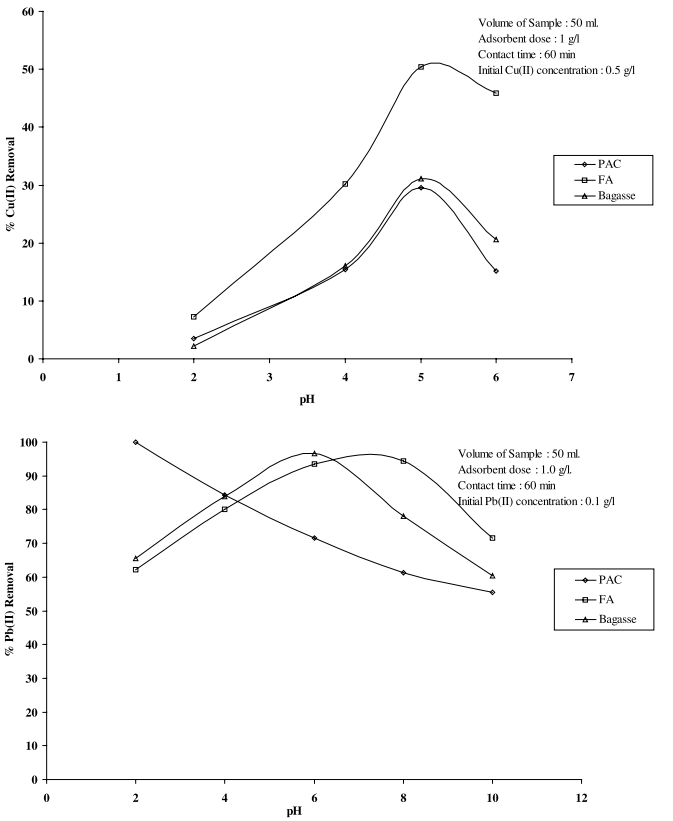


**Figure 1** | (a) Effect of pH on the removal of Cu(II). (b) Effect of pH on the removal of Pb(II).

Cu(II), the percentage of adsorption increased almost linearly between pH 2.0 to 5.0, attaining a maximum removal at pH 5.0 with all the adsorbents. But above pH 5.0, there was a decrease in adsorption. Fly-ash showed the maximum removal of $Cu^{2+}$ ions, compared to PAC and bagasse. With an initial Cu(II) concentration of 0.5 g $l^{-1}$, the percentage removal was found to be 50.5%, 31.1% and 29.5% respectively, for FA, bagasse and PAC at a dose of 1.0 g $l^{-1}$.

A significant removal of $Pb^{2+}$ ions was observed between pH 6.0 and 8.0 with bagasse and FA respectively. PAC showed maximum Pb(II) removal (i.e. 100%) at pH 2.0 which decreased to 55.5% at pH 10.0. The negative charge density on the surface of the PAC would be greater at lower pH; this accounts for the higher uptake of positively charged $Pb^{2+}$ ions. A fall in adsorption with increasing pH may be due to deprotonation. Removal of

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Pb(II) with bagasse was found to be 96.7% at pH 6.0 and 94.5% with FA at pH 8.0. This is due to FA and bagasse being positively charged in an acidic medium and hence recording a low uptake of lead ions at very low pH which might be due to electrostatic repulsion (Gupta *et al.* 1997b).

The variation in the removal of Cu(II) and Pb(II) with pH can also be explained by considering the surface charge of the adsorbent materials, which is very much dependent on the ZPC (zero point charge) value of silica and alumina (Gupta *et al.* 1997a). The uptake of metal ions would be quite low under these conditions due to electrostatic repulsion. With increasing pH, i.e. beyond the ZPC of FA and bagasse, the negative charge density on the surface of the adsorbent material increases, resulting in a sudden enhancement in $Pb^{2+}$ ions adsorption. This is also supported by considering the double layers at $SiO_2$ and $Al_2O_3$ surfaces which change in polarity from positive to negative as the $[H^+]$ ion changes from the acidic to the basic region. Thus, a dramatic jump in the uptake of lead ions with increasing pH may be ascribed to an increasing negative charge density on the surface of FA and bagasse and this also accounts for a downfall in the sorption of lead ions at low pH. Further Cu(II) removal studies were investigated at pH 5.0 with all three adsorbents. The removal of Pb(II) was studied with PAC at pH 2.0, bagasse at 6.0 and FA at 8.0.

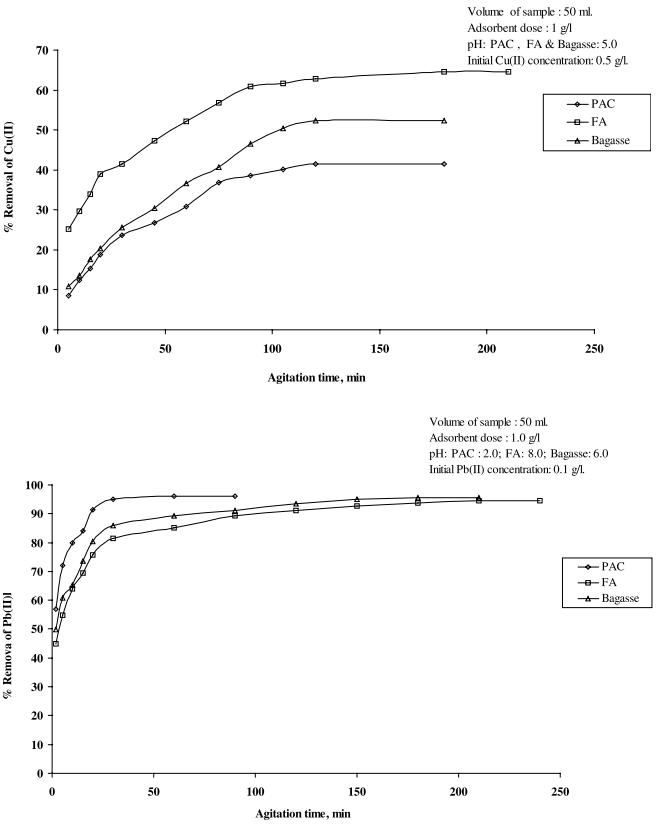


**Figure 2** | (a) Effect of contact time on the removal of Cu(II). (b) Effect of contact time on the removal of Pb(II).

## Effect of contact time

Figure 2a and b depict the effect of contact time on the rate of uptake of $Cu^{2+}$ and $Pb^{2+}$ ions. It was found that the removal of metal ions increased with increase in contact time to some extent. Further increase in contact time did not increase the uptake due to deposition of metal ions on the available adsorption sites on the adsorbent materials. Preliminary investigations into the uptake of $Cu^{2+}$ and $Pb^{2+}$ ions on the adsorbent materials at their optimum pH values indicated that the processes are quite rapid. Typically 66–85% of the ultimate adsorption capacity occurs within the first hour of contact for both $Cu^{2+}$ and $Pb^{2+}$ ions with an initial concentration of 0.5 g $l^{-1}$ and 0.1 g $l^{-1}$ respectively (Figure 2a and b). This initial rapid adsorption subsequently gives way to a very slow approach to equilibrium and saturation is reached in 3–4 h. For further optimization of other parameters, the contact time was considered as the equilibrium time corresponding to the adsorbent and adsorbate.

## Effect of adsorbent dose

The effect of the amount of adsorbent on the removal of $Cu^{2+}$ and $Pb^{2+}$ ions is depicted in Figure 3a and b. It is seen that the removal of metal ions increases with an increase in the amount of adsorbent. For all these runs, the initial $Cu^{2+}$ and $Pb^{2+}$ ion concentrations were fixed at 0.5 g $l^{-1}$ and 0.1 g $l^{-1}$ respectively. The amount of adsorbent dose varied from 0.5–20 g $l^{-1}$ and 0.05–5 g $l^{-1}$ for $Cu^{2+}$ and $Pb^{2+}$ ions respectively, and was added to aqueous solutions at their optimum pH values. Results

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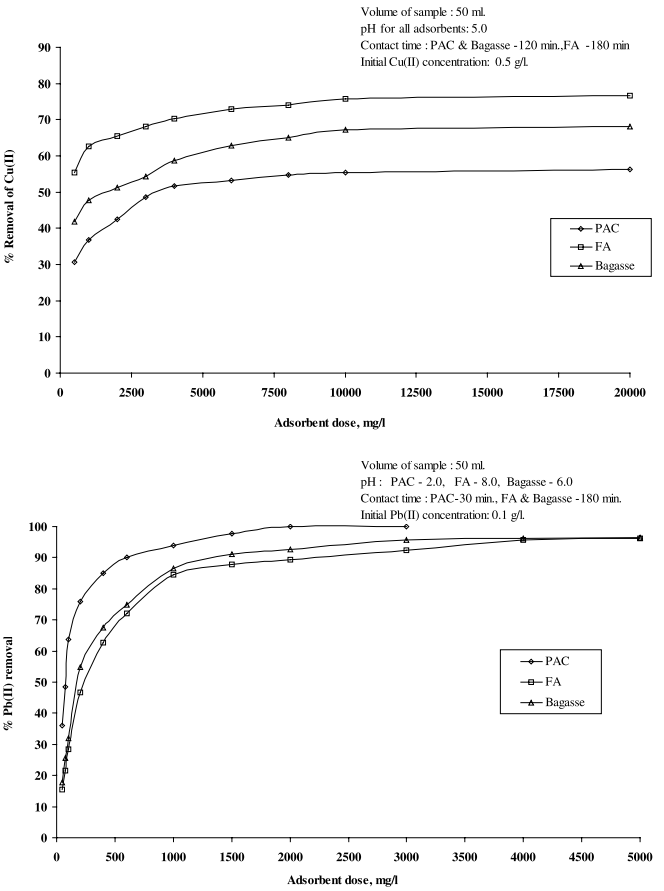


**Figure 3** | (a) Effect of adsorbent dose on the removal of Cu(II). (b) Effect of adsorbent dose on the removal of Pb(II).

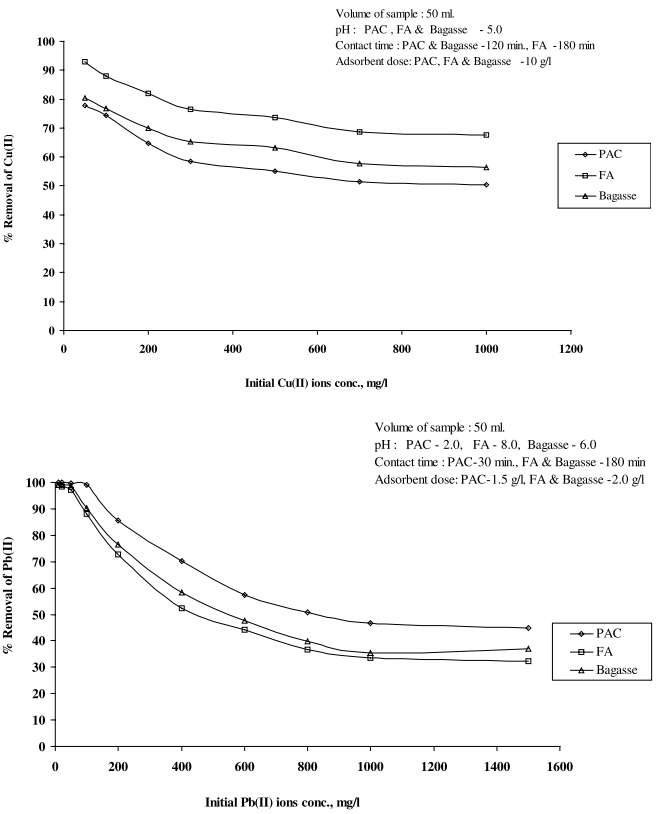


**Figure 4** | (a) Effect of initial concentration of Cu(II). (b) Effect of initial concentration of Pb(II).

showed that among the adsorbents used, FA was efficient for maximum removal of $Cu^{2+}$ ions at all the levels of adsorbent dose followed by bagasse and PAC. PAC showed the maximum uptake of $Pb^{2+}$ ions followed by bagasse and FA. About 74.1% removal of $Cu^{2+}$ ions at 0.4 g $l^{-1}$ of FA, followed by 67.3% and 55.4% with bagasse and PAC respectively, was observed at a room temperature of 32 ± 0.5°C. Similarly, for $Pb^{2+}$ ions (Figure 3b), a significant increase in uptake was observed when the PAC dose increased from 0.05 to 1.5 g $l^{-1}$, and 0.05 to 2.0 g $l^{-1}$ in the case of bagasse. Further addition of adsorbent dose did not cause any significant change. Considering this, in all the subsequent kinetic studies, the amount of adsorbents taken was 10 g $l^{-1}$ of PAC, FA and bagasse for Cu (II) ions removal, whereas for $Pb^{2+}$ ions removal, the adsorbent dose was 1.5 g $l^{-1}$ of PAC and 2.0 g $l^{-1}$ of FA & bagasse. The total capacities of PAC, bagasse and FA for $Pb^{2+}$ ions were found to be 26.2, 7.7 and 5.7 mg $g^{-1}$ respectively, based on the linearized Freundlich isotherm for the removal of Pb(II) ions (Table 3).

## Effect of initial adsorbate concentration

For a strictly adsorptive reaction, in the optimized period of contact, the rate varies directly with the concentration of adsorbate. The capacities of the adsorbent materials get exhausted sharply with an increase in initial metal ions concentration as is evident from Figure 4a and b. The adsorption capacities of PAC, FA and bagasse were systematically studied by varying the initial concentration of copper and lead ions from 0.05 to 1.0 g $l^{-1}$, and 0.05 to 1.5 g $l^{-1}$ respectively. The percentage removals of Cu(II)

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and Pb(II) as a function of initial concentration at different initial pH values are presented in Figure 4a and b. Fly-ash was fairly active in reducing $Cu^{2+}$ ions from 92.9% to 67.5% when the initial concentration of $Cu^{2+}$ ions was increased from 0.05 to 1.0 g $l^{-1}$ with a constant sorbent dose of 10 g $l^{-1}$ at a pH of 5.0. In the case of PAC and bagasse, $Cu^{2+}$ ions removal was found to be 77.8% and 80.5% at an initial Cu(II) concentration of 0.05 g $l^{-1}$ and 50.4% and 56.5% at 1.0 g $l^{-1}$ respectively. For all the three sorbents, the percentage removal was obtained at an optimised pH of 5.0 and a sorbent dose of 10 g $l^{-1}$.

PAC, bagasse and FA removed $Pb^{2+}$ ions by 100%, 99% and 99% at an initial Pb(II) concentration of 0.05 g $l^{-1}$, and the removal was reduced to 46.5%, 35.5% and 33.6% respectively at 1.0 g $l^{-1}$. It is evident from the data that at higher metal ion concentrations all three adsorbent materials are more efficient in the removal of $Cu^{2+}$ ions than in $Pb^{2+}$ ions removal.

**Table 1** | Particle size analysis of adsorbents

| Particle size (mm) | Percentage weight of adsorbents | | |
|---|---|---|---|
| | PAC | FA | Bagasse |
| 4.75 | — | — | 50 |
| 2.8 | — | — | 1.56 |
| 1.18 | — | — | 3.91 |
| 0.6 | — | — | 28.1 |
| 0.3 | — | — | 13.28 |
| 0.15 | 75 | 2 | 1.59 |
| 0.075 | 20 | 48 | 1.56 |
| 0.05 | 5 | 50 | — |

## Effect of adsorbent particle size

Experiments were conducted to evaluate the influence of adsorbent particle size for a constant weight on the removal of $Cu^{2+}$ and $Pb^{2+}$ ions. Particle size analysis was conducted on PAC, FA and bagasse and the percentage composition of particle size is presented in Table 1. The results obtained with the variation of adsorbent particle size and the percentage removal of $Cu^{2+}$ and $Pb^{2+}$ ions are graphically represented in Figure 5a and b. The uptake of Cu(II) and Pb(II) at different adsorbent particle size increased with the decrease in sorbent particle diameter. The presence of larger number of smaller particles provides the sorption system with a larger surface area available for $Cu^{2+}$ and $Pb^{2+}$ ions removal and it also reduces the external mass transfer resistance. Also the time required for 50% of the total adsorption is less with the particles of smaller size (Gupta *et al*. 1997b). This relationship clearly demonstrates the advantage of powdered adsorbent material over the granular particles from a kinetic viewpoint, indicating that the external transport limits the rate of adsorption in these cases. This also gives some idea of the rate limiting step of the adsorption process. The removal of $Cu^{2+}$ and $Pb^{2+}$ ions has been studied at a room temperature of 32 ± 0.5°C.

With the largest particle size of 150 μ, the amount of Cu(II) adsorbed was found to be 52.1% and 70.5% respectively with PAC and FA, and 66.5% and 82.5% with the smallest particle size of 75 μ for an initial Cu(II) concentration of 0.1 g $l^{-1}$. The removal with bagasse increased from 53.2% to 70.3% with the variation of sorbent particle size from 4.75 mm to 75 μ. For the smallest particles of PAC, FA and bagasse, $Pb^{2+}$ ions removal was found to be 62.8%, 52.7% and 50.6% respectively, and with the coarser particle size of PAC (150 μ), FA (150 μ) and bagasse (4.75 mm), the uptake of $Pb^{2+}$ ions was 61.2%, 40.8% and 28.6% respectively.

## Sorption mechanism

The sorption data for the removal of $Cu^{2+}$ and $Pb^{2+}$ ions have been correlated with the Freundlich and Langmuir models, and the estimated values of the Freundlich and Langmuir parameters for the sorption of $Cu^{2+}$ and $Pb^{2+}$ ions are presented in Tables 2 and 3. The Langmuir equation (Eq. 1) and Freundlich equation (Eq. 3) have the general form of:

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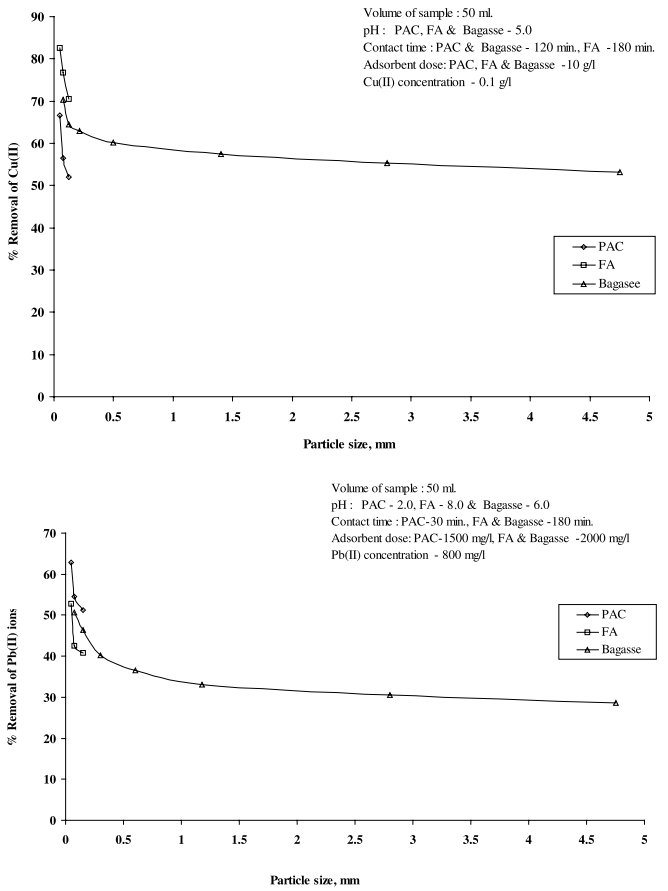


**Figure 5** | (a) Effect of particle size on the removal of Cu(II) ions. (b) Effect of particle size on the removal of Pb(II) ions.

$$q_e = \frac{Q^o b C_e}{1 + b C_e} \qquad \text{Langmuir equation} \quad (1)$$

$$\text{or, } m/x = 1/Q^o + 1/(Q^o b C_e) \qquad (2)$$

where $m$ is the weight of adsorbent (g) and $x$ is the amount of metal ions adsorbed (mg).

$$q_e = K_f C^{1/n} \qquad \text{Freundlich equation} \quad (3)$$

The linearized Freundlich adsorption isotherm is of the form:

$$\log(q_e) = \log K_f + 1/n \log C_e \qquad (4)$$

where $q_e$ is the amount of metal ions adsorbed per unit weight of adsorbents (mg $g^{-1}$). $K_f$ and 1/n are the Freundlich constants related to sorption capacity and sorption intensity respectively. $C_e$ is the equilibrium concentration (mg $l^{-1}$) and $Q^o$ the solid phase concentration corresponding to complete coverage of adsorption sites (Gupta *et al.* 1998). b is a Langmuir constant, which indicates the nature of adsorption and indicates the shape of the isotherm accordingly. Linear plots of $1/q_e$ vs $1/C_e$ and $\log(q_e)$ vs $\log(C_e)$ at different adsorbent doses are applied to confirm the applicability of the Langmuir and Freundlich models. The coefficient of correlation ($C_c$) values presented in Tables 2 and 3 indicate the applicability of the Freundlich model using PAC, FA and bagasse for the removal of Cu(II) ions, and both the Langmuir and Freundlich models for the removal of Pb(II) ions. The linearised rearranged Freundlich model for the removal of Cu(II) and Pb(II) ions is shown in Figure 6a and b. The isotherm constants derived from the linearised Freundlich and Langmuir models are presented in Tables 2 and 3 for the removal of Cu(II) and Pb(II) ions. The essential characteristics of a Langmuir isotherm can be expressed in terms of a dimensionless separation factor, $r$ (Weber & Chakraborti 1974) which describes the type of isotherm and is defined by:

$$r = 1/(1 + bC_o) \qquad (5)$$

where $C_o$ is the initial concentration of Cu (II) and Pb(II) ions. The dimensionless separation factor ($r$) values were found to be 0.1741, 0.596 and 0.8405 for PAC, FA and bagasse respectively for the removal of Pb(II) ions and indicates highly favorable sorption($r \ll 1$) and also the applicability of the Langmuir isotherm.

## Bhattacharya and Venkobachar model

The two important physico-chemical aspects for parameter evaluation of the sorption process as a unit operation are kinetics and the equilibria of sorption. Kinetics of sorption, describing the solute uptake rate, which in turn governs the residence time of the sorption

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**Table 2** | Values of Langmuir and Freundlich isotherm constants for sorption of copper(II) ions on different adsorbents

| | Langmuir constants | Freundlich constants | | | |
|---|---|---|---|---|---|
| **Adsorbent** | $C_c$ | $K_f$ | Slope 1/n | $C_c$ | Recommended isotherm, $q_e$ |
| PAC | 0.5750 | 2.4E-12 | 5.5666 | 0.9148 | $= 2.40E\text{-}12C_e^{5.566}$ |
| Fly-ash | 0.7557 | 2.23E-09 | 4.8722 | 0.9779 | $= 2.23E\text{-}09C_e^{4.8722}$ |
| Bagasse | 0.7688 | 2.75E-09 | 4.5072 | 0.9559 | $= 2.75E\text{-}09C_e^{4.5072}$ |

**Table 3** | Values of Langmuir and Freundlich isotherm constants for sorption of lead(II) ions on different adsorbents

| | Langmuir constants | | | | Freundlich constants | | | |
|---|---|---|---|---|---|---|---|---|
| **Adsorbent** | $Q^o$ mg/g | b l/mg | Separation factor, $r$ | $C_c$ | $K_f$ | Slope 1/n | $C_c$ | Recommended isotherm, $q_e$ |
| PAC | 584.4 | 0.0474 | 0.1741 | 0.9136 | 26.2 | 0.8166 | 0.9695 | $= 0.02619C_e^{0.8166}$ |
| Fly ash | 753.6 | 0.00067 | 0.596 | 0.9822 | 5.7 | 0.9157 | 0.9922 | $= 0.00567C_e^{0.9157}$ |
| Bagasse | 3294.9 | 0.00189 | 0.8405 | 0.9771 | 7.7 | 0.8897 | 0.9896 | $= 0.00772C_e^{0.8897}$ |

reaction, is one of the important characteristics defining the efficiency of sorption.

Hence, in the present investigation, a study of the kinetics of copper(II) and lead(II) ions removal has been carried out to understand the behaviour of PAC and the other two low-cost adsorbent materials. Uptake of $Cu^{2+}$ and $Pb^{2+}$ ions onto PAC, bagasse and FA as a function of time is presented in Figure 2a and b. The removal of metal ions is very rapid initially and decreased markedly before approaching gradually to equilibrium. The rate constant (k) was determined using the following Bhattacharya and Venkobachar equation (Bhattacharya & Venkobachar 1984):

$$\ln[1 - U(t)] = -k^1 t \quad (6)$$

and $U(t) = (C_o - C_t)/(C_o - C_e)$

Where $C_o$, $C_t$ and $C_e$ are the concentrations (mg $l^{-1}$) of the adsorbate initially, at any time $t$ and at the equilibrium respectively. The straight-line plot of $\ln[1 - U(t)]$ versus $t$ indicates the application of the Bhattacharya and Venkobachar equation and shows that the process follows first order kinetics (Figure 7a and b). The overall rate constants ($k^1$), which were calculated from the slopes of the straight lines obtained for each adsorbent and metal ion, are presented in Table 4.

## COST ESTIMATION

In India the cheapest variety of commercially available carbon costs Rs 11,000 $ton^{-1}$. Fly-ash is available at Rs 60 $ton^{-1}$ including the transportation cost, and the bagasse at Rs 1,000 $ton^{-1}$. Considering the total expenses for transport, chemicals required for removal of lignin from bagasse, etc., the finished bagasse product would cost approximately Rs 1,500 $ton^{-1}$. Recovery of metal ions before the disposal of wastewater may bring down the cost factor further.

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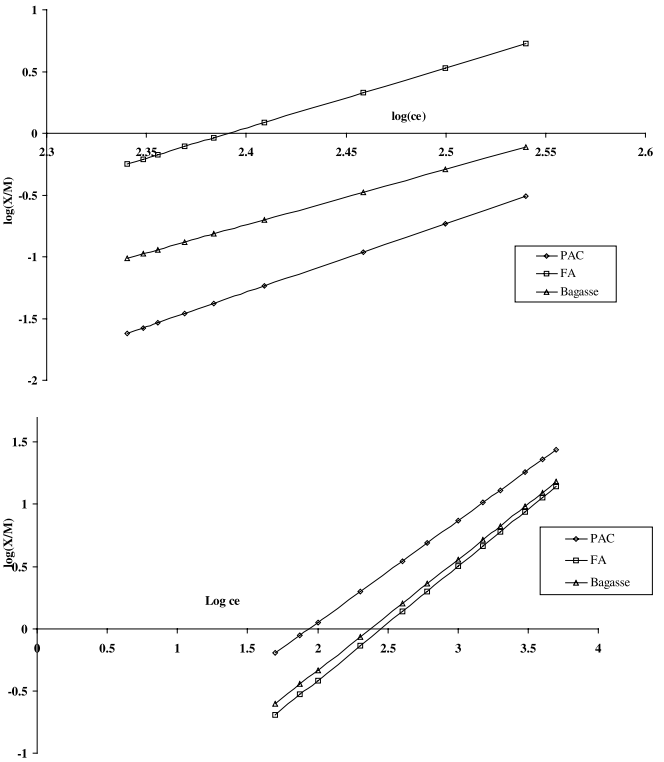


**Figure 6** | (a) Linearised Freundlich isotherm for the removal of Cu(II). (b) Linearised rearranged Freundlich isotherm for Pb(II) removal.

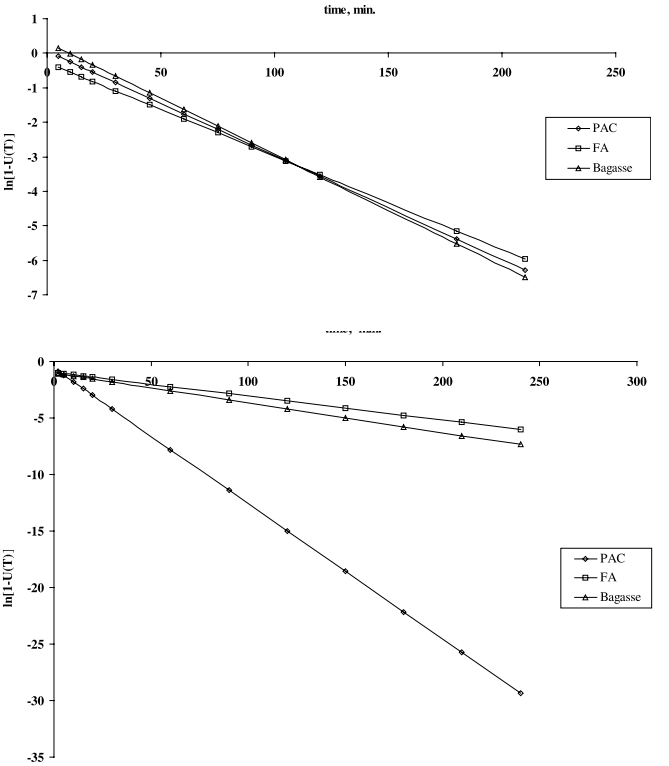


**Figure 7** | (a) Linearised rearranged Bhattacharya & Venkobachar plot for the removal of Cu(II). (b) Linearised rearranged Bhattacharya & Venkobachar plot for the removal of Pb(II).

## CONCLUSIONS

Fly-ash collected from the thermal power station and bagasse from the sugar industry are effective adsorbents as compared to costlier conventional powdered activated carbon for the removal of Cu(II) and Pb(II) from aqueous solution. Results showed that these low-cost adsorbents can be fruitfully used for the removal of Cu(II) and Pb(II) in a wide range of concentrations. Moreover bagasse and fly-ash were observed to be working efficiently in the uptake of both the metal ions between pH 5.0 and 8.0, which is preferable to the PAC at a low pH of 2.0. Further investigations are suggesting the use of FA and bagasse instead of the use of costlier PAC for the removal of Cu(II) and Pb(II) from industrial wastewater. Recovery and regeneration of PAC is difficult, whereas the exhausted bagasse could be recovered easily and disposed of safely by burning after drying. Bagasse and fly-ash are waste products and require a small cost for transportation and pretreatment. The authors are suggesting that there is no need to regenerate exhausted bagasse and fly-ash, because they are easily, cheaply and locally available.

**Table 4** | Overall rate constants for the removal of Cu(II) and Pb(II)

| | Overall rate constant | |
|---|---|---|
| **Adsorbent** | **Cu(II)** | **Pb(II)** |
| PAC | 0.0302 | 0.1197 |
| FA | 0.0271 | 0.021 |
| Bagasse | 0.0324 | 0.0264 |

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