

# EQUILIBRIUM STUDIES ON THE REMOVAL OF ZINC(II) USING ACTIVATED CARBON

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**Abstract:** The most important role Zinc plays in metallurgical, electroplating and other chemical industries. About 30% of the Zinc produced is used in steel factories, Zinc batteries and in the production of some alloys. On the other hand, it may pollute aqueous streams, arising therefore several environmental problems. *Manilkara hexandra* was evaluated for ZnS(II) adsorption. The tests were performed in batch equilibration method. The adsorption followed second order reaction equation and the rate is mainly controlled by intra-particle diffusion. Freundlich and Langmuir isotherm models were applied to the equilibrium data. The adsorption capacity ( $Q_m$ ) obtained from the Langmuir isotherm plot at an initial pH of 6.0 and at 30, 40, 50, 60  $\pm$  0.5 °C. The influence of pH on metal ion removal was significant and the adsorption was increased with increase in temperature. A portion of the Zinc ion was recovered from the spent MHC using 0.1M HCl.

**Keywords:** Zn(II), *Manilkara hexandra* Carbon (MHC), Adsorption models, Equilibrium.

## 1. INTRODUCTION

Adsorption process offers the advantages of low operating costs, possibility of metal recovery, potential biosorbent regeneration, though research has been carried out for developing cost effective heavy metal removal techniques. The use of agricultural plant materials and their waste products viz., papaya wood<sup>[1999]</sup>, capsicum annum seeds<sup>[2012]</sup>, cork biomass<sup>[2004]</sup>, tea industry waste<sup>[1990]</sup>, grape stalk wastes<sup>[1992]</sup> have been widely increased in the recent past as these byproducts does not possess commercial value in agricultural sector. Previous work has shown that the fruit shell of *Pithecellobium dulce* has an excellent ability in removing metal ion such as Zn(II) from aqueous solutions <sup>[1981,2001]</sup>. The Zinc element is present in aqueous solutions mainly in the divalent states. Zinc is released into the environment by a large number of processes such as electroplating, polishing, batteries <sup>[1999]</sup> manufacturing, mining, metal finishing, paints, pigments, forging etc. Due to the toxic effects of Zinc, it is necessary to eliminate it from the contaminated effluents.

The aim of this work is to evaluate the viability of the acid pre-treated of *Manilkara hexandra* to remove of Zn(II) from aqueous solution. Equilibrium and kinetic experiments were performed. The Langmuir and Freundlich isotherm model was applied to experimental data. The pseudo-first, pseudo-second-and intra-particle diffusion models were used to fit the kinetic data.

## 2. MATERIALS AND METHODS

### 2.1. Adsorbent

The *Manilkara hexandra* was collected from nearby Cuddalore district. The stems were washed with distilled water several times to remove the dirt and dust and were subsequently dried in a hot air oven at 120°C. Afterward, carbonization of the *Manilkara hexandra* was carried out at 170°C for 1 hour in a muffle furnace. The primary carbon was obtained; the primary carbon was activated at 700°C for 5 hrs under optimized conditions to obtain activated carbon. The activated carbon was thereafter looked to room temperature in an insert atmosphere of nitrogen and washed with hot distilled water and 0.5 N hydrochloric and until the pH of the material reached 7.0 the activated carbon was also dried in a hot air oven at 110°C, ground and sieved to obtain the desired particular size (150 $\mu$ m) and stored in desiccators for further use.



Fig.1. *Manilkara hexandra*

## 2.2. Chemicals

All chemicals used of high purity commercially available Analar grade purchased from scientific equipment company Trichy. Zinc ions stock solution was prepared from calculated quantity of Zinc sulphate in 1000 ml distilled water equivalent to one gram/liter. All experimental solutions were prepared by diluting the stock solution to the required concentration. The pH of each experimental solution was adjusted to the required initial pH value using dilute HCl (or) NaOH before mixing the adsorbent. The concentration of residual Zinc(II) was determined with atomic absorption spectrophotometer (Perkin Elmer 2380) or photo colorimeter.

## 2.3. Batch experiments

The effect of various parameters on the removal of Zinc(II) onto *MHC* was studied batch adsorption experiments were conducted at (30-60°C). For each experimental run, 50 ml of Zinc solution of known initial concentration and pH were taken in a 250 ml plugged conical flask. A 25 mg adsorbent dose is added to the solution and mixture was shaken at constant agitation speed (150 rpm) sample were withdrawn at appropriate time intervals (10-60 min) and the adsorbent was separated by filtration. The residual solutions were analyzed to determine the Zinc(II) concentration. The effect of dosage of adsorbent on the removal of Zinc(II) was measured by contacting 50 ml of 50 mg/L of Zinc(II) solution with 25 mg of *MHC* till equilibrium was attained.

Adsorption equilibrium isotherm is studied using 25 mg of *MHC* dosage per 50 ml of Zinc(II) solution. The initial concentration were ranged from (25 to 125 mg/L) in all sets of experiments. The plugged conical flask was shaken at a speed of 200 rpm for 60 minutes. Then the solution was separated from the mixture and analyzed for Zinc(II) concentration. The adsorption capacity was calculated by using a mass equilibrium equation as follows:

$$q_e = (C_0 - C_e) V/M \dots\dots\dots (1)$$

Where,  $C_0$  and  $C_e$  being the initial Zinc concentration (mg/L) and equilibrium concentration, respectively  $V$  is the experimental volume of Zinc(II) solution expressed in liters [L] and  $M$  is the adsorbent mass expressed in grams [g]. The Zinc(II) ions percentage can be calculated as follows:

$$\%R = (C_0 - C_t) \times 100/C_0 \dots\dots\dots (2)$$

The effect of pH on the rate of adsorption was investigated using Zinc concentration of 25 mg/L constant *MHC* dosage. The pH values were adjusted with dilute HCl and NaOH solution. The adsorbent – adsorbate mixture was shaken at room temperature using agitation

speed (200 rpm) for 60 minutes. Then the concentration of copper in solution was determined.

## 3. RESULT AND DISCUSSION

### 3.1 Characterization

The different chemical constituents of activated *Manilkara hexandra* are given in Table-1 along with some other characteristics. X-ray spectra of both adsorbents do not show any peak indicating the amorphous nature of activated *Manilkara hexandra*.

Properties	<i>MHC</i>
Particle size(mm)	0.023
Density (g/cc)	0.3021
Moisture content (%)	0.262
Loss in ignition (%)	0.021
pH of aqueous solution	6.5

**Table 1-Characteristics of the Adsorbent**

### 3.2 Adsorption studies

Batch experiments were performed to investigate the adsorption process of Zinc ions by the *MHC*. For each experimental run, 50 mL of Zinc ions solution of known concentration, initial pH, ionic strength and the amount of the *MHC* were taken in a 250-mL stoppered conical flask. This mixture was agitated in a temperature-controlled shaking water bath at a constant speed of 200 rpm/min and certain temperatures. For adsorption equilibrium studies, Zinc ions solutions of different concentrations were conducted with a certain amount of *MHC* under certain conditions for 12 hr insuring the equilibrium was achieved. The residual Zinc ions concentration was then measured and the amount of Zinc ions adsorbed onto *MHC* was calculated from mass balance. Effects of contact time, adsorbent dosage, initial Zinc ions concentration, initial solution pH, ionic strength and temperature on Zinc ions adsorption by *MHC* were investigated. Adsorption kinetics was determined by analyzing adsorptive uptake of Zinc ions from aqueous solution at different time intervals. The amount of Zinc ions adsorbed at time  $t$ ,  $q_t$  (mg/g) was calculated using mass balance equation [1997].

### 3.3 Effect of agitation speed

The effect of agitation speeds on adsorption for Zinc ion was studied in the range of 100-350 rpm for *MHC* adsorbent. From the results represented, the maximum adsorption of Zinc occurred at 250 for *MHC* adsorbent. At low agitation speed, the adsorbent do not spread in the sample but accumulated. This will bury the active sites of the lower layer adsorbent and only the upper layer adsorbent active sites adsorb the Zinc ion. This indicates that agitation rate should be sufficient to assure that all the surface binding sites are readily available for Zinc ion uptake. But for further increase in agitation speed, amount removal decrease. This may be attributed to an increase desorption tendency of adsorbate molecules [2002].

### 3.4 Effect of Contact Time

Figure-1 shows the effect of contact time on the adsorption of Zinc(II) ions using *MHC*. The concentrations of Zinc(II) ions in solution were varied from 25mg/L to 125mg/L and batch adsorption was carried out with 25mg of *MHC*. The percentage of Zinc(II) ions adsorbed increased with time until equilibrium was reached for each concentration. It is therefore evident from Fig 1 that at low concentration ranges the percent adsorption is high because of the availability of more reactive sites [16]. At higher concentration of metal ion more and more surface sites are covered, the capacity of the adsorbent get exhausted due to non-availability of active surface sites. This leads to a fall in the percentage of metal ion adsorbed at higher concentration. It was observed that the percentage adsorption of Zinc(II) ion rapidly reached equilibrium at 30 minutes of contact for 25mg/L to 125mg/L concentration it increased to 100% implied that Zinc(II) ion was completely removed from aqueous solution at this concentration.

### 3.5 Effect of Initial Concentration

The effect of initial concentration of the adsorption of Zinc(II) ion using *MHC*. Adsorption of Zinc(II) ions in solution increase significantly with reduction in the initial concentration of Zinc(II) ions in solution. The initial concentration of adsorbate varied from 25mg/L to 125mg/L. The rate of adsorption decreased from 92% - 70% as the concentration of Zinc(II) ions increased from 25mg/L to 125mg/L within 30 mins of adsorption. This was expected and shows that there more reactive sites on the pores of *Manilkara hexandra* activated carbon.

### 3.6 Effect of adsorbent doses

The effect of adsorbent dose was studied by varying the adsorbent quantity from 0.010 to 0.25g maintaining the initial Zinc concentration ( $50 \text{ mg L}^{-1}$ ) at constant temperatures  $30^\circ\text{C}$ . The results are shown in Fig. 2. The % adsorption increased with increasing adsorbent dose because of the increased availability of adsorption sites therefore in order to achieve maximum removal efficiency, 0.025 g dose of adsorbent was sufficient for fixed initial concentration of Zinc ( $50 \text{ mg L}^{-1}$ ). The adsorption amount ( $\text{mg g}^{-1}$ ) increases with increase in adsorbent dosage, this might be due to the fact that some adsorbent sites are saturated at higher adsorbent dose [1974].

### 3.7 Effect of pH

The effect of initial solution pH on Zinc removal by *MHC* is shown in Fig.3. The adsorption of Zinc increased with pH increasing from 2.0 to 10.0. The results indicated that at pH 7.0, the maximum adsorption capacity of  $91.10$  and  $70.12 \text{ mgg}^{-1}$  occurred at an initial Zinc concentration of 25 and  $125 \text{ mgL}^{-1}$  respectively. Within the range of pH values from 8.0 to 12.0, the adsorption capacity decreased uniformly with increasing of pH. This indicates that the adsorption of the adsorbent is clearly pH dependent. Similar trend was also observed with the removal of Zinc using natural Chinese, while some researchers have reported the different optimum pH on adsorption of Zinc ion by using different adsorbent [1982]. The maximum adsorption capacity of the *MHC* for Zinc occurred at a pH value of around 7.

### 3.8 Effect of temperature

In order to understand the effect of temperature on the influence of the removal of Zinc by *MHC*, experiments were carried out at temperatures of 30, 40, 50 and  $60^\circ\text{C}$  respectively, pH  $8.0 \pm 0.3$ , and adsorbent dosage 0.025g. The removal efficiency increased with rise in temperature from 30 to  $60^\circ\text{C}$  at the Manganese concentration 25 to 125 mg/L. The effect may be contributed to the weakening of hydrogen bonds and Vander Walls interaction at higher temperatures, resulting in the strengthening of physical interaction between the active sites of Zinc and *MHC* [1982].

### 3.9 Adsorption Models:

The adsorption equilibrium data were further analyzed into two well known isotherm models via Freundlich and Langmuir models.

### 3.9.1 Freundlich model

The Freundlich model [19] which is an indicative of surface heterogeneity of the adsorbent is described by the following equation.

$$\log q_e = \log k_f + 1/n + \log C_e \text{ ----- (3)}$$

Where,  $K_f$  and  $1/n$  are Freundlich constants associated with adsorption capacity and adsorption intensity respectively, The Freundlich plots between  $\log q_e$  and  $\log C_e$  for the adsorption of Zinc ions were drawn. It was found that correlation efficient values were less than 0.99 at both the temperature studied indicating that Freundlich model was not applicable to the present study.

### 3.9.2 Langmuir model

The adsorption isotherm was also fitted to Langmuir model [19,18]. The Langmuir equation which is valid for monolayer adsorption on to a surface is given below.

$$1/q_e = 1/q_m + 1/q_{mb}C_e \text{ -----(4)}$$

Where,  $q_e$  ( $mgg^{-1}$ ) is the amount adsorbed at the equilibrium concentration  $C_e$  ( $mol L^{-1}$ ),  $q_m$  ( $mgg^{-1}$ ) is the Langmuir constant representing the maximum monolayer adsorption capacity and  $b$  ( $L mol^{-1}$ ) is the Langmuir constant related to energy of adsorption. The plots  $1/q_e$  as a function of  $1/C_e$  for the adsorption of Zinc ions was found linear. Suggesting the applicability if Langmuir model in the present adsorption system. The correction coefficient ( $R^2 = 0.9926$  and  $0.9932$  at  $30$  &  $60^\circ C$  respectively for Langmuir model) confirm good agreement between both theoretical models and our experimental results the values of the monolayer capacity ( $q_m$ ) and equilibrium constant ( $b$ ) have been evaluated from the intercept and slope of these plots and given in table 3. It is adsorbent for the Zinc ions is comparable to the maximum adsorption obtained from the adsorption isotherms. These facts suggest that Zinc ions are adsorbed in the form of monolayer coverage on the surface of the prepared adsorbent. Satisfactory fitting of the Langmuir model to the adsorption of Zinc ions on *Manilkara hexandra* adsorbents has also been reported by various researchers.

### 3.10 Kinetics study

The Kinetic adsorption data were evaluated to understand the dynamics of the adsorption reaction in terms of the order of the rate constant batch experiments were conducted to explore the rate of Zinc ions adsorption by *Manilkara hexandra* as described in adsorption isotherms section at pH 7. Three Kinetic models were applied to the adsorption Kinetic data in

order to investigate the behavior of adsorption process of Zinc ions onto the adsorbents [2000]. These models include the pseudo first order Kinetics (reversible or irreversible), the pseudo - Second - order and the intra particle diffusion models the linear form of reversible pseudo - first - order model can be formulated as:

$$\ln (q_e - q_t) = \ln q_e - k_1 \times t \text{ -----(5)}$$

Where,  $q_e$  ( $mol/g$ ) and  $q_t$  ( $mole/g$ ) are the amount of Zinc ions adsorbed at equilibrium and at time  $t$ , respectively and  $K_1$  ( $min^{-1}$ ) is the rate constant  $K_1$  values were evaluated from the linear regression of  $\ln(q_e - q_t)$  versus data. Linear form of irreversible pseudo first order model can be formulated as:

$$\ln (C_o / C_t) = K \times t \text{ ----- (6)}$$

Where,  $C_o$  ( $mg/l$ ) is the initial concentration of Zinc ions and  $C_t$  ( $mg/l$ ) is equilibrium concentration of Zinc ions at time 't' respectively, and  $kg min^{-1}$  is the rate constant Evaluation of data has been done using linear plot of  $\ln (C_o / C_t)$  versus time. The Linear form of pseudo - Second - order equation can be formulated us.

$$t/q_t = 1/k_2 q_e^2 + t/q_e \text{ ----- (7)}$$

Where,  $q_e$  and  $q_t$  are surface loading of Zinc ions at equilibrium and time 't' respectively and  $K_2$  ( $g/mg/min$ ) is the second - order rate constant. The Linear plot of  $t/q_t$  as a function of provided not only the rate constant  $K_2$ , but also an independent evaluation of  $q_e$ . The fitting of experimental data to the pseudo - first - order and the pseudo - second- order equation seemed to be quite good for *MHC* where the calculated correlation coefficients ( $R^2$ ) almost the same values (Table-6).

### 3.11 The Elovich equation and intra-particle diffusion model

The Elovich model [22] equation is generally expressed as

$$dq_t / dt = \alpha \exp (-\beta q_t) \text{ -----(8)}$$

Where;  $\alpha$  is the initial adsorption rate( $mg g^{-1} min^{-1}$ ) and  $\beta$  is the desorption constant ( $g/mg$ ) during any one experiment. To simplify the Elovich equation. Chien and Clayton (1980) assumed  $\alpha\beta t \gg t$  and by applying boundary conditions  $q_t = 0$  at  $t = 0$  and  $q_t = q_t$  at  $t = t$  Eq. (8) becomes:

$$q_t = 1/\beta \ln (\alpha\beta) + 1/\beta \ln t \text{ ----- (9)}$$

Since Zinc ions adsorption fits with the Elovich model, a plot of  $q_t$  vs.  $\ln(t)$  yields a linear relationship with a slope of  $(1/\beta)$  and an intercept of  $(1/\beta)\ln (\alpha\beta)$ . The Elovich model parameters  $\alpha$ ,  $\beta$ , and correlation coefficient ( $\gamma$ ) are summarized in table 6. The experimental data such as the initial adsorption rate ( $\alpha$ )

adsorption constant ( $\beta$ ) and the correlation co-efficient ( $\gamma$ ) calculated from this model indicates that the initial adsorption ( $\alpha$ ) increases with temperature similar to that of initial adsorption rate ( $h$ ) in pseudo-second-order kinetics models. This may be due to increase the pore or active site on the *MHC* adsorbent.

For adsorption of Zinc ions on to *Manilkara hexandra* the obtained results represent more conformity to pseudo-second order model ( $R^2 = 0.95$ ), the initial adsorption rate  $k_2q_e^2$  for *Manilkara hexandra*. Kinetic data for the adsorption of Zinc ions were also analyzed according to intra-particle diffusion model achieve can be formulated as [1964].

$$Q_t = k_{pt} 0.5 \text{ ----- (10)}$$

Where,  $q_t$  is the amount of Zinc ions adsorbed (mg/g) at time  $t$ , and  $k_p$  (mg/g min<sup>0.5</sup>) is the rate constant for intra - particle diffusion. Results are shown in table 6. The plot of  $q_t$  versus  $t^{0.5}$  was distinguished in two or Where,  $K_D$  is the distribution coefficient for the adsorption in g/L,  $\Delta G^\circ$  is the Gibbs free energy in J/mol,  $R$  is the universal gas constant in J/mol K,  $T$  is the absolute temperature in K,  $\Delta S^\circ$  is the entropy change in J/mol K and  $\Delta H^\circ$  is the enthalpy change in kJ/mol [13]. The values of Gibbs free energy ( $\Delta G^\circ$ ) for various temperatures were calculated from the experimental data. The values of enthalpy change ( $\Delta H^\circ$ ) and entropy change ( $\Delta S^\circ$ ) were estimated from the slope and intercept of the plot of  $\ln K_D$  Vs  $1/T$ . The estimated thermodynamic parameters were tabulated and shown in table 5. The negative values of Gibbs free energy change ( $\Delta G^\circ$ ) obtained for the adsorption of Zinc ions by *MHC* at various temperatures had shown the spontaneous nature of the adsorption process.

The positive values of enthalpy change ( $\Delta H^\circ$ ) obtained for the adsorption of Zinc ions by *MHC* at various temperatures indicated that the adsorption reactions were endothermic. The positive values of entropy change ( $\Delta S^\circ$ ) for the adsorption of Zinc ions by *MHC* at various temperatures showed the increased randomness at solid liquid interphase during the sorption processes of ZinCs ions on the adsorbent *MHC*. This is a direct consequence of (i) opening up of structure of adsorbent beads (ii) enhancing the mobility and extent of penetration within the adsorbent beads and (iii) overcoming the activation energy barrier and enhancing the rate of intra-particle diffusion [1997].

more steps taking place during adsorption process including instantaneous adsorption stage by external mass transfer (first sharper portion), intra-particle diffusion which is the rate controlling stage (second portion as the gradual adsorption stage) and the final equilibration of age where the intra - particle diffusion starts to slow down due to extremely low solute concentration in solution (the third portion).

### 3.12 Adsorption Thermodynamics

The thermodynamic parameters for the adsorption of Zinc ions by *MHC* were determined using the following equations [2007]:

$$K_D = q_e/C_e \text{ ----- (11)}$$

$$\Delta G^\circ = - RT \ln K_D \text{ ----- (12)}$$

$$\ln K_D = (\Delta S^\circ/R) - (\Delta H^\circ/RT) \text{ ----- (13)}$$

The adsorption of Zinc ions by *MHC* slightly increased when temperature was raised up to 60 °C. It might be due to the generation of new active sites on the adsorbent surface and also due to the increased rate of pore diffusion. But when the temperature was further raised, adsorption processes had increased largely. It showed that the adsorption processes of Zinc ions by *MHC* were endothermic reactions and physical in nature which involved the weak forces of attraction between the sorbate-sorbent molecules.

### 3.13 Desorption studies

Desorption studies help to elucidate the nature of adsorption and recycling of the spent adsorbent and the Zinc ions. If the adsorbed metal ions can be desorbed using neutral pH water, then the attachment of the metal ion of the adsorbent is by weak bonds. The effect of various reagents used for desorption studies. The results indicate that hydrochloric acid is a better reagent for desorption, because we could get more than 92% removal of adsorbed metal ion. The reversibility of adsorbed Zinc ion in mineral acid or base is in agreement with the pH dependent results obtained. The desorption of Zinc ion by mineral acids and alkaline medium indicates that the Zinc ion was adsorbed onto the *MHC* through physisorption as well as by chemisorptions mechanisms [1986].

TABLES AND GRAPH

TABLE: 2. EQUILIBRIUM PARAMETERS FOR THE ADSORPTION OF ZINC(II) ION ONTO MHC

M <sub>0</sub>	Ce (mg / L)				Qe (mg / L)				Removal %			
	30°C	40°C	50°C	60°C	30°C	40°C	50°C	60°C	30°C	40°C	50°C	60°C
25	3.64	3.03	2.54	2.73	92.70	93.92	94.90	94.52	92.72	93.92	94.90	92.52
50	11.43	10.46	8.47	7.56	177.1	179.0	183.0	184.8	88.56	89.53	91.52	90.43
75	25.74	22.36	19.64	17.36	248.5	255.2	260.7	265.2	82.83	85.08	86.90	85.42
100	47.84	43.64	19.64	36.67	304.3	312.7	360.7	326.6	76.07	78.17	90.17	81.57
125	73.88	69.93	40.64	60.90	352.2	360.1	418.7	378.19	70.44	72.02	83.74	73.63

TABLE: 3. LANGMUIR AND FREUNDLICH ISOTHERM PARAMETER FOR THE ADSORPTION OF ZINC(II) ION ONTO MHC

Temp. (°C)	Langmuir Parameters		Freundlich Parameters	
	Q <sub>m</sub>	B	K <sub>f</sub>	N
30°C	413.34	0.0662	1.748	2.2300
40°C	417.07	0.0766	1.791	2.3121
50°C	565.53	0.0634	1.758	1.8065
60°C	437.88	0.0931	1.833	2.2613

TABLE: 4. DIMENSIONLESS SEPERATION FACTOR (R<sub>L</sub>) FOR THE ADSORPTION OF ZINC(II) ION ONTO MH

(C <sub>i</sub> )	Temperature °C			
	30°C	40°C	50°C	60°C
25	0.2318	0.2068	0.2395	0.1768
50	0.1311	0.1153	0.1360	0.0969
75	0.0914	0.0799	0.0950	0.0668
100	0.0701	0.0612	0.0730	0.0509
125	0.0569	0.0495	0.0592	0.0411

TABLE: 5. THERMODYNAMIC PARAMETER FOR THE ADSORPTION OF ZINC (II) ION ONTO MHC

(C <sub>0</sub> )	ΔG°				ΔH°	ΔS°
	30°C	40°C	50°C	60°C		
25	-	-	-	-	6.11	39.51
50	5786.1	6346.5	6702.7	6972.1	14.96	63.61
75	4319.1	4798.5	5878.6	6068.4	11.56	49.47
00	3485.4	3821.6	4392.9	4953.7	15.58	59.39
125	2250.9	2459.8	5293.1	3194.0	13.52	49.38

**TABLE: 6. THE KINETIC PARAMETERS FOR THE ADSORPTION OF ZINC (II) ION ONTO MHC**

C <sub>0</sub>	Temp °C	Pseudo second order				Elovich model			Intraparticle diffusion		
		q <sub>e</sub>	k <sub>2</sub>	γ	H	α	β	γ	K <sub>id</sub>	γ	C
25	30	99.490	0.0018	0.994	19.52	818.20	0.0916	0.9959	1.7335	0.9981	0.1291
	40	100.17	0.0016	0.991	20.90	1203.6	0.0951	0.9968	1.7504	0.9975	0.1225
	50	100.73	0.0014	0.992	20.87	1901.9	0.1004	0.9982	1.7651	0.9969	0.1145
	60	100.07	0.0014	0.991	22.10	2783.7	0.1052	0.9948	1.7738	0.9973	0.1092
50	30	190.41	0.0021	0.992	34.85	1260.1	0.0468	0.9961	1.7045	0.9989	0.1329
	40	192.37	0.0020	0.991	35.97	1460.5	0.0471	0.9987	1.7145	0.9928	0.1302
	50	195.86	0.0018	0.993	38.53	1968.7	0.0478	0.9967	1.7332	0.9941	0.1251
	60	197.17	0.0017	0.991	40.57	2144.5	0.0477	0.9989	1.7400	0.9948	0.1242
75	30	266.65	0.0022	0.992	51.10	2109.2	0.0341	0.9959	1.6825	0.9952	0.1296
	40	273.50	0.0022	0.994	52.60	2279.9	0.0334	0.9984	1.6953	0.9983	0.1286
	50	280.24	0.0021	0.991	55.94	2501.0	0.0328	0.9967	1.7095	0.9960	0.1276
	60	282.68	0.0020	0.992	47.44	4605.9	0.0362	0.9983	1.7245	0.9940	0.1143
100	30	329.80	0.0024	0.994	54.09	1150.9	0.0248	0.9943	1.6127	0.9946	0.1472
	40	338.49	0.0024	0.995	56.28	1394.5	0.0248	0.9982	1.6317	0.9988	0.1429
	50	343.90	0.0011	0.997	59.50	1673.6	0.0249	0.9972	1.6468	0.9954	0.1393
	60	351.13	0.0023	0.999	66.09	2414.7	0.0254	0.9969	1.6716	0.9990	0.1324
125	30	385.32	0.0022	0.998	57.66	839.01	0.0199	0.9981	1.5570	0.9987	0.1600
	40	392.62	0.0025	0.997	61.02	1034.8	0.0201	0.9948	1.5764	0.9967	0.1545
	50	405.44	0.0016	0.998	58.86	843.37	0.0188	0.9994	1.5756	0.9961	0.1609
	60	410.50	0.0025	0.992	65.92	1286.2	0.0197	0.9972	1.6052	0.9952	0.1499





- 10) Shukla S R and Pai R.S., "Adsorption of Cu(II), Ni(II) and Zn(II) on modified jute fibres", *Bioresour. Technol.*, 96, 1430 - 1438, 2005.
- 11) Munoz R, Alvarez M T, Munoz A, Terraazas E, Guieysse B and Mattiassion B, "Sequential removal of heavy metals ions and organic pollutants using an algal-bacterial consortium". *Chemosphere.*, 63, 903 - 911, 2006.
- 12) Badruzzaman M, Westerhoff P and Knappe D R U, "Intra-particle diffusion and adsorption of arsenate onto granular ferric hydroxide (GFH)", *Water Res.*38 (18), 4002 - 4012, 2004.
- 13) Bhattacharya K G and Sharma A, "Adsorption of Pb(II) from aqueous solution by
- 14) *Azadirachta indica* (Neem) leaf powder", *J.Hazard. Material.*,113, 97 - 109, 2004.
- 15) Desai M, Dogra A, Vora S, Bahadur P and Ram R N, *Indian J. Chem.* A36, 938,1997.
- 16) Parekh D C, Patel J B, Sudhakar P and Koshy V J., *Indian J. Chem. Technol.* 9, 540, 2002.
- 17) Siddiqui B A, Sharama P P and Sultan M, *Indian J. Environ. Protect.*, 19, 846,1999.
- 18) Weber T W, Chakravorti. R.K, Pore and Solid diffusion models for fixed bed adsorbers. *J. Am. Inst. Chem. Eng.*, 20, 228, 1974.
- 19) McKay G, Blair H S, Gardner J R, Adsorption of dyes on chitin. I. Equilibrium Studies. *J. Appl. Polym. Sci.* 27, 3043 - 3057, 1982.
- 20) Freundlich H, The dye adsorption is losungen (Adsorption in Solution), *Z Phys. Chem.*, 57, 385 - 470, 1906.
- 21) Langmuir I, The adsorption of gases plane surfaces of glass, mica and platinum. *J. Am. Soc.*, 579, 1361 - 1403, 1918.
- 22) Ho Y S and McKay G, The kinetic of sorption of divalent metal ions on to Sphagnum moss peat, *Water Res.* 34, 735 - 742, 2000.
- 23) Chien S H. and Clayton. W R , Application of Elovich Equation to the kinetics of Phosphate release and sorption on soil. *Soil Sci. Sco. Am, J.*, 44, 265 - 268, 1980.
- 24) Weber J.W and Morris J C., Kinetics of adsorption on Carbon from solution. *J. Sanitary Engg. Div.*, 90, 79, 1964.
- 25) Arivoli S. Kinetic and thermodynamic studies on the adsorption of some metal ions and dyes on to low cost activated carbons, Ph.D., Thesis, Gandhigram Rural University, Gandhigram, 2007.
- 26) Spark D L., Kinetics of reaction in pure and mixed system in soil physical chemistry. CRC, Press, Boca Raton, 1986.