



Equilibrium, thermodynamic and kinetic studies of nickel (ii) ions from aqueous solution on ODINA WODIER bark carbon

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ABSTRACT

The adsorption behavior of Nickel (II) ions from aqueous solution on ODINA WODIER (OW) bark carbon was investigated as a function of parameters such as adsorbent dose, initial Nickel (II) ions concentration, effect of solution P^H , contact time and temperature. The Freundlich and Langmuir adsorption models were applied to describe the equilibrium isotherms. From these experimental data and R_L value indicate the adsorption process is favourable. The thermodynamic parameters such as ΔH^0 , ΔS^0 , and ΔG^0 were evaluated and the adsorption process was physical adsorption. The pseudo-first-order, pseudo-second-order, Elovich kinetic models and the intra-particle diffusion model were used to fit the experimental data by using linear regression analysis method. The high correlation coefficient (γ) values indicate the fitness of the model. The kinetic of this process having high correlation coefficient (γ) were pseudo-second-order and intra-particle diffusion models. The adsorption mechanism is proved by FT-IR, XRD and SEM images. The OW bark carbon has high adsorption capacity and adsorption rate for the removal of Nickel (II) ions from aqueous solution.

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Introduction

The presence of trace amount of nickel (II) ions in water has been greater problems to the environment because of their toxicity and non-biodegradable nature. Waste water from various industries such as plating and cadmium–nickel battery, phosphate fertilizers, mining, pigments, stabilizers and alloys discharge large quantities to the environment. Therefore, a systematic study on the removal of nickel from wastewater is of considerable importance from an environmental point of view. A number of methods are available for the removal of metal ions from aqueous solutions. These are ion exchange, solvent extraction, reverse osmosis, precipitation and adsorption. Adsorption process has been and actually is the most frequently applied method in the industries, and consequently the most extensively studied. A number of workers have been used different adsorbents viz. pea nut shells [1], walnut shells [2], bone [3], automobile tires [5], Gypsum [6], activated carbon [7,8] baggase [9,10], soya cake [11], blast furnace slag [12], Fly ash [13], fertilizer plant waste slurry [14], activated carbon from olive pulp [15], perlite [16], modified natural clay [17], cation–exchange resin [18] and zeolites [19,20], etc., developed from various waste materials for the removal of heavy metals. There is still a need to develop low cost and efficient adsorbents for the removal of nickel (II) from wastewater.

Therefore, the objective of the present study was to investigate the feasibility of the use of Odina Wodier (*Lannea coromandelica*) bark carbon as a adsorbent for the removal of heavy metal in wastewater, Nickel(II) ion were chosen as the model metals in the present study. The effect of the initial concentration of the metals ions, contact time, adsorbent dose, temperature and pH on the adsorption capacity of OW was studied. In order to understand the adsorption process,

equilibrium isotherms, thermodynamic treatment of adsorption process and adsorption kinetic were also discussed.

Materials and Methods

Adsorbate

The Nickel (II) ions used in this study was purchased from Sigma-Aldrich. The stock solution was prepared by dissolving given amount of $NiSO_4 \cdot 6H_2O$ in double distilled water. The solutions of different concentrations used in various experiments were obtained by dilution of the stock solutions. The pH was adjusted using a 10% HNO_3 or a 1 N NaOH solution before adding adsorbent to the batch. The pH of the metal ion solution in the batch was kept relatively constant throughout the duration of the experiment by continually monitoring the solution pH with a pH meter. The solution temperature was monitored using thermostatic water bath.

Preparation of Odina Wodier (OW) bark carbon adsorbent

Odina Wodier bark was collected from near by areas. The collected materials were then washed with distilled water to remove all dust particles. The wasted materials were cut into small pieces (1-3 cm) and dried. The air dried odina wodier bark were treated with con sulphuric acid in a weight ratio of 1:1. The resulting black product was kept in a furnace maintained at $500^\circ C$ for about 12 hours followed by washing with water until free from excess acid and dried at $150 \pm 5^\circ C$, the carbon product obtained was grained well to fine powder (30 to 50 μm size), it was used for further adsorption experiment [21]. All chemical used for the experiments are S.d fine chemicals with high purity.

Effect of OW bark carbon adsorbent dose on the nickel (II) ions adsorption

To study the effect of OW bark carbon dose on the nickel(II) ions adsorption, different amounts of OW carbon(5-250mg) were added into a 250ml stopper glass containing a

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definite volume (50ml in each-flask) of fixed initial concentration (20mg/L) of nickel (II) ions solution without changing the solution pH at 30°C. The flasks were placed in a thermostatic water bath shaker and agitation was provided at 120 rpm for 60 min and the nickel (II) ions concentrations were measured at equilibrium.

Effect of contact time

The effect of contact time between adsorbent (OW bark carbon) and adsorbate (nickel (II) ions) was determined by keeping particle size, initial concentration, adsorbent dosage, pH and temperature are constant.

Effect of solution pH

In this study, the effect of pH on adsorption of nickel(II) ions on OW carbon was studied by mixing 20 mg/L initial nickel (II) ions concentration, 25 mg/50ml of adsorbent with different pH values (3.0-10.0) at 30°C. The pH was adjusted with 0.1N NaOH and 0.1N HCl solutions and measured by using a pH meter. Agitation was made for 60 min at a constant agitation speed of 120 rpm.

Batch adsorption method

The batch adsorption [22] experiments were carried out by adding a fixed amount of adsorbent (50 mg) into a number of 250 ml stopper glass flasks containing a definite volume(200 ml in each case) of different initial concentrations (5, 10, 15, 20 and 25 mg/L) of nickel(II) ions solutions without changing pH and at temperatures 30, 40, 50 and 60°C.

The flasks were placed in a thermostatic water bath shaker and agitation was provided 120 rpm for 180 min to ensure equilibrium was reached. At time t=0 and equilibrium, the nickel (II) ions concentration were measured by UV Visible spectrophotometer.

Each experiment was duplicated under identical conditions. The amount of adsorption at equilibrium, q_e (mg/g) was calculated by the following mass balance equation

$$q_e = \frac{(C_o - C_e)V}{W} \dots\dots\dots (1)$$

Where C_o and C_e (mg/L) are the liquid phase concentrations of nickel (II) ions at initial and equilibrium respectively. V (L) is the volume of the solution. w (g) is the mass of dry adsorbent used.

The nickel (II) ions removal percentage can be calculated as follows

$$\text{Removal percentage} = \frac{C_o - C_t}{C_o} \times 100 \dots (2)$$

Batch kinetic studies

The batch kinetic [22] experiments were basically identical to these of adsorption equilibrium method. The aqueous samples were taken at present time intervals and the concentrations of nickel (II) ions were similarly measured. All the kinetic experiments are carried out at 30, 40, 50 and 60°C at an initial concentration of 5, 10, 15, 20, and 25 mg/L. The amount of adsorption at time t, q_t (mg/g) was calculated by

$$q_t = \frac{(C_o - C_t)V}{W} \dots\dots\dots (3)$$

Where C_t (mg/L) is the liquid phase concentration of Nickel (II) ions at any time.

Theory of Adsorption isotherm

To quantify the sorption capacity of the absorbent for the removal of metal ions, the most commonly used isotherm, namely Freundlich and Langmuir have been adopted.

Freundlich isotherm

The linear form of Freundlich isotherm [23] is represented by the equation

$$\log q_e = \log K_f + \frac{1}{n} \log C_e \dots\dots\dots (4)$$

Where q_e is the amount of nickel (II) ions adsorbed per unit weight of the sorbent (mg/L), K_f is (mg/g(L/mg)) measure of adsorption capacity and $1/n$ is the adsorption Intensity. The value of K_f and n are calculated from the intercept and slope of the plot of $\log q_e$ vs $\log C_e$ respectively. The constant K_f and n values are given in table 1. In general K_f value increases the adsorption capacity for a given adsorbate increases. The magnitude of the exponent $1/n$ gives an indication of the favorability of adsorption. The value of $n > 1$ represents favorable adsorption condition [21] (or) the value of $1/n$ are lying in the range of 1 to 10 confirms the favorable condition for adsorption. This is further supported by Langmuir isotherm.

Langmuir isotherm

The Langmuir isotherm model [24] is based on the assumption that maximum adsorption corresponds to a saturated monolayer of solute molecules on the adsorbent surface. The linear form of the Langmuir isotherm equation can be described by

$$C_e/q_e = \frac{1}{Q_m b} + \frac{C_e}{Q_m} \dots\dots\dots (5)$$

Where C_e (mg/L) is the equilibrium concentration of the adsorbate, q_e (mg/g) is the amount of adsorbate per unit mass of adsorbent, Q_m and b are Langmuir constants related to adsorption capacity and rate of adsorption respectively. Q_m is the amount of adsorbate at complete monolayer coverage (mg/g) which gives the maximum adsorption capacity of the adsorbent and b (L/mg) is the Langmuir isotherm constant that relates to the energy of adsorption (or rate of adsorption)

The linear plot of specific adsorption capacity $\frac{C_e}{q_e}$ against the equilibrium concentration (C_e) (fig not given) shows that the adsorption obeys the Langmuir model. The Langmuir constant Q_m and b were determined from the slope and intercept of the plot and are presented in table (1)

In order to find out the feasibility of the isotherm, the essential characteristics of the Langmuir isotherm can be expressed in terms of dimensionless constant separation factor R_L [25,26] by the equation

$$R_L = \frac{1}{1 + bC_o} \dots\dots\dots (6)$$

Where C_o (mg/L) is the highest initial concentration of adsorbent and b (L/mg) is Langmuir isotherm constant. The parameter R_L indicates the nature of shape of the isotherm accordingly.

- $R_L > 1$ Unfavorable adsorption
- $0 < R_L < 1$ Favorable adsorption
- $R_L = 0$ Irreversible adsorption
- $R_L = 1$ Linear adsorption

The R_L values between 0 to 1 indicate favorable adsorption for all initial concentration (C_o) and temperatures studied. The calculated R_L value is given in Table. 2.

Thermodynamic treatment of the adsorption process

Thermodynamic parameters associated with the adsorption, viz standard free energy change (ΔG^0), standard enthalpy change (ΔH^0), and standard entropy change (ΔS^0) were calculated as follows. The free energy of adsorption process considering the adsorption equilibrium constant K_0 is given by the equation

$$\Delta G^0 = -RT \ln K_0 \dots\dots\dots (7)$$

Where ΔG^0 is the free energy of adsorption (kJ/mol), T is the temperature in Kelvin and R is the universal gas constant (8.314 J mol⁻¹K⁻¹).

The adsorption distribution coefficient K_0 for the sorption reaction was determined from the slope of the plot of $\ln(q_e/C_e)$ against C_e at different temperature and extrapolating to zero C_e according to the method suggested by Khan and Singh [27]. The adsorption distribution coefficient may be expressed in terms of enthalpy change (ΔH^0) and entropy change (ΔS^0) as a function of temperature,

$$\ln K_0 = \frac{\Delta H^0}{RT} + \frac{\Delta S^0}{R} \dots\dots\dots (8)$$

Where ΔH^0 is the standard heat change of sorption (kJ/mol) and ΔS^0 is standard entropy change (kJ/mol).

The value of ΔH^0 and ΔS^0 can be obtained from the slope and intercept of plot of $\ln K_0$ against $1/T$.

The value of thermodynamic parameter calculated from equation 7 and 8 are shown in table (3).

The thermodynamic treatment of the sorption data indicates that ΔG^0 values were negative at all temperatures.

Adsorption kinetics

The study of adsorption dynamics describes the solute uptake rate and evidently this rate controls the residence time of adsorbate uptake at the solid-solution interface.

The kinetics of nickel (II) ions adsorption on the OW bark carbons were analyzed using pseudo first-order [28] pseudo second-order [29] Elovich [30,31] and intra-particle diffusion [32] kinetic models.

The conformity between experimental data and the model-predicted values was expressed by the correlation coefficients (γ), (γ , and values close or equal to 1).

A relatively high correlation coefficient (γ) value indicates that the model successfully describes the kinetics of nickel (II) ions adsorption.

The pseudo first- order equation

The pseudo first-order equation is generally expressed as follows:

$$\frac{dq_t}{dt} = k_1(q_e - q_t) \dots\dots\dots (9)$$

Where: q_e and q_t are the adsorption capacity at equilibrium and at time t, respectively (mg g⁻¹). K_1 is the rate constant of pseudo first-order adsorption (L min⁻¹). After integration and applying boundary conditions $t = 0$ to $t = t$ and $q_t = 0$ to $q_t = q_t$ the integrated form of Eq.(9) becomes:

$$\log(q_e - q_t) = \log q_e - \frac{k_1}{2.303} t \dots\dots\dots(10)$$

The values of $\log(q_e - q_t)$ were linearly correlated with t. The plot of $\log(q_e - q_t)$ Vs t should give a linear relationship from which k_1 and q_e can be determined from slope and intercept of the plot respectively. The parameter of pseudo-first-order model is summarized in table 4.

The pseudo second- order equation

The pseudo second-order adsorption kinetic rate equation is expressed as

$$\frac{dq_t}{dt} = k_2(q_e - q_t)^2 \dots\dots\dots (11)$$

Where: K_2 is the rate constant of pseudo second-order adsorption (g mg⁻¹min⁻¹). For the boundary conditions $t = 0$ to $t = t$ and $q_t = 0$ to $q_t = q_t$ the integrated form of Eq. (11) becomes:

$$\frac{1}{(q_e - q_t)} = \frac{1}{q_e} + k_2 t \dots\dots\dots(12)$$

This is the integrated rate law for a pseudo second-order reaction. Equation (12) can be rearranged to obtain Eq.(13), which has a linear form:

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e} t \dots\dots\dots (13)$$

If the initial adsorption rate (h)(mg g⁻¹ min⁻¹) is :

$$h = k_2 q_e^2 \dots\dots\dots (14)$$

then Eqs. (13) and (14) become:

$$\frac{t}{q_t} = \frac{1}{h} + \frac{1}{q_e} t \dots\dots\dots(15)$$

The plot of (t/q_t) and t of Eq.(15) should give a linear relationship from which q_e and k_2 can be determined from the slope and intercept of the plot, respectively. The pseudo-second-order rate constants K_2 , the calculated h values, and the correlation coefficients (γ) are summarized in Table 4.

The Elovich equation

The Elovich model equation is generally expressed as

$$\frac{dq_t}{dt} = \alpha \exp(-\beta q_t) \dots\dots\dots (16)$$

Where: α is the initial adsorption rate (mg g⁻¹ min⁻¹) and β is the desorption constant (g mg⁻¹) during any one experiment. To simplify the Elovich equation. Chien and Clayton (1980) assumed $\alpha\beta t \gg 1$ and by applying boundary conditions $q_t = 0$ at $t = 0$ and $q_t = q_t$ at $t = t$ Eq.(16) becomes:

$$q_t = \frac{1}{\beta} \ln(\alpha\beta) + \frac{1}{\beta} \ln t \dots(17)$$

If nickel (II) ion adsorption fits the Elovich model, a plot of q_t vs. $\ln(t)$ should yield a linear relationship with a slope of $(1/\beta)$ and an intercept of $(1/\beta)\ln(\alpha\beta)$. The Elovich model parameters α , β , and correlation coefficient (γ) are summarized in table 4.

The intra particle diffusion model

The intra -particle diffusion model used here refers to the theory proposed by Weber and Morris [32] based on the following equation for the rate constant:

$$q_t = k_{id} t^{1/2} + C \dots\dots\dots(18)$$

Where k_{id} is the intra -particle diffusion rate constant (mg g⁻¹ min^{-1/2}) and C is the constant. If the rate limiting step is intra -particle diffusion, the graphical representation of (q_t) adsorbed nickel (II) ions(mg g⁻¹) depending on the square root of the contact time($t^{1/2}$) should yield a straight line passing through the origin[32].The slope of the plot of q_t Vs $t^{1/2}$ will give the value of the intra -particle diffusion coefficient (k_{id}) and correlation coefficient(γ) indicate the fitness of this model. The intercept value indicates that the curve is not passing through the origin, so the intra- particle diffusion is not only rate controlling step. The intra-particle parameters are summarized in table 4.

Results and discussion

Effect of OW bark carbon dose on Nickel (II) ions adsorption

The effect of OW bark carbon on nickel(II) ions adsorption were studied by varying the adsorbent concentration 5-250 mg/L for nickel (II) ion concentration of 20 mg/L. The adsorption increases with increase in adsorbent concentration; this is due to the increase in surface area and availability of more adsorption site. The maximum adsorption takes place at the range of 25-150 mg/50ml shown in Fig.1. So the optimum adsorbent carbon dose for the experiments was carried out using 25 mg/50 ml.

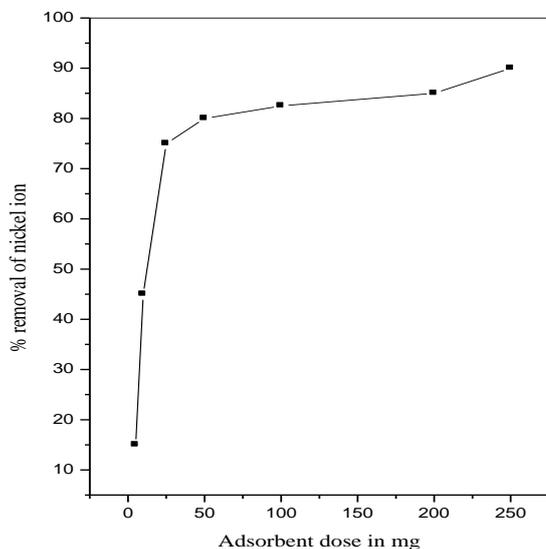


Fig.1-Effect of adsorbent dose on the adsorption of nickel ion by OWC

[Ni]=20 mg/L; Contact time=60 min; Temp=30°C

Effect of contact time

The effect of contact time were determined by using initial concentration of Nickel(II) ions is 20mg/L, adsorbent dose is 25 mg/50 ml, and pH is 6.5 at 30° C with different time interval such as 10,20,30,40,50,60,70 and 80 minutes. The experimental results indicate that adsorption equilibrium established within 40 minutes shown in Fig.2. Similar experiments were carried out at different metal ion concentration (5, 10,15, 20 and 25 mg/L), different temperature (30, 40, 50 and 60° C) and optimum pH also equilibrium reached within this time. So the further experiments were also carried out up to 40 minutes.

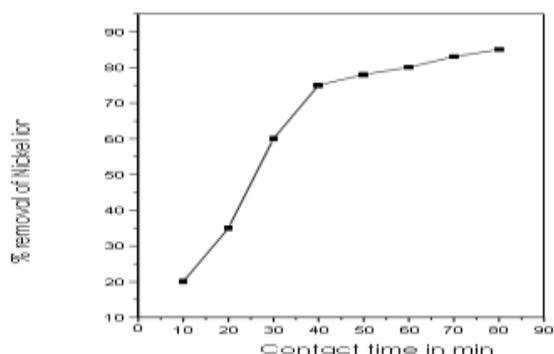


Fig.2-Effect of contact time on the adsorption of nickel ion by OWC
[Ni]=20 mg/L; Temp=30° C
Adsorbent dose=25 mg/50 ml

Effect of solution pH

The solution pH is one of the most important factors that control the adsorption of metal ions on the sorbent material. The adsorption capacity can be attributed to the chemical form of heavy metals in the solution at a specific pH (i. e, pure ionic metal form or hydroxyl-metal form). In addition, due to different functional groups on the adsorbent surface, which become active sites for the metal binding at a specific pH, the effect of adsorption can vary substantially. Therefore, an increase in pH may cause an increase or decrease in the adsorption capacity, resulting different optimum pH values dependent on the type of the adsorbent. To examine the effect of pH on the % removal of nickel, the pH of initial solutions were varied from 3.0 to 10.0 by adding acid or base into them [1]. This increase may be due to the presence of negative charge on the surface of the adsorbent that may be responsible for metal binding. However, as the pH is lowered, the hydrogen ions compete with the metal ions for the adsorption sites in the adsorbent; the overall surface charge on the particles become positive and hinders the binding of positively charged metal ions. On the other hand, decrease in adsorption under pH > 7 may be due to the occupation of the adsorption sites by anionic species which retards the approach of such ions further toward the adsorbent surface. From the experimental results, the optimum pH range for adsorption of the nickel (II) ions is 3.0 to 6.5 shown in Fig.3

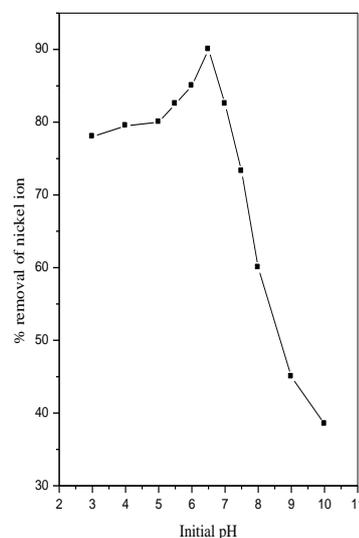


Fig.3-Effect of initial pH on the adsorption of Nickel ion by OWC

[Ni]=20 mg/L; Temp=30°C; Adsorbent dose=25 mg/50 ml; Contact time=60 min

Adsorption isotherms

The significance of the adsorption isotherms is that they show how the adsorbate molecules are distributed between the adsorbate at equilibrium conditions and the effect of equilibrium concentration on the adsorption capacity at different temperature. Two different isotherm models were used to fit the experimental data. These are Freundlich and Langmuir model constants values are given in the Table 1.

From the table it is clear that, the Langmuir isotherm constant value indicate the adsorption capacity (Q_m) linearly increases with increase in temperature. But adsorption intensity non-linearly increases with temperature. The Freundlich isotherm indicates that the adsorption capacity linearly increases with temperature and the n value indicates the adsorption is favorable process.

The Langmuir isotherm can be expressed in terms of a dimensionless separation factor (R_L). The R_L values at different temperature studied were calculated and are given in Table. 2. The R_L values between 0 and 1 indicate favorable adsorption for all the initial concentrations and temperature.

Thermodynamic parameters

The thermodynamic parameters of the adsorption process of nickel (II) ions with OW bark carbon are the changes in standard free energy change (ΔG^0), standard enthalpy change (ΔH^0), and standard entropy change (ΔS^0). The values of these parameters were calculated using eq.(7&8) at various initial concentrations and are shown in Table .3.

The thermodynamic treatment of the adsorption data indicates that ΔG^0 values were negative at all temperatures. The negative ΔG^0 confirm the spontaneous nature of adsorption nickel (II) ions by OW bark carbon. The lesser value of ΔG^0 suggests that adsorption is physical adsorption process. The positive value of ΔH^0 further confirms the endothermic nature of adsorption process. The positive ΔS^0 showed increased randomness at the solid –solution interface during the adsorption of metal ions onto OW adsorbent. In this condition the adsorbed water molecules, which are displaced by the adsorbate species, gain more translational entropy than is lost by adsorbate molecules, thus allowing the prevalence of randomness in the system [33]. This is also further supported by the positive values of ΔS^0 , which suggest that the freedom of metal ions is not too restricted in the adsorbent, confirming a physical adsorption. However, the value of ΔS^0 were found to be decrease as the initial concentration increases due to the decrease the randomness of nickel (II) ions. The ΔG^0 value increases with increase in temperature, the increase in enhancement of the adsorption capacity of adsorbent may be due to increase or enlargement of pore size and/or activation of the adsorbent surface.

Adsorption Kinetics

The kinetics of nickel (II) ions adsorption on OW bark carbon was studied with respect to different initial concentration. For evaluating the adsorption kinetics of nickel (II) ions, the pseudo-first-order, the pseudo-second-order, Elovich model and intra -particle diffusion model were used to fit the experimental data by using linear regression analysis method. The parameters of these model are summarized in table 4. The correlation coefficient (γ) values indicate the fitness of the model.

From the kinetic data, the pseudo-first- order and pseudo-second -order correlation coefficient (γ) value were almost same. But the q_e calculated from the model and the experimental value in pseudo first order are wide range of variations, but the q_e calculated from the pseudo-second order model and experimentally calculated value are almost same.. So that the adsorption of Ni^{2+} on OW barks carbon follow pseudo–second -order kinetic model.

The experimental data were used for Elovich model, the initial adsorption rate(α), desorption constant(β) and the correlation coefficient(γ) are calculated. From Elovich model indicate that the initial adsorption (α) increases with temperature similar to that of initial adsorption rate (h) in pseudo-second-order kinetics models. But the correlation coefficient (γ) is less than that of pseudo second order model.

The same experimental data were used for intra -particle diffusion model, the intra -particle diffusion constant (Kid), intercept and the correlation coefficient (γ) are calculated. From these data the intercept value indicate that the line were not

passing through origin, there are some other process affect the adsorption. But the correlation coefficient (γ) value is very high, so that the intra -particle diffusion takes place along with other process that may affect the adsorption.

Analytical evidenced for adsorption.

The FT-IR spectra of the raw OWC and nickel ion loaded OWC is recorded with an aim to understand the nature of adsorption.

A representative spectrum is shown in Figure 4a and 4b. it is evident from the spectra that the positions of the peaks remain unaltered after adsorption of nickel ion indicating that the chemical nature of the adsorbent remains unaffected.

Thus, the adsorption of nickel ions on the adsorbent is by physical forces but not by chemical forces which might alter the chemical nature of the adsorbent and consequently the position of the peaks

A representative X-ray diffraction (XRD) pattern of OWC before and after adsorption of nickel ion is shown in Fig.5a and 5b. In Fig.5a, the intense peaks show the presence of highly organized crystalline structure of raw activated carbon, after the adsorption of metal ions, the intensity of the highly organized peaks were slightly diminished (Fig.5b). however, there is no change in the 2 theta values.

This has been attributed to the adsorption of nickel ion on the upper layer of the crystalline structure of the carbon surface by means of physisorption

The SEM image of the raw OWC and nickel ion loaded OWC is recorded with an aim to understand the nature of adsorption. A representative spectrum is shown in Fig 6a and 6b. it is evident from the image that the bright and darkened portions indicating that the adsorption of nickel ions on the adsorbent

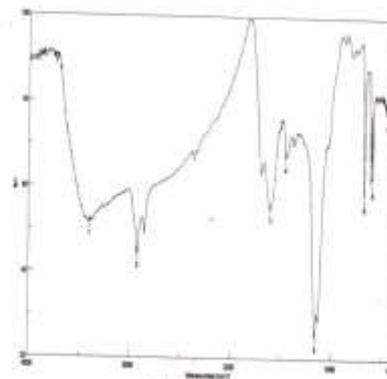


Fig.4a-FT-IR Spectrum of OWC before adsorption of nickel ion

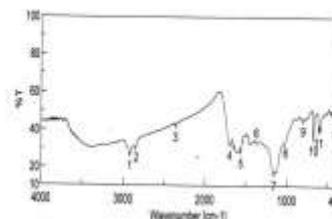


Fig.4b- FT-IR Spectrum of OWC after adsorption of nickel ion

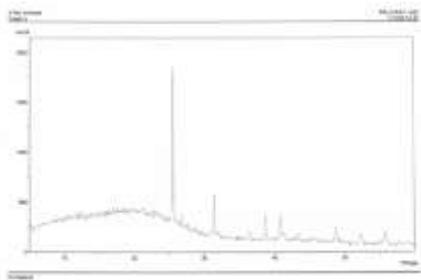


Fig.5a- XRD pattern of OWC before adsorption of nickel ion

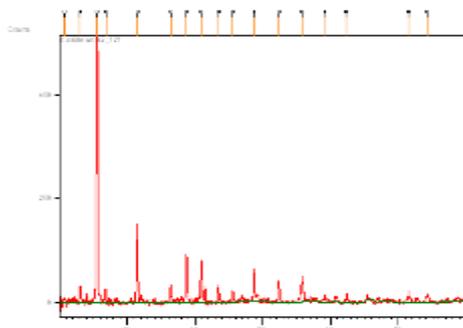


Fig.5b- XRD pattern of OWC after adsorption of nickel ion

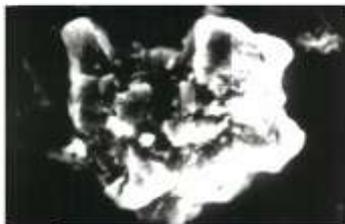


Fig.6a- SEM image of OWC before adsorption of nickel ion



Fig.6b- SEM image of OWC after adsorption of nickel ion

Conclusions

The adsorption of Nickel (II) ions from aqueous solution using OW bark carbon was investigated under different experimental conditions in batch process. The Freundlich and Langmuir adsorption capacity was found to be linearly increases. The thermodynamic parameters were found to be thermodynamically favourable physical adsorption process. The kinetic parameters with high correlation coefficient were pseudo-second-order and intra-particle diffusion models. The adsorption mechanism is proved by FT-IR, XRD and SEM images.

The results of the present studies indicate that the OW bark carbon could be employed for the removal of Nickel (II) ions from aqueous solution.

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Table .1.Langmuir and Freundlich isotherm parameter for adsorption of Nickel (II) on OW bark carbon adsorbent

Temperature °C	Langmuir parameter		Freundlich parameter	
	Q _m	b	K _f	n
30	32.3625	0.8262	14.1644	2.9735
40	33.7838	0.9164	15.2265	2.9525
50	35.2112	0.9331	16.5463	2.9516
60	36.6300	0.8205	17.7787	2.9129

Table. 2. Dimensionless separation factor (R_L)

Initial concentration(C _i)	Temperature			
	30°C	40°C	50°C	60°C
5	0.1950	0.1791	0.1765	0.1960
10	0.1080	0.0984	0.0967	0.1086
15	0.0746	0.0678	0.0667	0.0752
20	0.0571	0.0517	0.0509	0.0574
25	0.0462	0.0418	0.0411	0.0465

Table. 3. Thermodynamic parameter for the adsorption of nickel (II) ions on OW adsorbent

C _o	ΔG ^o				ΔH ^o	ΔS ^o
	30°C	40°C	50°C	60°C		
5	-6.7456	-7.4226	-8.1276	-8.7218	13.3724	66.4367
10	-4.2556	-4.8281	-5.6846	-6.4890	18.6217	75.2702
15	-3.0109	-3.5801	-4.215.04	-4.8837	15.9227	62.4062
20	-1.6965	-2.0991	-2.5630	-3.0765	12.2373	45.8997
25	-0.9400	-1.2929	-1.6784	-2.0648	10.4485	37.5553

Table.4.The kinetic parameter for the adsorption of Nickel (II) ions on OW bark carbon

C ₀	Temp °C	Pseudo first order			Pseudo second order				Elovich model			Intraparticle diffusion		
		q _e	K ₁	γ	q _e	K ₂	γ	h	α	β	γ	K _{id}	γ	Intercept
5	30	1.5177	0.0107	0.9973	10.7296	0.01372	0.9963	1.5797	7.2405	0.5535	0.9846	0.8081	0.9972	4.1773
	40	1.487	0.01004	0.999	10.7296	0.01462	0.996	1.6829	9.1537	0.5794	0.9799	0.7739	0.995	4.4645
	50	1.4548	0.00945	0.9995	10.7239	0.01572	0.9962	1.8077	11.7872	0.6064	0.9782	0.7181	0.9962	4.8405
	60	1.4585	0.00955	0.9991	10.7991	0.0155	0.9964	1.8057	11.3174	0.5964	0.9802	0.7517	0.9951	4.7422
10	30	1.5552	0.0112	0.9968	20.2429	0.00632	0.9963	2.5913	10.8861	0.9845	0.9845	1.5198	0.9968	7.0986
	40	1.5346	0.0108	0.9991	19.8689	0.00715	0.9951	2.8225	12.7043	0.9792	0.9792	1.5078	0.9945	7.5537
	50	1.4907	0.01013	0.9982	20.284	0.0077	0.9962	3.1666	9.0457	0.983	0.983	1.4737	0.9963	8.363
	60	1.4849	0.01011	0.9966	20.7469	0.00763	0.9969	3.2841	17.0269	0.9869	0.9869	1.5088	0.9981	8.5947
15	30	1.6346	0.0125	0.9982	27.027	0.004394	0.9941	3.2092	10.6474	0.1975	0.981	2.2694	0.9955	8.4194
	40	1.5827	0.0117	0.9974	27.933	0.00465	0.9952	3.6284	13.582	0.2006	0.9837	2.2304	0.9967	9.5976
	50	1.5371	0.01107	0.9955	28.7356	0.004901	0.9965	4.0469	18.9184	0.207	0.9635	2.2233	0.9973	10.665
	60	1.614	0.01101	0.9952	29.3	0.004032	0.9721	3.4614	19.381	0.2145	0.8578	2.1708	0.9041	10.5287
20	30	1.8059	0.0151	0.9969	32.8947	0.002751	0.9919	2.9762	7.4763	0.1471	0.9835	3.0447	0.9962	6.9105
	40	1.743	0.01414	0.998	33.67	0.002944	0.9921	3.3368	9.1569	0.149	0.9801	3.01	0.995	8.2498
	50	1.6916	0.0134	0.998	34.7222	0.003088	0.9931	3.723	11.0405	0.1491	0.9808	3.0062	0.9954	9.5102
	60	1.6129	0.0123	0.9955	35.461	0.003462	0.9957	4.3535	14.5795	0.1521	0.9869	2.9372	0.9981	11.3332
25	30	1.9364	1.0169	0.9966	38.3142	0.001976	0.9894	2.901	6.566	0.1205	0.9814	3.7181	0.9957	5.6901
	40	1.8945	0.0163	0.9973	39.5257	0.00203	0.9896	3.1746	9.5845	0.1185	0.9804	3.783	0.9951	6.6805
	50	1.898	0.0163	0.9983	41.4938	0.001919	0.9883	3.3036	9.9647	0.1135	0.9772	3.9558	0.9935	6.9801
	60	1.7947	0.0149	0.9959	41.841	0.002213	0.9922	3.3875	9.8409	0.1162	0.9835	3.8508	0.9964	9.1004