



International Journal of Engineering Research and Science & Technology

ISSN : 2319-5991
Vol. 2, No. 2
May 2013



www.ijerst.com

Email: editorijerst@gmail.com or editor@ijerst.com

Research Paper

ADSORPTION OF LEAD AND ZINC FROM AQUEOUS SOLUTION USING *TERMINILIA CATAPPA* L. AS ADSORBENT

L Nageswara Rao¹

*Corresponding Author: **L Nageswara Rao**, ✉ lnrao1978@gmail.com

The capacity of *Terminilia Catappa* L. for lead and zinc removal from aqueous solutions was investigated. The Langmuir, Freundlich, Redlich-Peterson and Temkin adsorption models, were used to represent the experimental data and equilibrium data. It is fitted well with the Langmuir, Temkin isotherms for lead and Langmuir and Freundlich Isotherms for Zinc. The parameters studied are contact time, initial metal concentration, dosage, particle size and pH of the solution. The percentage of removal increases with the increase in pH from 2 to 6 and reaches the maximum when the pH is 6. The contact time is to be 20 min and 10 min for lead and zinc respectively. The lead and zinc sorption process onto *Terminilia Catappa* L. particles tend to follow second order kinetics.

Keywords: Biosorption, *Terminilia Catappa* L., Adsorption isotherms, Kinetic studies

INTRODUCTION

The removal of toxic metal ions and recovery of valuable ions from mine wastewaters, soils and waters have been important in the study of economic and environmental problems (Kadaverlu *et al.*, 2001; Sandau *et al.*, 1996; Dabrowski, 2000; Hsieh and Teng, 2000). Heavy metals and other metal ions exist as contaminants in aqueous waste streams of many industries, such as tanneries and mining. Some metals associated with these activities are Pb, Hg, Cr and Cd. Some of these metals are

accumulated in living organisms and produce diseases and disorders.

Heavy metals such as lead, mercury, arsenic, copper, zinc and cadmium are highly toxic when adsorbed into the body (Ho *et al.*, 2002). They can cause accumulative poisoning, cancer, brain damage, etc. Lead is a general metabolic poison and enzyme inhibitor. It can cause mental retardation and semi permanent brain damage in young children (Mathialagon and Viraraghavan, 2002). Lead has the ability to replace calcium in the bone to form sites for long-term release. Toxic

¹ Department of Chemical Engineering, RVR & JC College of Engineering, Guntur, AP, India 522019.

metals are released into the environment in a number of ways. Coal combustion, sewage wastewaters, automobile emissions, battery industry, mining activities, and the utilization of fossil fuels are just a few examples (Demirbas, 2004). Among the various water-treatment techniques described, adsorption is generally preferred for the removal of heavy metal ions due to its high efficiency, easy handling, availability of different adsorbents and cost effectiveness (Bailey *et al.*, 1999; Buffle *et al.*, 1990; Nederlof *et al.*, 1990).

The potentialities of *Terminilia Catappa* L as a sorbent material for metal ions removal from waste waters has been the focus of our research. The purpose of this study was to investigate the sorption of lead and zinc onto *Terminilia Catappa* L particles. Experiments were done in a batch system and the metal ions sorption was investigated with respect to contact time, initial pH, initial metal ion concentration, adsorbent dosage and size. The adsorption equilibrium was modeled using the Langmuir, Freundlich, Temkin and Redlich-peterson isotherm models. The kinetic experimental data were correlated by first and second order kinetics models.

MATERIALS AND METHODS

Preparation of Biosorbent

The *Terminilia Catappa* L. leaves were collected from RVR and JC College of Engineering Campus of Guntur, Andhra Pradesh, India. The leaves were washed with distilled water several times to remove dirt. Then the dried leaves were powdered in a grinder to the powder size of 75-212 μm and used as a biosorbent without any pretreatment for lead and zinc adsorption.

Chemical

Analytical grades of $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$, $\text{Pb}(\text{NO}_3)_2$, HCl

and NaOH were purchased from Merck (Mumbai, Maharashtra, India). Lead and zinc ions were prepared by dissolving its corresponding salts in distilled water. The pH of solutions was adjusted with 0.1 N HCl and NaOH. All the experiments were repeated five times and the average values have been recorded. Blank experiments were also conducted to ensure that no adsorption was taking place on the walls of the apparatus used.

Biosorption Experiments

Biosorption experiments were performed at room temperature ($30 \pm 1^\circ\text{C}$) in a rotary shaker at 180 rpm containing 30 mL of different lead and zinc concentrations using 250 mL Erlenmeyer flasks. After 1 h of contact (according to the preliminary sorption dynamics tests), with 0.1 g *Terminilia Catappa* L. leaves the biomass, equilibrium was reached and the reaction mixture was centrifuged for 5 min. The metal content in the supernatant was determined using Atomic Absorption Spectrophotometer (GBC Avanta Ver 1.32, Australia) after filtering the adsorbent with 0.45 μm filter paper. The amount of metal adsorbed by *Terminilia Catappa* L. leaves was calculated from the differences between metal quantity added to the biomass and metal content of the supernatant using the following equation:

$$q = (C_0 - C_f) \frac{V}{M} \quad \dots(1)$$

where q is the metal uptake (mg/g); C_0 and C_f are the respective initial and final metal concentrations in the solution (mg/L); V the solution volume (mL) and M the mass of biosorbent (g). The pH of the solution was adjusted by using 0.1 N HCl and 0.1 N NaOH.

The Langmuir (1916) sorption model was chosen for the estimation of maximum ions sorption by the biosorbent. The Langmuir isotherm can be expressed as

$$q = \frac{Q_{max} b C_{eq}}{1 + b C_{eq}} \quad \dots(2)$$

where Q_{max} indicates the monolayer adsorption capacity of adsorbent (mg/g) and the Langmuir constant b (L/mg) is related to the energy of adsorption. For fitting the experimental data, the Langmuir model was linearized as

$$\frac{1}{q} = \frac{1}{Q_{max}} + \frac{1}{b Q_{max} C_{eq}} \quad \dots(3)$$

The Freundlich (1906) model is represented by the equation:

$$q = K C_{eq}^{\frac{1}{n}} \quad \dots(4)$$

where K (mg/g) is the Freundlich constant related to adsorption capacity of adsorbent and $1/n$ is the Freundlich exponent related to adsorption intensity (dimensionless). For fitting the experimental data, the Freundlich model was liberalized as follows:

$$\ln q = \ln K + \frac{1}{n} \ln C_{eq} \quad \dots(5)$$

The Temkin (Aharoni and Ungarish, 1977) isotherm has generally been applied in the following form:

$$q = \frac{RT}{b_T} \ln(A_T C_{eq}) \quad \dots(6)$$

where A_T (L/mg) and b_T are Temkin isotherm constants.

The Redlich-Peterson Jossens *et al.* (1978) modified the three parameter isotherm proposed by Redlich and Peterson (1959) to incorporate features of both the Langmuir and Freundlich equations. It can be described as follows:

$$q_e = \frac{A C_e}{1 + B C_e^g} \quad \dots(7)$$

Applying the natural logarithm of both sides,

$$\ln \left(A \frac{C_{eq}}{q_{eq}} - 1 \right) = g \ln(C_{eq}) + \ln(B) \quad \dots(8)$$

Although a linear analysis is not possible for a three parameter isotherm, three isotherm constants, A, B and g, can be evaluated from the pseudo-linear plot represented by Equation (13) using a trail and error optimization method. A general trail and error procedure which is applicable to computer operations was developed to determine the coefficient of determination, r^2 for a series of values of A for the linear regression of $\ln(C_{eq})$ on $\ln[A(C_{eq}/q_{eq}) - 1]$ and to obtain the best value of A which yields a maximum “optimized” value for r^2 .

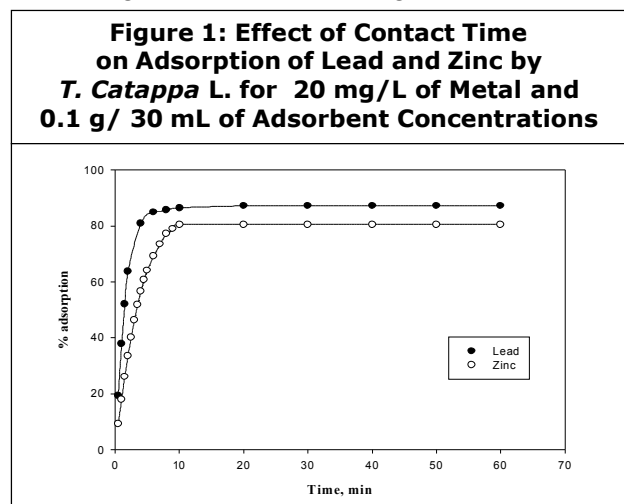
Biosorption Kinetics

The kinetic studies were carried out by conducting batch biosorption experiments with different initial lead and zinc concentrations. Samples were taken at different time periods and analyzed for their ion concentrations.

RESULTS AND DISCUSSION

Effect of Contact Time

The adsorption of lead and zinc from a solution of 20 mg/L are shown in Figure 1. The data



obtained from the biosorption of lead and zinc ions on the *Terminilia Catappa* L. showed that a contact time of 20 min for lead and 10 min for zinc was required to achieve an optimum adsorption and there was no significant change in concentration of the metal ion with further increase in contact time. Therefore, the uptake and unadsorbed lead, zinc concentrations at the end of 20 and 10 min are given as the equilibrium values, q_{eq} (mg/g) and C_{eq} (mg/L). For further studies of biosorption with other variable parameters, with this *Terminilia Catappa* L. as biosorbent, the optimum time of 20 and 10 min has been chosen for contact period.

Effect of Initial Metal Ion Concentration

Experiments were undertaken to study the effect of the initial metal ion concentration on the lead and zinc removal kinetics from the solution. The results obtained are shown in Figure 2. The obtained curves show that the metal uptake increases with increase in initial concentration of metal ion while the percentage biosorption of lead and zinc decreases with an increase in initial metal ion concentration. The increase of metal uptake is a result of the increase in the driving force, i.e., concentration gradient, with an increase in the

initial lead and zinc ion concentrations (from 20 to 100 mg/L). However, the percentage biosorption of lead and zinc ions on *Terminilia Catappa* L. was decreased from 87.18 to 72.57% and 80.51 to 67.86%. Though an increase in metal uptake was observed, the decrease in percentage biosorption may be attributed to lack of sufficient surface area to accommodate much more metal available in the solution. The percentage biosorption at higher concentration levels shows a decreasing trend whereas the equilibrium uptake of lead and zinc displays an opposite trend. At lower concentrations, all lead and zinc ions present in the solution could interact with the binding sites and thus the percentage biosorption was higher than those at higher initial lead and zinc ion concentrations. At higher concentrations, the lower biosorption yield is due to the saturation of biosorption sites. As a result, diluting the wastewaters containing high metal ion concentrations can increase the purification yield.

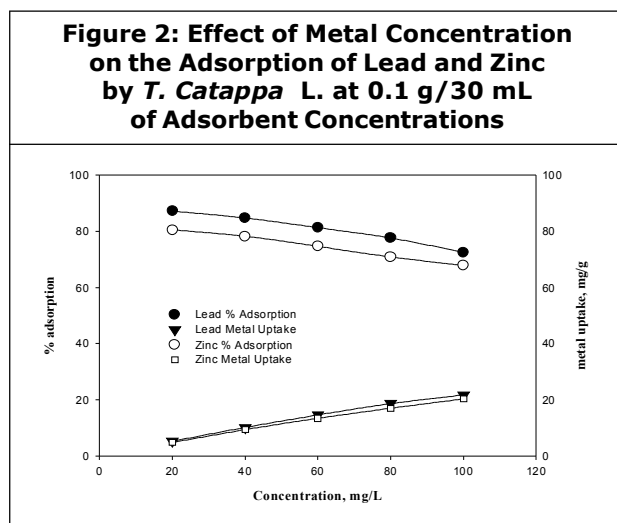
$$\% \text{ Adsorption} = \frac{(C_i - C_f)}{C_i} \times 100 \quad \dots(1)$$

The metal uptake was calculated by the simple concentration difference method. The initial concentration C_i (mg/L) and final metal concentration C_f (mg/L) at any time were determined and the metal uptake q_{eq} (mg metal adsorbed /g adsorbent) was calculated from the mass balance as follows:

$$q_{eq} = \frac{V(C_i - C_{eq})}{1000w} \quad \dots(2)$$

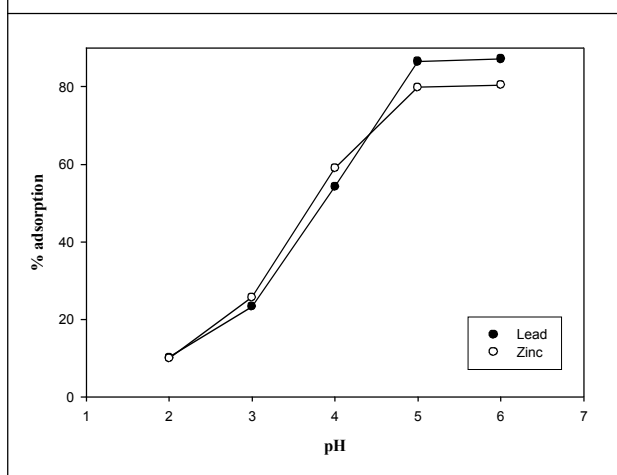
Effect of pH

It is well known that the pH of the medium affects the solubility of metal ions and the concentration of the counter ions, on the functional groups of



the biomass cell walls. Thus pH is an important parameter on biosorption of metal ions from aqueous solutions (Gong *et al.*, 2005; Abu Al-rub *et al.*, 2004; Sheng *et al.*, 2004; Ozdemir *et al.*, 2004; Iyer *et al.*, 2004). *Terminilia Catappa* L. presents a high content of ionizable groups (carboxyl groups) on the cell wall polysaccharides, which makes it very liable to the influence of the pH. As shown in Figure 3, the uptake of free ionic lead and zinc depends on pH. The biosorption of metallic ion was observed to increase, with the increase in pH up to a value of 6. At pH values lower than 3.0, lead and zinc removal was inhibited, possibly as a result of the competition between hydrogen and metal ions on the sorption sites, with an apparent preponderance of hydrogen ions, which restricts the approach of metal cations as in consequence of the repulsive force. As the pH increased, the ligands such as carboxylate groups in *Terminilia Catappa* L. would be exposed, increasing the negative charge density on the biomass surface, increasing the attraction of metallic ions with positive charge and allowing the biosorption onto the cell surface.

Figure 3: Effect of pH on Adsorption of Lead and Zinc by *T. Catappa* L. for 20 mg/L of Metal and 0.1 g/30 mL of Adsorbent Concentrations

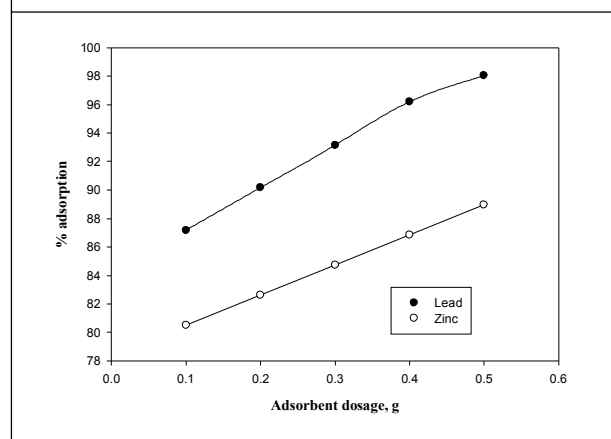


Similar results were also reported in the literature for different biomass systems (Sag *et al.*, 1998; Zhou *et al.*, 1998; Matheickal and Yu, 1999).

Effect of Biosorbent Dosage

For studying the effect of biosorbent dosage on removal of lead and zinc ions, the biosorbent dosage is changed from 0.1 to 0.5 g, fixing other parameters like initial concentration at 20 mg/L, pH 6 and particle size 75 mm. The contact time was 20 min for lead and 10 min for zinc as stated in the earlier article 4.1 in this chapter. The biosorption plot of Figure 4 shows an increase in % biosorption with an increase in biosorbent dosage. This is because of the availability of more binding sites for complexation of metal ions (Bhattacharyya and Sharma, 2004).

Figure 4: Effect of *T. Catappa* L. Dosage Adsorption of Lead and Zinc for 20 mg/L of Metal Concentrations



Effect of Biosorbent Particle Size

Fixing the initial concentration of solution at 20 mg/L, pH 6, the fixed volume of 30 mL solution is allowed for 20 min for lead and 10 min for zinc biosorption with 0.1 g each of the varied size of particles of biosorbent ranging from 75 to 212 mm, the plot (Figure 5) drawn for the variation of the percentage biosorption against particle size, shows that with increase in particle size the

Figure 5: Effect of *T. Catappa* L. Particle Size on Adsorption of Lead and Zinc for 20 mg/L of Metal and 0.1 g/30 mL of Adsorbent Concentrations

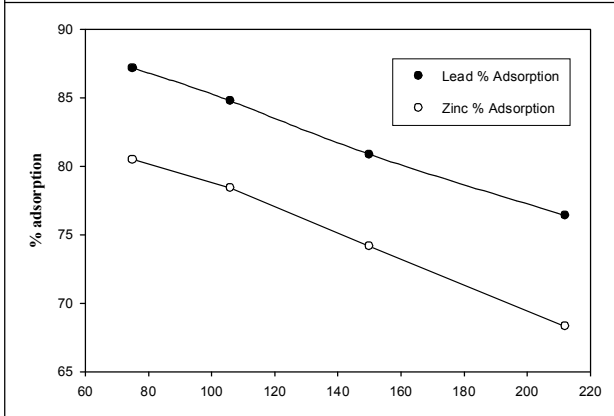
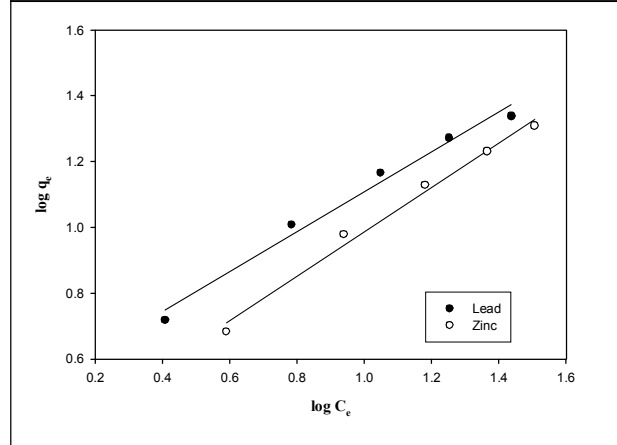


Figure 7: Freundlich Isotherm for Lead and Zinc at 0.1 g/ 30 mL of Adsorbent Concentrations



biosorption decreases. This is due to less surface area available with increased particle size, thus reducing the biosorption.

BIOSORPTION EQUILIBRIUM

The equilibrium biosorption of lead and zinc on the *Terminilia Catappa* L. as a function of the initial concentrations is shown in Figures 6 to 9. There was a gradual increase of adsorption for ions until equilibrium was attained. The Langmuir, Freundlich, Temkin and Redlich-peterson models

Figure 6: Langmuir Isotherm for Lead and Zinc at 0.1 g/30 mL of Adsorbent Concentrations

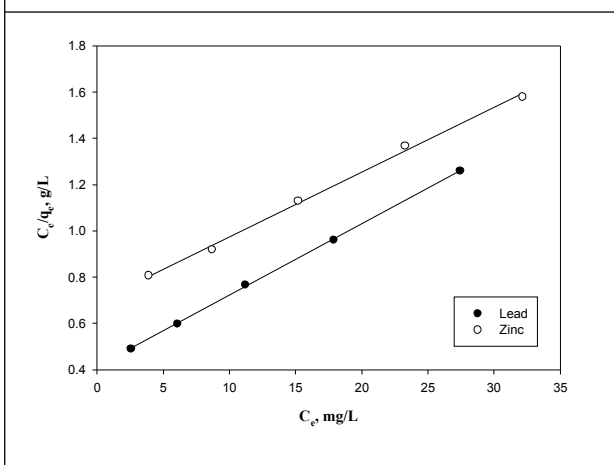


Figure 8: Redlich-Peterson Isotherm for Lead and Zinc at 0.1 g/30 mL of Adsorbent Concentrations

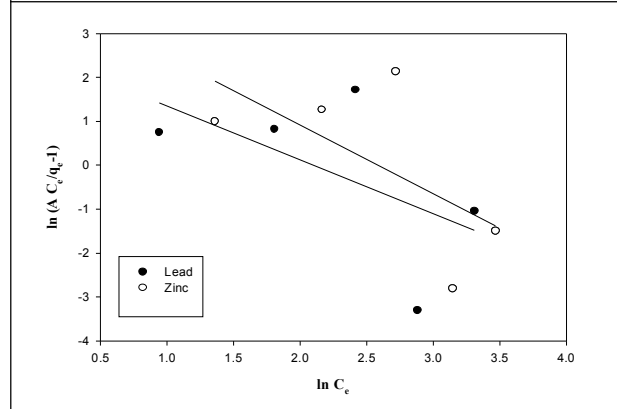
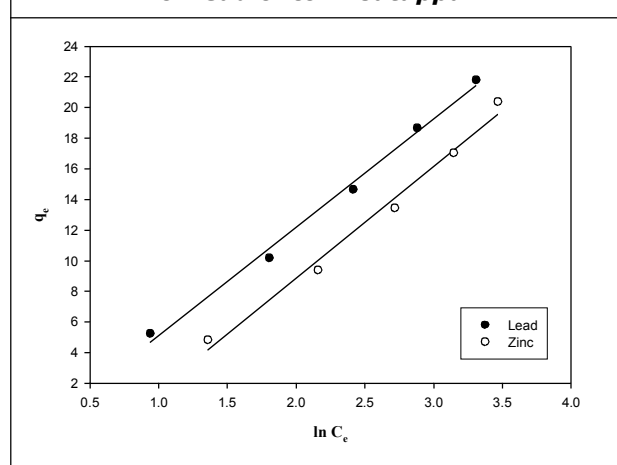


Figure 9: Equilibrium Curves for lead onto *T. Catappa* L



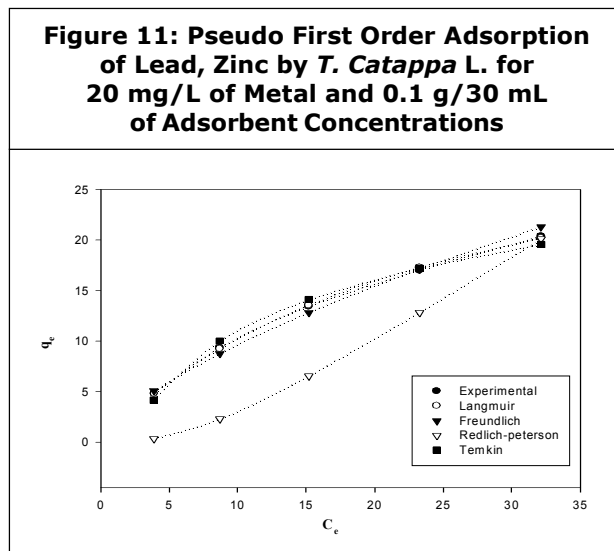
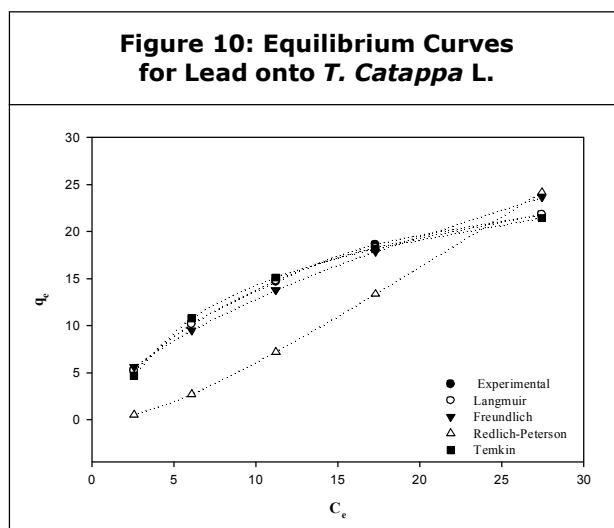
are often used to describe equilibrium sorption isotherms. The calculated results of the Langmuir, Freundlich, Temkin and Redlich-peterson isotherm constants are given in Table 1.

Table 1: Langmuir, Freundlich, Temkin and Redlich-Peterson Isotherm Constants and Correlation Coefficients		
Langmuir	Lead	Zinc
Q (mg/g)	32.187	34.956
b (L/mg)	0.0846	0.0481
R ²	0.9979	0.9982
Freundlich		
K _f (mg/g)	3.5852	2.0278
n(g/L)	0.687	0.679
R ²	0.9956	0.9967
Temkin		
A _T (L/mg)	1.4081	0.9967
b _T	362.37	259.67
R ²	0.9911	0.9899
Redlich-Peterson		
A (L/g)	1.0601	0.679
B(L/mg)	12.112	52.99
R ²	0.3168	0.3956

It is found that the adsorption of lead and zinc on the *Terminilia Catappa L.* was correlated well with the Langmuir, Temkin models and Langmuir, Freundlich models.

KINETICS OF ADSORPTION

The prediction of adsorption rate gives important information for designing batch adsorption systems. Information on the kinetics of solute uptake is required for selecting optimum operating conditions for full-scale batch process. Figures 10 and 11 shows the plot between metal uptake, q (mg/g) versus time, t (min) for initial solute



concentration of 20 mg/L for different isotherms compared with experimental values of q (mg/g). From the figure, it was observed that q value increased with increase in contact time. The kinetics of the adsorption data was analyzed using two kinetic models-pseudo-first order and pseudo-second order. These models correlate solute uptake, which are important in predicting the reactor volume. These models are explained as follows:

Pseudo-First Order Model

The possibility of adsorption data following Lagergren and Kungliga (1898) pseudo-first order

kinetics is given by:

$$\frac{dq}{dt} = K_I (q_{eq} - q) \quad \dots(16)$$

Integrating Equation (16) with respect to integration conditions q=0 to q=q at t=0 to t=t, the kinetic rate expression becomes:

$$\log(q_{eq} - q) = \log q_{eq} - \frac{K_I}{2.303} t \quad \dots(17)$$

In order to obtain the rate constant, the straight-line plot (Figure 12) of log (q_{eq}-q) versus time was made for *Terminilia Catappa.L* for initial lead and zinc concentration, 20 mg/L. The intercept of the above plot should equal log q_{eq}. However, if q_{eq} from intercept does not equal the equilibrium lead and zinc metals uptake, then the reaction is not likely to be first order, even if this plot has a high correlation coefficient with the experimental data. Correlation coefficients were found to be 0.9633 for lead and 0.968 for zinc, but the calculated q_e is not equal to experimental q_{eq}, suggesting the insufficiency of Pseudo-first-order model to fit the kinetic data for the initial lead and zinc concentration examined.

Pseudo-Second Order Model

A pseudo-second order model proposed by Ho and McKay was used to explain the sorption kinetics (Ho and Mckay, 1998). This model is based on the assumption that the adsorption follows second order chemisorption. The pseudo-second order model can be expressed as

$$\frac{dq}{dt} = K_{II} (q_{eq} - q)^2 \quad \dots(18)$$

Separating the variables in Equation (18) gives:

$$\frac{dq}{(q_{eq} - q)^2} = K_{II} dt \quad \dots(19)$$

Integrating Equation (19) for the boundary conditions q=0 to q=q at t=0 to t=t, Eq. (19) simplifies to:

$$\frac{t}{q} = \frac{1}{K_{II} q_{eq}^2} + \frac{1}{q_{eq}} t \quad \dots(20)$$

where t is the contact time (min), q_{eq} (mg/g) and q (mg/g) are the amount of metal adsorbed at equilibrium and at any time, t. Correlation coefficients were found to be 0.999 for lead and 0.996 for zinc for the initial concentration of 20 mg/L. If second order kinetics is applicable, the plot (Figure 13) of t/q versus time of Equation (20) should give a linear relationship from which the

Figure 12: Pseudo First Order Adsorption of Lead, Zinc by *T. Catappa L.* for 20 mg/L of Metal and 0.1 g/30 mL of Adsorbent Concentrations

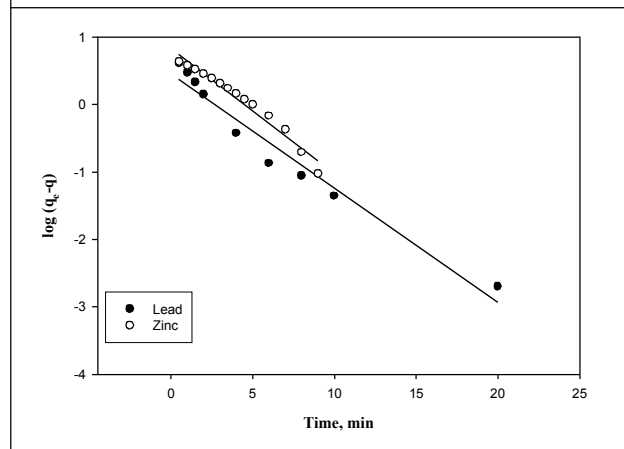
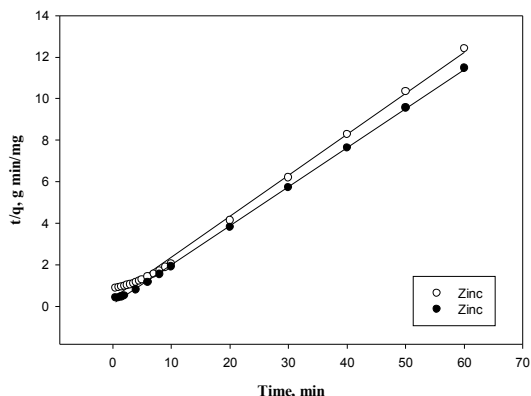


Table 2: Kinetic Constants for Lead and Zinc onto *T. Catappa L.*

Initial Concentration (mg/L)	Pseudo-First-Order			Pseudo-Second-Order		
	Rate constant k ₁ (min ⁻¹)	Amount of Zinc Adsorbed on Adsorbent, q _e (mg/g)	Correlation Coefficient R ₁ ²	Rate constant k ₁ (min ⁻¹)	Amount of Zinc Adsorbed on Adsorbent, q _e (mg/g)	Correlation Coefficient R ₂ ²
Lead(20)	0.3801	2.7661	0.9633	0.2398	5.3242	0.9994
Zinc(20)	0.4172	6.731	0.9681	0.0935	5.0128	0.9973

Figure 13: Pseudo Second Order Adsorption of Lead, Zinc by *T. Catappa* L. for 20 mg/L of Metal and 0.1 g/30 mL of Adsorbent Concentrations



constants q_{eq} and K_{II} can be determined. The rate constants and the correlation coefficients of both the metals and for both tested models have been calculated and summarized in Table 2.

CONCLUSION

The equilibrium uptake was increased and percentage biosorption was decreased by increasing the initial concentration. The plot of pH versus percentage biosorption shows that significant biosorption takes place at 6. The percentage biosorption of lead and zinc increases with increasing the biosorbent dosage. The

Table 3: Maximum Adsorption Capacities for Lead and Zinc Adsorption to Different Adsorbents

Adsorbent Material	Adsorption Capacity (mg/g)	pH	Reference
Na-Mont morillonite	3.61	5	(Abollino <i>et al.</i> , 2003)
Crushed concrete fines	33	5.5	(Coleman <i>et al.</i> , 2005)
Coir	8.6	5.5	(Kathrine and Hansen, 2006)
Barley straw	5.3	5.5	(Kathrine and Hansen, 2006)
Peat	11.71	5.5	(Kathrine and Hansen, 2006)
Coniferous bark	7.4	5.5	(Kathrine and Hansen, 2006)
Si/PE1/GA _{0.5}	32.79	5–6	(Ghoul <i>et al.</i> , 2003)
<i>Fontinalis antipyretica</i>	14.7	5.0	(Martins <i>et al.</i> , 2004)
<i>Aspergillus niger</i> 405	4.70	5.0	(Filipovic-kovacevic <i>et al.</i> , 2000)
<i>Penicillium digitatum</i>	9.7	5.5	(Galun <i>et al.</i> , 1987)
<i>Streptomyces noursei</i>	1.6	5.8	(Mattuschka and Straube, 1993)
<i>Mucor rouxii</i> (live)	4.89	5.0	(Yan and Viraraghavan, 2000)
<i>Mucor rouxii</i> (NaOH pretreated)	5.63	5.0	(Yan and Viraraghavan, 2000)
<i>Mucor rouxii</i> (Na ₂ CO ₃ pretreated)	3.26	5.0	(Yan and Viraraghavan, 2000)
<i>Mucor rouxii</i> (NaHCO ₃ pretreated)	6.28	5.0	(Yan and Viraraghavan, 2000)
<i>Pseudomonas syringae</i>	8.0	n.a	(Cabral, 1992)
<i>Rhizopus arrhizus</i>	13.5	6–7	(Fourest and Roux, 1992)
<i>Citrobacter strain</i> MCMB-181	23.62	6.5	(Puranik and Paknikar, 1999)
<i>Sargassum</i> sp.	24.35	4.5	(Esteves <i>et al.</i> , 2000)
Animal bones	11.55	5.0	(Banat <i>et al.</i> , 2000)
<i>Botrytis cinerea</i> biomass	12.98	5–6	(Tunali and Tamer, 2005)
<i>Terminilia Catappa.L</i>	32.49	6	(King <i>et al.</i> , 2007)
<i>Terminilia Catappa.L</i>	28.66	6	Present study

percentage biosorption of lead and zinc decreases by increasing the particle size of the biosorbent.

The Langmuir, Temkin models for lead and Longmuir and Freundlich models for zinc proved to be the best adjustment of the experimental data for *Terminilia Catappa* L. However, comparing the representative models of the biosorption between the biosorbents, a better adjustment of the equilibrium data was observed by the biosorbent *Terminilia Catappa* L. The results obtained in these studies open perspectives with relation to the utilization of *Terminilia Catappa* L., in the removal of lead and zinc ions, in the treatment of wastewater provided from industrial effluents.

The kinetics of the biosorption of lead and zinc on *Terminilia Catappa* L. can be better described with the use of second-order kinetics. Intra-particle diffusion might also have a significant role in the biosorption process slowing down the approach towards equilibrium.

REFERENCES

1. Abollino O, Aceto M, Malandrino M, Sarzanini C and Mentasti E (2003), "Adsorption of Heavy Metals On Na-montmorillonite. Effect of pH and Organic Substances", *Water Res.*, Vol. 37, pp. 1619-1627.
2. Abu Al-rub F A, El-naas M H, Benyahia F and Ashour I (2004), "Biosorption Of Nickel On Blank Alginate Beads, Free And Immobilized Algal Cells", *Process. Biochem.*, Vol. 39, pp. 1767-1773.
3. Aharoni C and Ungarish M (1977), "Kinetics Of Activated Chemisorption Part 2: The Oriental Models", *J. Chem. Soc. Faraday Trans.*, Vol. 73,, pp. 456-464.
4. Bailey S E, Olin J T, Bricka R M and Adrian D D (1999), "A Review Of Potentially Low-cost Sorbents For Heavy Metals", *Water Res*, Vol. 33, pp. 2469-79.
5. Banat F, Al-asheh S, Mohai F (2000), "Batch Zinc Removal From Aqueous Solution Using Dried Animal Bones", *Sep. Purif. Technol.*, Vol. 21, pp. 155-164.
6. Bhattacharyya K G and Sharma A (2004), "Adsorption Of Pb(ii) From Aqueous Solution By *Azadirachta Indica* (Neem) Leaf Powder", *J. Hazard. Mater.*, Vol. B113, pp. 97-109.
7. Buffle J, Altmann R S, Filella M and Tessier A (1990), "Complexation By Natural Heterogeneous Compounds – Site Occupation Distribution Functions, A Normalized Description Of Metal Complexation", *Geochim Cosmochim Acta.*, Vol. 54, pp. 1535-53.
8. Cabral J P S (1992), "Selective Binding Of Metal Ions To *Pseudomonas Syringae* Cells", *Microbios*, Vol. 71, pp. 47-53.
9. Coleman N J, Lee W E and Slipper I J (2005), "Interactions Of Aqueous Cu²⁺, Zn²⁺ And Pb²⁺ Ions With Crushed Concrete Fines", *J. Hazard. Mater.*, Vol. B121, pp. 203-213.
10. Dabrowski A (2000), "Adsorption – From Theory to Practice", *Adv Colloid Interface Sci.*, Vol. 93, pp. 135-224.
11. Demirbas A (2004), "Adsorption Of Lead And Cadmium Ions In Aqueous Solutions Onto Modified Lignin From Alkali Glycerol Delignification", *J. hazard Mater*, Vol. 109, pp. 221-6.
12. Esteves A J P, Valdman E and Leite S F (2000), "Repeated Removal of Cadmium

- And Zinc From An Industrial Effluent By Waste Biomass *Sargassum Sp.*”, *Biotechnol. Lett.* Vol. 22, pp. 499-502.
13. Filipovic-kovacevic Z, Sipos L and Briski F (2000), “Biosorption Of Chromium, Copper, Nickel And Zinc Ions Onto Fungal Pellets Of *Aspergillus Niger* 405 From Aqueous Solutions”, *Food Technol.*, Vol. 38, pp. 211-216.
 14. Fourest E and Roux J (1992), “Heavy Metal Biosorption By Fungal Mycelium Byproducts: Mechanisms and Influence of pH”, *Appl. Microbiol. Biotechnol.*, Vol. 37, pp. 399-403.
 15. Freundlich H M F (1906), “Over The Adsorption In Solution”, *J. Phys. Chem.*, Vol. 57, pp. 385-470.
 16. Galun M, Galun M, Siegel B Z, Keller P, Lehr H and Siegel S M (1987), “Removal Of Metal Ions From Aqueous Solutions By *Penicillium* Biomass: Kinetic And Uptake Parameters”, *Water Air Soil Pollut.*, Vol. 33, pp. 359–371.
 17. Ghoul M, Bacquet M and Morcellet M (2003), “Uptake Of Heavy Metals From Synthetic Aqueous Solutions Using Modified Pei-silica Gels”, *Water Res.*, Vol. 37, pp. 729-734.
 18. Gong R, Ding Y D, Liu H, Chen Q and Liu Z (2005), “Lead Biosorption By Intact And Pretreated *Spirulina Maxima* Biomass”, *Chemosphere*, Vol. 58, pp. 125-130.
 19. Ho Y S and McKay E (1998), “The Kinetics Of Sorption Of Basic Dyes From Aqueous Solution By *Sphagnum Moss Peat*”, *Can. J. Chem. Eng.*, Vol. 76, pp. 822–827.
 20. Ho Y S, Huang C T and Haung H W (2002), “Equilibrium Sorption Isotherm For Metal Ions On Tree Fern”, *Process Biochem*, Vol. 37, pp. 1421-30.
 21. Hsieh C T and Teng H (2000), “Influence of Mesopore Volume and Adsorbate Size on Adsorption Capacities of Activated Carbons in Aqueous Solutions”, *Carbon*, Vol. 38, pp. 863-9.
 22. Iyer A, Mody K and Jha B (2004), “Accumulation Of Hexavalent Chromium By An Exopolysaccharide Producing Marine *Enterobacter Cloaceae*”, *Mar. Pollut. Bull.*, Vol. 49, pp. 974-977.
 23. Kadaverlu K, Thamaraiselvi K and Namasivayam C (2001), “Removal of Heavy Metals From Industrial Wastewaters by Adsorption onto Activated Carbon Prepared From an Agricultural Solid Waste”, *Bioresour Technol.*, Vol. 76, pp. 63-5.
 24. Kathrine C and Hansen H C B (2006), “Sorption Of Zinc And Lead On Coir”, *Bioresour. Technol.*
 25. King P, Rakesh N, Beenalahari S, Prasanna Kumar Y and Prasad V S R K (2007), “Removal Of Lead From Aqueous Solution Using *Syzygium Cumini* L.: Equilibrium And Kinetic Studies”, *J. Hazard Mater.*, Vol. 142, pp. 340-347.
 26. Lagergren S, Kungliga S (1898), *Venska Ventenskapsakademiens SHandlingar, Band*, Vol. 24, No. 4, p. 1.
 27. Langmuir I (1916), “The Adsorption Gasses On Plane Surface Of Glass, Mica And Platinum”, *J. Am. Chem. Soc.*, Vol. 40, pp. 1361-1368.
 28. Martins R J E, Pardo R and Boaventura R A

- R (2004), "Cadmium(ii) And Zinc(ii) Adsorption By The Aquatic Moss *Fontinalis Antipyretica*: Effect Of Temperature, pH And Water Hardness", *Water Res.*, Vol. 38, pp. 693-699.
29. Matheickal J T and Yu Q (1999), "Biosorption Of Lead(ii) And Copper(ii) From Aqueous Solution By Pre-treated Biomass Of Australian Marine Algae", *Bioresour. Technol.*, Vol. 69, pp. 223-229.
30. Mathialagon T and Viraraghavan T (2002), "Adsorption Of Cadmium From Aqueous Solutions By Perlite", *J. Hazard Mater*, Vol. B94, pp. 247-91.
31. Mattuschka B and Straube G (1993), "Biosorption Of Metals By A Waste Biomass", *J. Chem. Technol. Biotechnol.*, Vol. 58, pp. 57-63.
32. Nederlof M M, Van Riemsdijk W H and Koopal L K (1990), "Determination Of Adsorption Affinity Distributions – A General Framework For Methods Related To Local Isotherm Approximations", *J Colloid Interface Sci.*, Vol. 135, pp. 410-26.
33. Ozdemir G, Ceyhan N, Ozturk T, Akirmak F and Cosar T (2004), "Biosorption Of Chromium(vi), Camium(ii) And Copper(ii) By *Pantoea* Sp. Tem 18", *Chem. Eng. J.*, Vol. 102, pp. 249-253.
34. Puranik P R and Paknikar K M (1999), "Biosorption of Lead, Cadmium And Zinc By *Citrobacter* Strain Mcmb-181: Characterization Studies", *Biotechnol. Prog.*, Vol. 15, pp. 228-237.
35. Sag Y, Kaya A and Kutsal T (1998), "The Simultaneous Biosorption of Cu(ii) And Zn(ii) On *Rhizopus Arrhizus*: Application of The Adsorption Models", *Hydrometallurgy*, Vol. 50, No. 3, pp. 297-314.
36. Sandau E, Sandau P and Pulz O (1996), "Heavy metal sorption by microalgae", *acta Biotechnol*, Vol. 16, pp. 227-35.
37. Sheng P X, Ting Y P, Chen J P and Hong L (2004), "Sorptions Of Lead, Copper, Cadmium, Zinc, And Nickel By Marine Algal Biomass: Characterization Of Biosorptive Capacity And Investigation Of Mechanisms", *J. Colloid Interface Sci.*, Vol. 275, pp. 131-141.
38. Tunali S and Tamer A (2005), "Zn (ii) Biosorption Properties of *Botrytis Cinereabiomass*", *J. Hazard. Mater.*
39. Yan G and Viraraghavan T (2000), "Effect Of Pretreatment On The Biosorption Of Heavy Metals On *Mucor Rouxii*", *Water Sa*, Vol. 26, pp. 119-123.
40. Zhou J I, Huang P I and Lin R G (1998), "Sorption And Desorption Of Cu And Cd²⁺ By Macroalgae And Microalgae", *Environ. Pollut.*, Vol. 101, No. 1, pp. 67-75.



International Journal of Engineering Research and Science & Technology
Hyderabad, INDIA. Ph: +91-09441351700, 09059645577
E-mail: editorijerst@gmail.com or editor@ijerst.com
Website: www.ijerst.com

