

Removal of Cd(II) from Aqueous Solution Using Dried Plant (*Azadirachta indica*) Biomass

SOUMYA RANJAN MISHRA* and RACHNA CHANDRA

Terrestrial Ecology Division, Gujarat Institute of Desert Ecology (GUIDE), P.O. # 83, Mundra Road, Bhuj, Gujarat-370 001, India

*Corresponding author: Fax: +91 2832 235027; Tel: +91 2832 235025; E-mail: soumya.env@gmail.com

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In the present study, we have used neem (*Azadirachta indica*) leaf powder as a non-conventional biosorbent for the removal of Cd(II) from aqueous solutions. Batch experiments were conducted to identify equilibrium time, equilibrium adsorbent dosage and equilibrium metal concentration. The data were analyzed by applying Freundlich, Langmuir and Temkin isotherm models. The kinetics of adsorption was studied from the data obtained through pseudo-first-order and pseudo-second-order equations. The adsorption data best fitted for Freundlich isotherm and the process obeyed pseudo-second-order. The adsorption of Cd(II) was rapid initially and reached the peak at 180 min of agitation (96.9 %). The adsorbent dose indicated instantaneous adsorption (92.8 %) at 0.4 g and reached equilibrium at 1.6 g (97.4 %). The adsorption was rapid initially (99.6 %) at Cd(II) concentration of 60 mg L⁻¹ and decreased (96.2 %) at 200 mg L⁻¹. It was revealed that neem leaf powder has effective potential for the removal of Cd(II) from aqueous solution.

Keywords: Adsorption, *Azadirachta indica*, Biosorbent, Cadmium, Isotherms.

INTRODUCTION

Heavy metals build up as metal-organic complexes in living organisms and eventually increase their concentration in biological cycles [1]. Issues related to metal contamination and management are common due to human activities and subsequent impact on the environment. Environmental contamination due to heavy metals accumulation from anthropogenic sources is one of the major areas of concern. Various industries viz., manufacturing, mining, power generating significantly contribute to water pollution through the generation of effluents containing higher concentrations of heavy metals. If left untreated, these contaminated effluents may pollute both surface and sub-surface water. Inadequate treatment of effluents from industries impacts both health and environment [2]. Their removal being a prerequisite, various physical, chemical and biological techniques have been brought forth. Several methods, like precipitation, coagulation/flocculation, chemical reduction, ion exchange, electrodialysis, reverse osmosis, filtration, etc. [3] are followed for the decontamination of wastewater. However, these methods cannot be always implemented due to capital investments and operating costs. Adsorption is a physical technique used for the removal of toxic metals [3] and known for its simple usage and availability of wide range of adsorbents. Adsorption plays a significant role in the effective removal of pollutants not only from the aqueous sources but also from

the soil and gaseous medium [4]. Adsorption may result either from the universal van der Waals interactions like physisorption or from chemical processes like chemisorption, but the later occurs only as monolayer [5]. Surface area, ionic strength, pH and temperature of the medium, interactive forces between adsorbent and adsorbate, particle size and nature of adsorbent, physico-chemical features of adsorbate, etc. govern the rate of adsorption [4]. Activated carbon is the most efficient biosorbent owing to its higher adsorptive capacity and versatility. Nevertheless, the higher cost has limited its wide application in developing countries [6]. Considering the quantum of effluent produced by the industries in developing countries, researchers are progressively exploring alternatives as adsorbent that are non-conventional and economical. As a result, several pollutants in wastewater are treated following low cost adsorbents in laboratories.

Biosorption involves a two phase system, having a solid phase (dead/live biomass/adsorbent) and a liquid phase (solution/adsorbate) containing metal ions [7]. It has many advantages over the conventional methods of adsorption as it (i) uses very low-priced and abundantly available materials [8], and (ii) is effective in low metal concentrations in wastewater [9]. Adsorption isotherm represents the adsorbable solutes distribution between the liquid and adsorbed phase at several equilibrium concentrations [10]. Sorption of pollutants from the contaminated aqueous solution plays a significant role in treatment of

wastewater. Thus, the study of adsorption kinetics in wastewater decontamination process is important as it governs the reaction pathways and the sorption reaction mechanisms [11]. The development of adsorption technique and availability of several non-conventional biosorbents have paved ways for wastewater decontamination. Cadmium, well known for its harmful environmental impacts [12], has gained significance due to its persistence and subsequent toxicity in the ecosystem. Sources of cadmium in the environment largely include fertilizers and pesticides, cadmium batteries, smelting processes, electroplating and extensive mining activities [13,14]. Cadmium being toxic, it can be mutagenic, teratogenic as well as carcinogenic in nature [15]. Industrial effluents carry higher concentrations of heavy metals like cadmium, which can significantly harm the environmental components. Researchers have used several cost-effective/non-conventional materials as biosorbent for the removal of cadmium and other heavy metals *viz.*, maize husk [12], agricultural waste [13], green algal biomass [14], bamboo activated carbon [15] and sugar beet pulp [16]. Neem leaf powder (NLP), a low cost potential adsorbent, has been explored for metal removal elsewhere [4,17,18]. Several researchers have concluded that surface area and pore sizes are involved during biosorption. Since earlier studies [4], considered neem leaf powder fractions between 10 and 75 μ , we aimed at assessing the potential of neem leaf powder for Cd(II) adsorption with a particle size of 500 μ . Thus, in the present study we used neem leaf powder of < 0.5 mm as a low cost widely available adsorbent for the removal of Cd(II) from aqueous solutions and the data obtained were fitted into pseudo-first and pseudo-second order equations and adsorption isotherm models *viz.*, Freundlich, Langmuir and Temkin. The adsorption characteristics were studied under different batch mode experiments considering the effect of contact time, initial Cd(II) concentration and dosage of neem leaf powder. Further, since the structural characteristics of neem leaf powder by SEM are already well reported elsewhere [17,18], the same was not intended to be covered under the present study.

EXPERIMENTAL

Sorbent preparation: We collected fresh neem leaves from the campus of Gujarat Institute of Desert Ecology (GUIDE), Bhuj, Gujarat, India and washed thoroughly using deionized water and dried under shade. The leaves were then grinded, sieved through 0.5 mm, washed further to remove colour and turbidity and allowed to dry under room conditions. The powder thus obtained was stored in pre-cleaned bottles to study its potential for Cd(II) removal.

Batch experiments: The stock solution of Cd (1000 mg L⁻¹) was prepared by using the salt of CdCl₂·H₂O (Make: FINAR) and diluted further to obtain the required concentrations. We conducted batch adsorption experiments to identify the equilibrium time for Cd(II) adsorption on neem leaf powder. 1 g of neem leaf powder (biosorbent) was transferred to the conical flasks. To this, 50 mL of 100 mg L⁻¹ Cd(II) was added. The flasks were placed on rotary shaker at 120 rpm [19]. At pre-fixed intervals (1 to 300 min), the samples were withdrawn from the shaker, filtered (Whatman 42) and analyzed for Cd(II) (Table-1). Another batch experiment was conducted to deter-

mine the equilibrium dosage by taking 50 mL of 100 mg L⁻¹ solution of Cd(II) to different dosages of neem leaf powder (0.4 to 2.0 g) and shaking for a fixed time interval (obtained from equilibrium time) at 120 rpm. To identify the equilibrium concentration, single input dosage of neem leaf powder (obtained from equilibrium dosage) was taken in conical flasks containing 50 mL of Cd(II) in varying concentrations (60 to 200 mg L⁻¹) and samples were agitated for fixed duration (obtained from equilibrium time). All samples were taken in triplicates and analyzed for Cd(II) using atomic absorption spectrophotometer (Perkin Elmer, AAnalyst400). All the batch experiments were conducted under room conditions. As the wastewater is available in a wide range of pH, we carried out the experiment with neutral pH using double distilled water. Amount of metal adsorbed, q_e (mg g⁻¹) was calculated by the following equation:

$$q_e = \frac{(C_i - C_e)V}{W} \quad (1)$$

where, C_i is the initial concentration (mg L⁻¹), C_e is the equilibrium concentration (mg L⁻¹), V represents the volume (L) of the adsorbate and W represents the adsorbent mass (g).

TABLE-1
ATTRIBUTES OF BATCH EXPERIMENT FOR
ADSORPTION OF Cd(II) BY NEEM LEAF POWDER

Agitation time (min)	1, 10, 20, 60, 100, 120, 150, 180, 200 and 240
Initial Cd(II) concentration (mg L ⁻¹)	60, 80, 100, 125, 150, 175 and 200
Adsorbent dose (g) (50 mL)	0.4, 0.8, 1.0, 1.2, 1.6 and 2.0
Particle size	< 0.5 mm (> 35 mesh)

Kinetics of adsorption: The kinetics of adsorption was studied by taking a definite amount of adsorbent (1 g) and 100 mg L⁻¹ of Cd(II) under varying agitation times (1 to 180 min). In the present study, pseudo-first order [20] and pseudo-second order [21] equations were used for deriving the data. The adsorption kinetics for pseudo-first order model in linear form was presented by the following equation:

$$\log(q_e - q_t) = \log q_e - \left(\frac{k_1}{2.303} \right) t \quad (2)$$

where, q_e is the metal amount adsorbed at equilibrium (mg g⁻¹), q_t is the metal amount adsorbed at any time t (mg g⁻¹) and k_1 (min⁻¹) represents the rate constant for pseudo-first order.

The linear graph of $\log(q_e - q_t)$ (mg g⁻¹) *versus* t (min) was plotted for the evaluation of k_1 constant, q_e constant and correlation coefficient (R^2).

Similarly, for pseudo-second order the following linear equation was employed to test the adsorption kinetics:

$$\frac{t}{q_t} = \frac{1}{h} + \left(\frac{1}{q_e} \right) t \quad (3)$$

where, t = time of metal adsorption (min), q_t = amount of metal adsorbed at time ' t ' (mg g⁻¹), q_e = amount of metal adsorbed at equilibrium (mg g⁻¹); further $h = k_2 q_e^2$, where h represents initial sorption rate (mg g⁻¹ min⁻¹) and k_2 = rate constant for pseudo-second-order (g mg⁻¹ min⁻¹). The linear graph of t/q_t (min g mg⁻¹) *versus* t (min) was plotted using the above equation to determine the constants and the correlation coefficient.

Adsorption isotherms: Adsorption isotherm describes the metal uptake per unit mass of adsorbent (q_e) to the equilibrium concentration of adsorbate in the aqueous solution (C_e) under fixed temperature conditions [22]. In the present study we used Freundlich, Langmuir and Temkin isotherms to describe the adsorption mechanisms.

Langmuir isotherm: This isotherm model estimates maximum adsorption capacity, as a function of the monolayer coverage on the surface of adsorbent at or before the equilibrium [12]. The Langmuir isotherm equation is as follows:

$$\frac{1}{q_e} = \frac{1}{q_m} + \frac{1}{q_m K_L} \left(\frac{1}{C_e} \right) \quad (4)$$

where, q_m is the constant of maximum adsorption capacity (mg g^{-1}), K_L (L mg^{-1}) is the constant of adsorption/desorption energy, q_e (mg g^{-1}) represents amount of metal adsorbed per unit mass and C_e (mg L^{-1}) represents equilibrium concentration.

Freundlich isotherm: Freundlich isotherm model corresponds to the relationship between the quantum of metal adsorbed per unit mass (q_e) and the equilibrium concentration (C_e). It assumes that sites with varying degrees of adsorption energies are involved in the process of adsorption [23]. The Freundlich isotherm is represented by the following equation:

$$\log q_e = \log K_f + \frac{1}{n} \log C_e \quad (5)$$

where, n and K_f are Freundlich constants/coefficients.

Temkin isotherm: The Temkin isotherm describes the interaction between the adsorbate and the surface (adsorbent) in a biosorption system [24]. It provides the relation between the amount of metal ions adsorbed and the heat of adsorption [25]. The derivation of the Temkin isotherm is based on the assumption that the decrease in heat of sorption as a function of temperature is linear rather than logarithmic, as implied in the Freundlich equation [2].

The equation of Temkin isotherm in linear form is expressed as:

$$q_e = \frac{RT}{b} \ln A + \frac{RT}{b} \ln C_e \quad (6)$$

Eqn. 6 can be modified as:

$$q_e = B \ln A + B \ln C_e \quad (7)$$

where, A (L g^{-1}) and B are constants of Temkin isotherm; further $B = RT/b$, R is the gas constant ($8.314 \text{ J mol}^{-1} \text{ K}^{-1}$) and T is temperature ($^{\circ}\text{C}$). The Temkin isotherm can be determined by plotting q_e (mg g^{-1}) versus $\ln C_e$ (mg L^{-1}) to determine the constants A (L g^{-1}) and B .

RESULTS AND DISCUSSION

Effect of agitation time: Agitation time highly influenced the adsorption rate of Cd(II) by neem leaf powder. Adsorption was fast (96.4 %) initially due to higher concentration of Cd(II) ions upto 40 min of agitation and reached the peak at 180 min (96.9 %). Changes in adsorption rate were insignificant beyond 180 min of agitation (Fig. 1). The rate of adsorption is controlled by the concentration gradient between the liquid layer surrounding the adsorbent particles and the active sites available for binding Cd(II). Thus, after equilibrium only lesser number

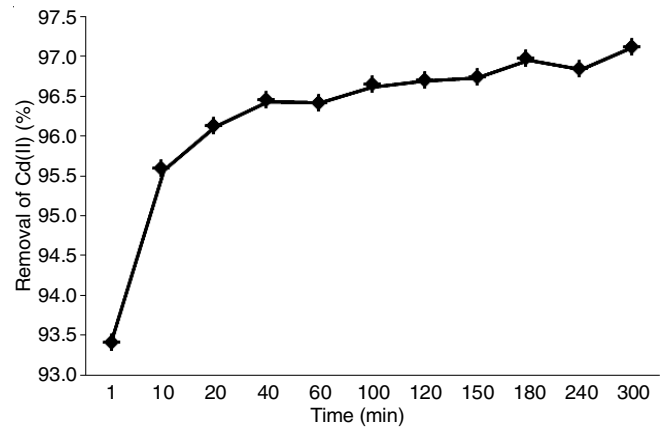


Fig. 1. Effect of agitation time on % removal of Cd(II), ($\text{Cd}-100 \text{ mg L}^{-1}$; Neem leaf powder - 1 g)

of active sites participated in metal ions adsorption [26] and the uptake rate was governed by the rate of transport of ions from the outer to the inner sites of adsorbent.

Effect of adsorbent dosage: The amount of Cd(II) removed from the solution increased with increase in neem leaf powder dosage (0.4 g to 1.6 g). No significant increase in adsorption was recorded with further addition of neem leaf powder (Fig. 2). With adsorbent dosage the percentage removal of Cd(II) increased from 92.8 % (0.4 g of neem leaf powder) to 97.4 % (1.6 g of neem leaf powder). The increased adsorption in the present case is attributable to the increase in the available sites for Cd(II). This is due to the fact that at a given concentration, if the dose of adsorbent increases, the uptake of metal gradually lowers as lesser number of Cd(II) ions are available to bind [27]. Further, studies have attributed the overlapping of adsorption sites due to excess adsorbent [28].

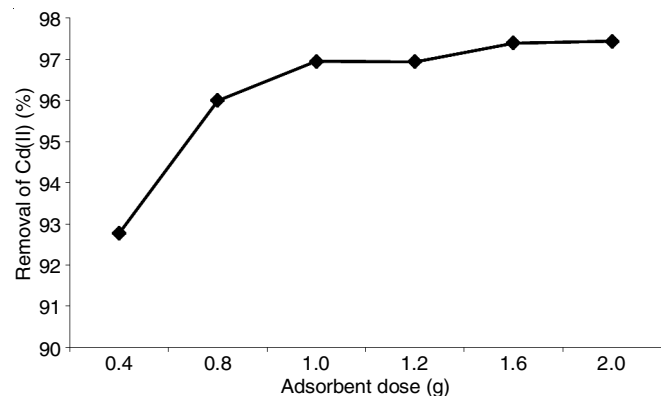


Fig. 2. Effect of adsorbent dose (neem leaf powder) on % removal of Cd(II), ($\text{Cd}-100 \text{ mg L}^{-1}$; Time-180 min)

Effect of initial concentration: The effect of initial concentration on rate of adsorption was determined by taking the equilibrium time (180 min) and equilibrium dosage of neem leaf powder (1.6 g) under varying Cd(II) concentrations. The Cd(II) adsorption was highest (99.6 %) at a concentration of 60 mg L^{-1} Cd(II), which gradually decreased to 96.2 % at 200 mg L^{-1} of Cd(II) (Fig. 3). Increased initial concentration results in significant decrease in adsorption [29] because (i) at lower concentrations, higher number of unsaturated sites are present on the adsorbent surface, and (ii) adsorption kinetics is depen-

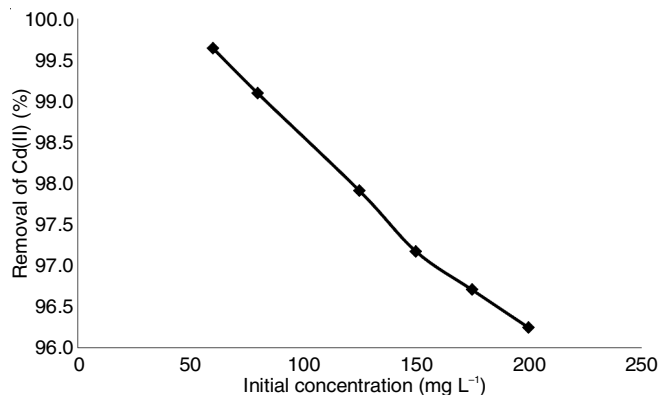


Fig. 3. Effect of initial concentration of Cd(II) on % removal of Cd(II), (Neem leaf powder - 1.6 g; Time-180 min)

dent on the adsorbent's surface area [30]. Further, higher metal concentrations adversely affect the adsorption because the moles of available ions on the surface of adsorbent remain high [31] and eventually these binding sites become saturated [32], thus leading to reduced adsorption.

Kinetics of adsorption: The kinetics of Cd(II) adsorption on neem leaf powder was studied applying pseudo-first and pseudo-second order equations. Though, both the equations showed a good correlation with the adsorption process, the later one fitted best. While pseudo-first order reaction fails in providing the concrete adsorption mechanism, pseudo-second order equation is suitable for describing such process to a large extent [21]. The regression plot of t (min) *versus* $\log(q_e - q_t)$ (mg g^{-1}) was linear with correlation coefficient (R^2) of 0.83, first-order rate constant (k_1) of 0.012 min^{-1} and maximum adsorption capacity (q_e) of 1.81 mg g^{-1} (Fig. 4). Similar values of k_1 (0.012 min^{-1}) for Cd(II) was reported by Sharma and Bhattacharya [33] (Table-2). Thus, it could be inferred that k_1 was independent of neem leaf powder particle size.

In the case of pseudo-second order equation the graph for t/q_t (min g mg^{-1}) against t (min) resulted in R^2 value of 0.99, k_2 of $0.013 \text{ g mg}^{-1} \text{ min}^{-1}$ and q_e of 66.44 mg g^{-1} . Similar values of k_2 (0.032 and $0.010 \text{ g mg}^{-1} \text{ min}^{-1}$) were obtained for the adsorption of Cd(II) using different adsorbents [4,36] (Table-2). In the present study, the adsorption process can be best explained by pseudo-second order equation (Fig. 5), where chemisorption played significant role by involving covalent forces during the sharing of electrons [41] between neem leaf powder and

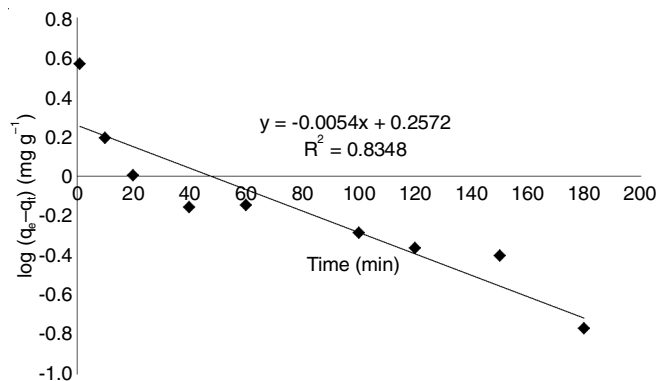


Fig. 4. Plot of pseudo-first order kinetics of the interaction between Cd(II) and neem leaf powder

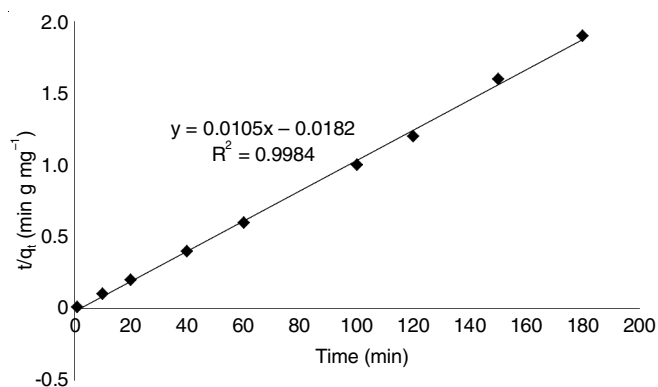


Fig. 5. Plot of pseudo-second order kinetics of the interaction between Cd(II) and neem leaf powder

the Cd(II) ions. Thus, in pseudo-second order kinetics, chemisorption is the rate controlling/limiting step, where the removal from a solution is due to physico-chemical interactions between two phases [37].

Langmuir isotherm: The adsorption process can be best understood by considering its behaviour with different isotherm models. The plot of $1/C_e$ (L mg^{-1}) *versus* $1/q_e$ (g mg^{-1}) (Fig. 6) in the present study represents the Langmuir equation and the values of q_m (mg g^{-1}), K_L (L mg^{-1}) and R^2 were calculated from the equation of the plot. Langmuir constants of adsorption capacity (q_m) was 4.34 mg g^{-1} at room temperature and adsorption energy (K_L) was 3.726 L mg^{-1} . In general, higher q_m values denote that the adsorbent is more effective. Thus, q_m value in the present study revealed that neem leaf powder is

TABLE-2
VARIOUS ADSORBENTS STUDIED BY RESEARCHERS FOR Cd(II) REMOVAL AND THEIR COEFFICIENTS OF PSEUDO-FIRST AND PSEUDO-SECOND ORDER EQUATION

Biosorbent	Pseudo-first order			Pseudo-second order			Ref.
	q_e (mg g^{-1})	k_1 (min^{-1})	R^2	q_e (mg g^{-1})	k_2 ($\text{g mg}^{-1} \text{ min}^{-1}$)	R^2	
Sugar beet pulp	–	0.332	0.99	0.15	11.190	0.99	[16]
Neem leaf powder (oven dried)	–	0.012	0.99	–	0.315×10^{-2}	0.99	[33]
Tree fern	–	–	–	12.00	0.107	0.93	[34]
Coconut copra meal	–	–	–	1.84	0.191	1.00	[35]
Green coconut shell powder	4.59	1.335×10^{-2}	0.32	15.31	1.015×10^{-2}	0.99	[36]
Dried activated sludge	–	–	–	61.30	0.005	0.98	[37]
<i>Caulerpa lentillifera</i>	3.85	1.395	0.98	3.97	621.000	1.00	[38]
Fruit wastes	23.05	–	–	33.17	0.003	0.99	[39]
<i>Egeria densa</i> (Dead biomass)	–	–	–	1.03	0.826	–	[40]
Agricultural waste (modified)	118.50	0.046	0.95	200.00	0.096×10^{-2}	0.99	[13]

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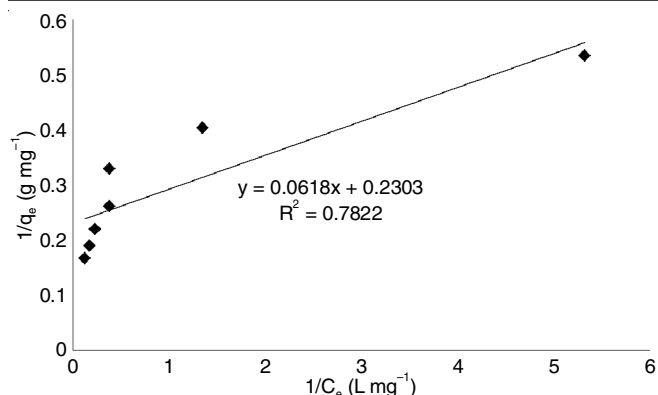


Fig. 6. Langmuir plot for adsorption of Cd(II) on neem leaf powder

more efficient in Cd(II) adsorption than sugar beet pulp ($q_m = 0.22 \text{ mg g}^{-1}$), modified cassava waste ($q_m = 0.94 \text{ mg g}^{-1}$) and dead biomass of *Egeria densa* ($q_m = 1.25 \text{ mg g}^{-1}$), respectively [16,40,42] (Table-3). Nevertheless, the Langmuir correlation coefficient (R^2) in the present study was 0.78, which was lower than the other isotherm models. Thus, based on R^2 value it is known that in the present study Langmuir isotherm is unsuitable (Table-3).

Freundlich isotherm: The experimental data were tested using Freundlich isotherm equation by making the plot of $\log C_e$ (mg L^{-1}) vs. $\log q_e$ (mg g^{-1}) (Fig. 7). The value of K_f and n from the plot were 2.854 mg g^{-1} and 3.24, respectively. The results revealed that Freundlich adsorption isotherm was the best model for Cd(II) ions adsorption onto neem leaf powder with R^2 of 0.92. Similar values of n (3.85) and K_f (1.42 and 1.44 mg g^{-1}) using different biosorbents were found in several adsorption studies [16,18] (Table-3). For the adsorption to be favourable, the Freundlich constant 'n' should be between 1 and 10 [2]. Higher value of 'n' denotes stronger interaction between the adsorbent and adsorbate and $1/n = 1$ denotes linear adsorption leading to identical adsorption energies for all sites [56].

Temkin isotherm: The Temkin isotherm showed R^2 , A and B value of 0.83, $1198.395 \text{ L g}^{-1}$ and 1.015, respectively. With lower value of correlation coefficient (R^2), the adsorption process did not obey Temkin isotherm model (Fig. 8). Thus, in the present case, Temkin isotherm is unsuitable in predicting the biosorption equilibria. A study revealed that since Temkin equation is a simple postulation, which does not involve complex phenomenon in liquid phase adsorption, its application for complex systems remains unsuitable [4].

TABLE-3
VARIOUS ADSORBENTS STUDIED ELSEWHERE FOR Cd(II) REMOVAL AND
THEIR COEFFICIENTS OF LANGMUIR ISOTHERM AND FREUNDLICH ISOTHERM

Adsorbent used	Coefficients of Langmuir isotherm			Coefficients of Freundlich isotherm			Ref.
	K_L (L mg^{-1})	q_m (mg g^{-1})	R^2	K_f (mg g^{-1})	n	R^2	
Chitin	0.04	14.71	–	1.42	0.45	–	[43]
Sugar beet pulp	6.92	0.22	0.94	0.19	3.85	0.98	[16]
Cassava Waste (Unmodified)	0.06	0.87	0.62	18.05	0.77	0.35	[42]
Cassava Waste (Modified)	0.02	0.94	0.85	9.99	1.10	0.93	[42]
Waste coirpith	1.73	93.40	0.99	27.51	2.08	–	[44]
Coffee residues	0.02	39.52	0.95	–	–	–	[45]
Low grade phosphate	0.20	7.54	0.98	1.69	2.23	0.93	[46]
Wild cocoyam (<i>Caladium bicolor</i>)	0.028	42.19	0.99	0.80	0.90	0.94	[9]
Neem leaf powder (oven dried)	0.09	157.80	0.99	18.70	0.45	–	[33]
<i>Chlorella vulgaris</i>	28.30	0.02	0.99	2.92	2.13	1.00	[47]
<i>Caulerpa lentillifera</i>	0.07	4.69	0.99	5.54	2.21	0.96	[48]
Coconut copra meal	0.18	4.92	1.00	1.09	2.76	0.86	[35]
Green coconut shell powder	0.19	285.70	0.99	9.92	1.79	0.97	[36]
Dried activated sludge	0.02	84.30	0.99	2.12	1.17	0.99	[37]
Live <i>Spirulina</i>	0.04×10^{-2}	655.00	–	–	2.30	–	[49]
Dead <i>Spirulina</i>	0.13×10^{-2}	355.00	–	–	0.86	–	
Maize Husk (Unmodified)	-0.07	-151.51	0.96	0.04×10^{-4}	0.38	0.98	[12]
Maize Husk (Modified)	0.89×10^{-3}	833.33	0.99	114.10	3.42	0.97	
Poly (amic acid) modified biomass baker's yeast	4.00	95.20	0.99	182.00	33.30	0.93	[50]
Cystine modified biomass (baker's yeast)	1.520	11.03	0.99	2.42	6.16	0.51	[51]
<i>Cupriavidus taiwanensis</i>	0.02	19.60	0.96	–	–	–	[52]
<i>Mimosa pudica</i> (inoculated)	0.03	42.90	0.98	–	–	–	
<i>Mimosa pudica</i> (not inoculated)	0.04	25.30	0.92	–	–	–	
<i>Bacillus jeotgali</i>	0.20	37.30	0.99	0.03	1.67	0.71	[53]
Vegetable biomass (olive pits)	0.04	9.39	0.99	33.60	3.15	0.93	[54]
Orange peel	1.379×10^{-3}	150.63	0.35	0.17×10^{-2}	2.00	0.78	[39]
Grape fruit	5.382×10^{-3}	110.16	0.93	0.21×10^{-2}	3.20	0.72	
Lemon peel	1.557×10^{-3}	209.08	0.88	0.21×10^{-2}	1.70	0.94	
Sugar beet pulp	0.124	0.13	0.74	7.16	0.98	0.99	[55]
<i>Egeria densa</i> (Dead biomass)	0.43	1.25	0.98	0.42	0.42	0.94	[40]
Modified agricultural waste	0.001	41.60	0.96	0.17	1.44	0.99	[13]
Native maleic acid-treated plant	0.002	500.00	0.97	4.93	1.66	0.97	
Activated carbon prepared from cashew nut shells	0.13	14.29	0.85	0.29	6.21	0.93	[31]
Neem leaf powder (activated and oven dried)	0.12	8.77	0.96	1.23	1.71	0.97	[18]

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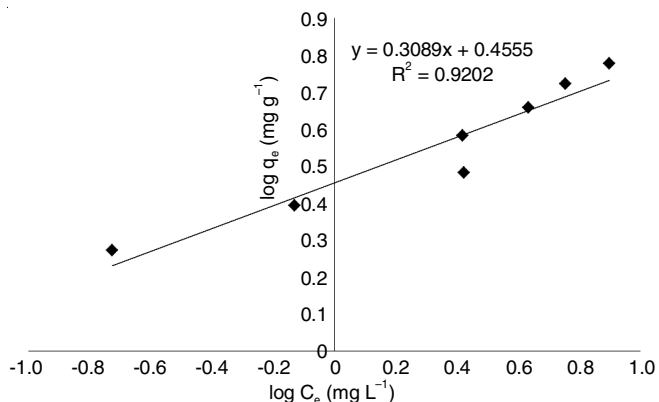


Fig. 7. Freundlich plot for adsorption of Cd(II) on neem leaf powder

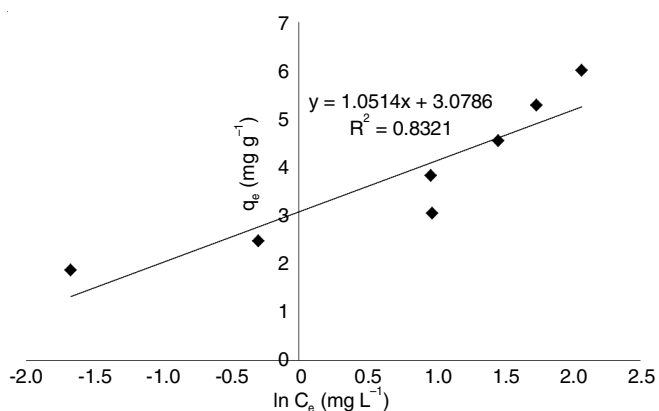


Fig. 8. Temkin plot for adsorption of Cd(II) on neem leaf powder

Conclusion

The neem (*Azadirachta indica*) leaf powder can be effectively used for the removal of Cd(II) ions. The adsorption process is influenced by factors, *viz.*, agitation time, Cd(II) concentration and adsorbent dosage. Thus, it is prerequisite to attain desired conditions for maximum efficiency prior to its application for Cd(II) decontamination from wastewater at large scale. The adsorption process was best fitted with the pseudo-second order kinetic equation and Freundlich isotherm model. Use of *Azadirachta indica* with particle size 500 μ for removing Cd(II) from wastewaters is effective, economically viable, eco-friendly and a sustainable approach.

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REFERENCES

- M. Rashad, E.M. Selim and F.F. Asaad, *Adv. Environ. Biol.*, **6**, 1716 (2012).
- J. Febrianto, A.N. Kosasih, J. Sunarso, Y.A. Ju, N. Indraswati and S. Ismadji, *J. Hazard. Mater.*, **162**, 616 (2009); <https://doi.org/10.1016/j.jhazmat.2008.06.042>.
- T.A. Khan, S.A. Chaudhry and I. Ali, *J. Mol. Liq.*, **202**, 165 (2015); <https://doi.org/10.1016/j.molliq.2014.12.021>.
- A. Sharma and K.G. Bhattacharyya, *Adsorption*, **10**, 327 (2005); <https://doi.org/10.1007/s10450-005-4818-x>.
- A. Dabrowski, *Adv. Colloid Interface Sci.*, **93**, 135 (2001); [https://doi.org/10.1016/S0001-8686\(00\)00082-8](https://doi.org/10.1016/S0001-8686(00)00082-8).
- D. Park, Y. Yun, J.H. Jo and J.M. Park, *Test. Ind. Eng. Chem. Res.*, **45**, 5059 (2006); <https://doi.org/10.1021/ie060002d>.
- N. Das, R. Vimala and P. Karthika, *Indian J. Biotechnol.*, **7**, 159 (2008).
- M. Rafatullah, O. Sulaiman, R. Hashim and A. Ahmad, *J. Hazard. Mater.*, **177**, 70 (2010); <https://doi.org/10.1016/j.jhazmat.2009.12.047>.
- M. Horsfall Jr. and A.I. Spiff, *Electron. J. Biotechnol.*, **8**, 162 (2005); <https://doi.org/10.2225/vol8-issue2-fulltext-4>.
- C. Ng, J.N. Losso, W.E. Marshall and R.M. Rao, *Bioresour. Technol.*, **85**, 131 (2002); [https://doi.org/10.1016/S0960-8524\(02\)00093-7](https://doi.org/10.1016/S0960-8524(02)00093-7).
- Y.S. Ho and G. McKay, *Process Biochem.*, **34**, 451 (1999); [https://doi.org/10.1016/S0032-9592\(98\)00112-5](https://doi.org/10.1016/S0032-9592(98)00112-5).
- J. C. Igwe and A. A. Abia, *Electron. J. Biotechnol.*, **10**, 536 (2007); <https://doi.org/10.2225/vol10-issue4-fulltext-15>.
- Z.A. Al Othman, A. Hashem and M.A. Habila, *Molecules*, **16**, 10443 (2011); <https://doi.org/10.3390/molecules161210443>.
- P.K. Ghosh, S. Bandyopadhyay and N.C. Jana, *Model. Earth Syst. Environ.*, **2**, 1 (2016); <https://doi.org/10.1007/s40808-015-0044-z>.
- N. Asizah, L.O.M. Harafah, N. Nurwati and B. Baheri, *Int. J. Eng. Sci.*, **5**, 8 (2016); <https://doi.org/10.9790/1813-0511020815>.
- Z. Reddad, C. Gerente, Y. Andres and P. Le Cloirec, *Environ. Sci. Technol.*, **36**, 2067 (2002); <https://doi.org/10.1021/es0102989>.
- A. Sharma and K.G. Bhattacharyya, *Indian J. Chem. Technol.*, **12**, 285 (2005).
- G.G. Pandhare, N. Trivedi, R. Pathrabe and D. Dawande, *Int. J. Innov. Res. Sci.*, **2**, 5752 (2013).
- B. Kiran and K. Thanasekaran, *Int. Biodeterior. Biodegrad.*, **65**, 840 (2011); <https://doi.org/10.1016/j.ibiod.2011.06.004>.
- S. Lagergren, *K. Sven. Vetensk. Akad. Handl.*, **24**, 1 (1898).
- Y.S. Ho and G. McKay, *J. Environ. Sci. Health A*, **34**, 1179 (1999); <https://doi.org/10.1080/10934529909376889>.
- P.S. Kumar and K. Karthika, *J. Eng. Sci. Technol.*, **4**, 351 (2009).
- N.M. Agyei, C.A. Strydom and J.H. Potgieter, *Cement Concr. Res.*, **30**, 823 (2000); [https://doi.org/10.1016/S0008-8846\(00\)00225-8](https://doi.org/10.1016/S0008-8846(00)00225-8).
- A.O. Dada, A.P. Olalekan, A.M. Olatunya and O. Dada, *J. Appl. Chem.*, **3**, 38 (2012).
- N. Sharma, D.P. Tiwari and S.K. Singh, *Int. J. Sci. Eng. Res.*, **3**, 1 (2012).
- S.R. Mishra, R. Chandra, J. Kaila A and S. Darshi B, *Environ. Technol. Innovat.*, **7**, 87 (2017); <https://doi.org/10.1016/j.eti.2016.12.006>.
- A. Shukla, T.H. Zhang, P. Dubey, J.L. Margrave and S.S. Shukla, *J. Hazard. Mater. B*, **95**, 137 (2002); [https://doi.org/10.1016/S0304-3894\(02\)00089-4](https://doi.org/10.1016/S0304-3894(02)00089-4).
- V.K. Garg, R. Gupta, A.B. Yadav and R. Kumar, *Bioresour. Technol.*, **89**, 121 (2003); [https://doi.org/10.1016/S0960-8524\(03\)00058-0](https://doi.org/10.1016/S0960-8524(03)00058-0).
- S.R. Mishra and R. Chandra, In Proceedings of 12th International Phytotechnologies Conference, Kansas State University, Manhattan, USA, pp. 27-30 (2015).
- A. Günay, E. Arslankaya and I. Tosun, *J. Hazard. Mater.*, **146**, 362 (2007); <https://doi.org/10.1016/j.jhazmat.2006.12.034>.
- S. Tangjuank, N. Insuk, J. Tontrakoon and V. Udeye, *World Acad. Sci. Eng. Technol.*, **3**, 4 (2009).
- S. Gupta and B.V. Babu, *J. Environ. Manage.*, **90**, 3013 (2009); <https://doi.org/10.1016/j.jenvman.2009.04.006>.
- A. Sharma and K.G. Bhattacharyya, *J. Hazard. Mater. B*, **125**, 102 (2005); <https://doi.org/10.1016/j.jhazmat.2005.05.012>.
- Y. Ho, *Water Res.*, **40**, 119 (2006); <https://doi.org/10.1016/j.watres.2005.10.040>.
- Y.S. Ho and A.E. Ofomaja, *Biochem. Eng. J.*, **30**, 117 (2006); <https://doi.org/10.1016/j.bej.2006.02.012>.
- G.H. Pino, L.M.S. de Mesquita, M.L. Torem and G.A. Saavedra Pinto, *Miner. Eng.*, **19**, 380 (2006); <https://doi.org/10.1016/j.mineng.2005.12.003>.

37. H. Wang, A. Zhou, F. Peng, H. Yu and J. Yang, *J. Colloid Interface Sci.*, **316**, 277 (2007); <https://doi.org/10.1016/j.jcis.2007.07.075>.
38. R. Apiratikul and P. Pavasant, *Bioresour. Technol.*, **99**, 2766 (2008); <https://doi.org/10.1016/j.biortech.2007.06.036>.
39. S. Schiewer and S.B. Patil, *Bioresour. Technol.*, **99**, 1896 (2008); <https://doi.org/10.1016/j.biortech.2007.03.060>.
40. J.M.T. de Abreu Pietrobelli, A.N. Módenes, F.R. Espinoza-Quiñones, M.R. Fagundes-Klen and A. Kroumov, *Int. J. Bioautom.*, **12**, 21 (2009).
41. D. Robati, *J. Nanostruc. Chem.*, **3**, 55 (2013); <https://doi.org/10.1186/2193-8865-3-55>.
42. A.A. Abia, M. Horsfall Jr. and O. Didi, *Bioresour. Technol.*, **90**, 345 (2003); [https://doi.org/10.1016/S0960-8524\(03\)00145-7](https://doi.org/10.1016/S0960-8524(03)00145-7).
43. B. Benguella and H. Benaissa, *Water Res.*, **36**, 2463 (2002); [https://doi.org/10.1016/S0043-1354\(01\)00459-6](https://doi.org/10.1016/S0043-1354(01)00459-6).
44. K. Kadirvelu and C. Namasivayam, *Environ. Res.*, **7**, 471 (2003); [https://doi.org/10.1016/S1093-0191\(02\)00018-7](https://doi.org/10.1016/S1093-0191(02)00018-7).
45. V. Boonamnuayvitaya, C. Chaiya, W. Tanthapanichakoon and S. Jarudilokkul, *Sep. Purif. Technol.*, **35**, 11 (2004); [https://doi.org/10.1016/S1383-5866\(03\)00110-2](https://doi.org/10.1016/S1383-5866(03)00110-2).
46. M.I. Kandah, *Sep. Purif. Technol.*, **35**, 61 (2004); [https://doi.org/10.1016/S1383-5866\(03\)00131-X](https://doi.org/10.1016/S1383-5866(03)00131-X).
47. Z. Aksu and G. Donmez, *Process Biochem.*, **41**, 860 (2006); <https://doi.org/10.1016/j.procbio.2005.10.025>.
48. P. Pavasant, R. Apiratikul, V. Sungkhum, P. Suthiparinyanont, S. Wattanachira and T.F. Marhaba, *Bioresour. Technol.*, **97**, 2321 (2006); <https://doi.org/10.1016/j.biortech.2005.10.032>.
49. H. Doshi, A. Ray and I.L. Kothari, *Curr. Microbiol.*, **54**, 213 (2007); <https://doi.org/10.1007/s00284-006-0340-y>.
50. J. Yu, M. Tong, X. Sun and B. Li, *Biochem. Eng. J.*, **33**, 126 (2007); <https://doi.org/10.1016/j.bej.2006.10.012>.
51. J. Yu, M.S. Tong, X. Sun and B. Li, *J. Hazard. Mater.*, **143**, 277 (2007); <https://doi.org/10.1016/j.jhazmat.2006.09.021>.
52. W. Chen, C. Wu, E.K. James and J. Chang, *J. Hazard. Mater.*, **151**, 364 (2008); <https://doi.org/10.1016/j.jhazmat.2007.05.082>.
53. C. Green-Ruiz, V. Rodriguez-Tirado and B. Gomez-Gil, *Bioresour. Technol.*, **99**, 3864 (2008); <https://doi.org/10.1016/j.biortech.2007.06.047>.
54. Z. Salem and K. Allia, *Int. J. Chem. React. Eng.*, **6**, 1 (2008); <https://doi.org/10.2202/1542-6580.1448>.
55. E. Pehlivan, B.H. Yanik, G. Ahmetli and M. Pehlivan, *Bioresour. Technol.*, **99**, 3520 (2008); <https://doi.org/10.1016/j.biortech.2007.07.052>.
56. A.D. Site, *J. Phys. Chem. Ref. Data*, **30**, 187 (2001); <https://doi.org/10.1063/1.1347984>.