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# Biosorption of Nickel (II) from Aqueous Solutions and Electroplating Wastewater using Tamarind (*Tamarindus indica* L.) Bark

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**Abstract:** The biosorption experiments were carried out in a batch system as a function of pH, contact time, adsorbent dosage and initial concentration of nickel. Biosorption was pH dependent and maximum removal of Ni(II) was obtained at pH 7.0. The uptake of metal was very fast initially, but gradually slowed down and approached steady state after 30 minute during which no significance biosorption was observed. Langmuir, Freundlich and Dubinin-Radushkevich adsorption isotherm models were applied to the equilibrium data. The Langmuir isotherm model was found to be better applicable to the equilibrium data. The maximum biosorption capacity was 15.34 mg/g. From Dubinin-Radushkevich isotherm model, the free energy was calculated as 15.81 kJ/mol indicating that the biosorption of nickel was taken place by chemisorption. Kinetic evaluation of the experimental data showed that the biosorption process followed well pseudo-second order kinetics. The results of the study showed that the tamarind bark powder can be efficiently used as low cost alternative for the removal of divalent nickel from rinsing wastewater of plating factory.

**Key words:** biosorption, tamarind bark, Ni(II), electroplating, adsorption isotherm, adsorption kinetic.

## INTRODUCTION

Heavy metals released into the environment have been increasing continuously as a result of industrial activities and technological development. Due to their extended persistence in biological systems and tendency to bioaccumulate as they move up the food chain, they represent important environmental and occupational hazards (Wang *et al*., 2006). Wastewaters discharge from electroplating, electronic and metal cleaning industries often contain high concentrations of nickel (II) ions and causes serious water pollution (Borba *et al*., 2006). In India, the acceptable limit of nickel in drinking water is 0.01 mg/l and the industrial discharge limit in wastewaters is 2 mg/l (Kadirvelue *et al*., 2001).

The presence of nickel above critical levels may cause various types of acute and chronic disorder in human health, such as severe damages of lungs and kidney, gastrointestinal distress (e.g. nausea, vomiting and diarrhea), pulmonary fibrosis, renal edema and skin dermatitis (Akhtar and Iqbal., 2004). A number of treatment methods for the removal of metals ion from aqueous solutions have been reported, mainly, reduction, ion exchange, electrodialysis, electrochemical precipitation, evaporation, solvent extraction, reverse osmosis and adsorption (Zhang *et al*., 1998). The main drawbacks of these methods lie with relatively low treatment efficiency, complicated operation, high cost and possible secondary pollution (Saeed and Iqbal., 2003). Therefore eco-friendly and cost effective new technologies are required for the removal of heavy metals from these waste streams by appropriate treatment before releasing into receiving water bodies (Akar *et al*., 2009). Biosorption, which is the ability of certain biomaterials to bind and concentrate heavy metals from even dilute aqueous solutions, offers a technically feasible and economically attractive alternative to the conventional technologies for removal of heavy metal from the contaminated effluents (Qi and Aldrich., 2008).

The present work investigates the potential use of *Tamarindus indica* bark for biosorption of nickel from aqueous solution. The factors that affect biosorption capacity such as pH, contact time, metal ion concentration and adsorbent dosage were examined. Three adsorption isotherm models were used to evaluate the equilibrium data. The kinetic data were analyzed using adsorption kinetic models. The mechanism of the biosorption was examined using FTIR analysis

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## MATERIALS AND METHODS

### *- Preparation of Biosorbent:*

The bark of tamarind (*Tamarindus indica*) used in this study was collected from tamarind trees. The collected bark crushed into small size pieces, washed with 0.1 M HCl followed by rinsing with deionized water and dried in the oven at 60 ºC for 24 hours. The dried biomaterials powdered using domestic mixer and stored in airtight plastic bottles for further use as biosorbents without any chemical or physical treatment.

### *- Metal solution:*

Stock solution of Ni (II) (1000 mg/l) was prepared by dissolving the desired quantity of ($NiSO_4.6H_2\,O$) salt in double distilled water. Other concentrations were obtained by a proper dilution of stock solution. The chemicals used were of analytical grade.

### *- Metal Plating Wastewater:*

The rinse wastewater was collected from one of the nickel/chromium electroplating unit located in Mysore, India. The physicochemical characteristics of wastewater are delineated in Table 1.

**Table 1:** Physicochemical characteristics of electroplating rinse wastewater.

| Contents in mg/l | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $Ni^{2+}$ | Total Cr | $Cr^{6+}$ | $Ca^{2+}$ | $Mg^{2+}$ | $Cl^-$ | $SO_4^{2-}$ | $NO_3^-$ | $Na^+$ | $K^+$ | TDS | pH | Conductivity (µS/cm) |
| 177.6 | 8.62 | 7.70 | 126.23 | 56.14 | 159.75 | 26.78 | ND* | 63.8 | 3.14 | 790 | 7.19 | 1670 |

* Not detected

### *- Batch adsorption studies*

Batch biosorption experiment was carried out in 100 ml Erlenmeyer flask containing 50 ml of synthetic Ni(II) solution. 0.2 g of the previously prepared biosorbent was added to the solution. The mixture was shaken on a rotary shaker at 200 rpm at room temperature (25 ºC) for over the night to ensure equilibrium. The suspensions were filtered and the concentration of Ni(II) ions in the filtrate was analyzed spectrophotometrically using dimethyl glyoxime method (Vogel., 1961). The influence of pH on the biosorption of Ni(II) by biosorbent was investigated by mixing biosorbent with metal solution ($C_i$= 40 mg/l) at the pH range 1.0-7.0. The pH of the solution was adjusted to the desired values using 0.1 M HCl and 0.1 M NaOH. The amount of nickel ions adsorbed on biosorbent was calculated from the mass balance equation as follows

$$q_e = \frac{C_i - C_e}{m} \times V \tag{1}$$

where $q_e$ is the metal ion adsorbed (mg metal ion/ g biosorbent) at equilibrium, $V$ is the volume of the solution (L) , $C_i$ and $C_e$ are the initial and equilibrium concentration of metal ion (mg/l) and $m$ is the dry weight of the biosorbent (g). A control experiment was carried out at the same conditions in the absence of biosorbent and there was no change observed in the nickel concentration in this experiment.

### *- Adsorption Isotherm:*

Different concentrations of nickel solution (20-120 mg/l) were prepared and 4 g/l dose of tamarind bark powder was added to each of them. The pH of solution was adjusted to pH 7.0. The mixture was shaken to equilibrium, filtered and the filtrates were analyzed as mentioned in batch biosorption experiment.

### *- Adsorption Kinetic:*

Kinetic biosorption experiments were carried out at optimum pH for nickel adsorption (pH 7.0) at a biosorbent dosage of 4 g/l. In all kinetic experiment, the volume of the nickel solution ($C_i$= 40 mg/l) was 100 ml. The mixture was shaken and the solution samples were collected at regular time intervals, filtered and the filtrate analyzed as described above.

### *- FTIR Analysis:*

FTIR spectroscopy was done to identify the chemical functional groups present on unloaded and nickel loaded tamarind bark powder biomass using a JASCO-4100 model FTIR spectrometer. IR absorbance data were obtained for wavenumbers in the range of 400–4000cm$^{-1}$.

### - *Desorption and Regeneration:*

One g of tamarind bark was mixed with 100 ml of nickel solution (40 mg/l) for one hour at room temperature. The mixture was filtered using Whatman filter paper. The filter papers with its constituents were washed with 100 ml of 0.1 M HCl. The obtained mixture was shaken for 30 minutes and filtered. The filtrate was analyzed for desorbed metal ion. The sorbent was washed several times with deionized water and the regenerated sorbent was used in four consecutive adsorption-desorption cycles.

## RESULTS AND DISCUSSION

### - *Effect of pH:*

The pH of the aqueous solution is an important controlling parameter in the heavy metals adsorption processes (Barrera *et al*., 2006). This parameter is directly related with competition of hydrogen ions with metal ions to active sites on the biosorbent surface (Lodeiro *et al*., 2006). As the pH increased from 1.0 to 7.0, the biosorption efficiency of tamarind bark powder to remove nickel also increased from 21.9 to 90.5 % (Figure 1). The removal efficiency of nickel by tamarind bark increased with the increase of pH. When pH increased from 1.0 to 7.0, the biosorption efficiency increased from 21.9 to 90.5 %. At high pH, the reaction sites are deprotonated and negatively charged, so attract the metal and the removal increases (Lohani *et al*., 2008). As the pH lowered, however the over all surface charged on the biomass cells become positive, which will inhibit the approach of positively charge metal cations (Arshad *et al*., 2008). It is likely that protons will then compete with metal ions for ligands and thereby decreases the interaction of metal ions with the cells (Sag *et al*., 1995).

### - *Effect of Initial Ni(II) Concentration:*

Figure 2 showed the effect of metal ion concentration on the removal of Ni(II) by tamarind bark. The results showed that the metal uptake increases from 4.78 to 14.92 mg/g. The percentage removal of nickel by tamarind bark decreases from 95.61 to 49.74 % with increase in metal ion concentration from 20 to 120 mg/l. The initial concentration of metal provides an important driving force to overcome all mass transfer resistance of metal ion between the aqueous and solid phases (Nemr., 2009). Hence, a higher initial concentration of metal ions will increase the nickel uptake by tamarind bark. Though an increase in metal uptake was observed, the decrease in percentage biosorption may be attributed to lack of sufficient surface area to accommodate much more metal available in the solution (King *et al*., 2008).

### - *Effect of the Adsorbent Dose:*

The effect of adsorbent dosage on the biosorption of nickel by tamarind bark is shown in Fig.3. The biosorption of Ni(II) was studied at various sorbent dosage, ranging from 1.0 to 4.0 g/l. The initial concentration of nickel was 40 mg/l and the solution pH was 7.0. It was observed that the biosorption efficiency increased from 61.37 to 90.82 % and the metal uptake decreased from 24.55 to 9.08 mg/g with increase in adsorbent dosage from 1.0 to 4.0 g/l. An increase in biomass dosage generally increases the amount of biosorbed metal ions because an increase in surface area of the biosorbent, which consequently increases the number of binding sites (Esposito *et al*., 2001; Mohanty *et al*., 2006). The decrease in sorption capacity may be due to the fact that some sorption sites may remain unsaturated during the sorption process whereas the number of sites available for sorption increases by increasing the sorbent dose (Sharma and Foster., 1993).

### - *Adsorption Isotherm:*

Modeling equilibrium sorption is important for industrial applications of biosorption; it yields data that facilitates designing and optimizing the process (Schiewer and Patil., 2008). In this study, three important sorption isotherm models were selected to fit experimental data namely; Langmuir, Freundlich and Dubinin-Radushkevich (D-R) isotherm models.

The Langmuir isotherm model (Langmuir., 1918) is based on the assumption that a maximum adsorption corresponds to a saturated monolayer of solute molecules on the adsorbent surface, that the energy of adsorption is constant, and that there is no transmigration of adsorbate in the plane of the surface (Li *et al*., 2008). Langmuir isotherm is given by the following equation;

$$\frac{C_e}{q_e} = \frac{1}{K_L \cdot q_{\max}} + \frac{C_e}{q_{\max}} \tag{2}$$

where $q_e$ is the equilibrium metal ion concentration on the adsorbent (mg/g), $C_e$ is the equilibrium metal ion concentration in the solution (mg/l), $q_{\max}$ is the maximum biosorption capacity of adsorbent (mg/g) and $K_L$ is the Langmuir biosorption constant (l/mg). The values of Langmuir constants $q_{\max}$ and $K_L$ were calculated from the slope and intercept of the linear plot of $C_e/Q_e$ versus $C_e$.

The Freundlich isotherm model (Freundlich., 1906) was applied to study the biosorption behavior assuming a heterogeneous adsorption surface and active sites with different energy and its linearized equation can be given as:

$$\log q_e = \log K_f + \frac{1}{n}\log C_e \tag{3}$$

Where $K_f$ a constant is related to the biosorption capacity and $\frac{1}{n}$ is an empirical parameter related to the biosorption intensity of the adsorbent. The Freundlich isotherm constants $\frac{1}{n}$ and $K_f$ were calculated from the slopes and intercepts of the linear plot of $\log q_e$ versus $\log C_e$ .

The equilibrium data were applied to the Dubinin-Radushkevich (D-R) isotherm model (Dubinin., 1960) to determine the nature of biosorption processes as physical or chemical. The linear form of (D-R) isotherm equation is;

$$\ln q_e = \ln q_m - \beta\varepsilon^2 \tag{4}$$

where $q_e$ is the equilibrium metal ion concentration on the adsorbent (mol/g), $q_m$ is the maximum adsorption capacity (mol/g), $\beta$ is the activity coefficient related to the mean free energy of biosorption (mol$^2$/J$^2$) and ε is Polanyi potential. The value of ε can be calculated from the following relation:

$$\varepsilon = RT\ln(1+\frac{1}{C_e}) \tag{5}$$

where R is the universal gas constant (J /mol), T is the absolute temperature in Kelvin and $C_e$ is the equilibrium metal ion concentration in the solution (mol/l). Plots of In$q_e$ versus $\varepsilon^2$ gave a linear relationship with slopes of $\beta$ and intercepts of $q_{m.}$ The activity coefficient $\beta$ was further used to calculate the biosorption mean free energy (E; kJ/mol) which is required to transfer the sorbate to the surface of biosorbent from infinity in the solution, and the relationship can be calculated using the following equation:

$$E = \frac{1}{\sqrt{-2\beta}} \tag{6}$$

The Langmuir, Freundlich and Dubinin-Radushkevich (D-R) adsorption constants calculated from linearized form of the corresponding isotherms with their coefficients of determination are listed in Table 2.

**Table 2:** Theoretical parameters for isotherm models fitted on experimental data of Ni(II) sorption on tamarind bark .

| Langmuir isotherm | | | Freundlich isotherm | | | D-R isotherm | | |
|---|---|---|---|---|---|---|---|---|
| $q_{\max}$ (mg/g) | $K_L$(l/mg) | $R^2$ | 1/n | $K_f$ (l/g) | $R^2$ | $q_{\max}$ (mol/g) | E (kJ/mol) | $R^2$ |
| 15.34 | 0.261 | 0.991 | 0.25 | 5.53 | 0.947 | 4.955 x10$^{-4}$ | 15.81 | 0.965 |

The essential feature of Langmuir isotherm model can be expressed by means of a separation factor or equilibrium parameter ($R_L$), which is calculated according to the following equation:

$$R_L = \frac{1}{1+K_L C_i} \tag{7}$$

The value of $R_L$ indicates the type of biosorption isotherm to be linear ($R_L$=1), favorable (0<$R_L$<1), unfavorable ($R_L$>1) and irreversible ($R_L$=0). The $R_L$ value for the adsorption of Ni(II) onto tamarind bark was 0.161 at initial concentration of 20 mg/l and 0.031 at initial concentration of 120 mg/l. The maximum adsorption capacity $q_{\max}$ (mg/g) calculated from Langmuir isotherm in this study was compared with those adsorbent reported in literature and the values of adsorption capacities have been presented in Table 3. It is observed that tamarind bark has good adsorption capacity 15.34 mg/g when compared with other biosorbents. The data represent a favorable biosorption of Ni(II) by tamarind bark.

For the case of Freundlich isotherm model the small value of $\frac{1}{n}$ (Table 2) which is related to the distribution of bonded ions on the sorbent surface indicate that Ni(II) ions are favorably adsorbed by tamarind bark under all examined experimental conditions.

The numerical value of mean free energy $E$ calculated from Dubinin-Radushkevich (D-R) isotherm model was 15.81 kJ/mol. For an adsorption process with $E$ between 8 and 16 kJ/mol, the process is known to follow chemical ion exchange while the process is physical adsorption if $E$ value is less than 8 kJ/mol (Lodeiro *et al*., 2006). In the present study, it was found that the biosorption process of Ni(II) onto tamarind bark is chemical adsorption.

According to coefficient of determination, all models fit the data reasonably well, but the best fit was obtained with the Langmuir isotherm model. This suggests that Ni(II) ions are adsorbed onto the surface of tamarind bark in a monolayer pattern.

**Table 3:** Comparison of biosorption capacity of tamarind bark for Ni(II) removal with that of different biosorbents.

| Adsorbent | pH | $q_{max}$ (mg/g) | References |
|---|---|---|---|
| Tea factory waste | 4.0 | 15.26 | (Malkoc and Nuhoglu., 2005) |
| Activated sludge | 5.00 | 7.78 | (Hammaini *et al*., 2007) |
| Baker's yeast | 6.75 | 11.40 | (Patmavathy *et al*., 2003) |
| Lignin | 5.5 | 5.99 | (Guo et al., 2008) |
| Irish peat moss | 4.5 | 14.50 | (Gupta *et al*., 2009) |
| Waste pomace of olive oil factory | 4.0 | 14.80 | (Nuhoglu and Malkoc., 2009) |
| Cross- linked chitosan | 5.6 | 6.40 | (Tan *et al*., 1999) |
| *Aspergillus niger* | 7.2 | 6.63 | (Amini *et al*., 2009) |
| Protonated rice brane | 6.0 | 46.51 | (Zafar *et al*., 2007) |
| *Bacillus thuringiensis* | 6.0 | 35.46 | (Ozturk., 2007) |
| Bagass fly ash | 6.0 | 6.49 | (Srivastava *et al*., 2006) |
| Tamarind bark | 7.0 | 15.34 | Present study |

### - *Adsorption Kinetic:*

The rate of metal sorption is an important factor and prerequisite for determining the reactor design and process optimization for a successful practical application (Iqbal *et al*., 2009). Fig.4. presents the removal efficiency of Ni(II) by tamarind bark as a function of time. The results revealed that the biosorption efficiency increased rapidly at initial stages with increasing contact time up to 30 min and after that no significant biosorption was observed with the time. This could be attributed to a large number of vacant binding sites, which are available for biosorption during the initial stages, but thereafter the occupation of the remaining vacant sites will be difficult due to the repulsive forces between the Ni(II) ions on the solid and the liquid phases (Vijayaraghavan *et al*., 2008). The rapid kinetics has significant practical importance, as it will facilitate small reactor volumes ensuring high efficiency and economy (Loukidou *et al*., 2004).

The results obtained from kinetic experiments were analyzed using pseudo-first-order (Lagergren., 1898), pseudo-second-order (Ho and McKay., 2000) and intra-particle diffusion kinetic models (Weber and Morris., 1963).

The pseudo-first-order kinetic model assumes that the rate of change of solute uptake with time is directly proportional to the difference in saturation concentration and the amount of solid uptake with time (Yuan *et al*., 2009). The linear form of pseudo-first order is generally expressed as;

$$\log(q_e - q_t) = \log q_e - \frac{K_{1,ads}}{2.303} t \quad (8)$$

where $q_t$ (mg/g) is the amount of metal ion adsorbed at time $t$, (min), $q_e$ is the amount of metal ion adsorbed at equilibrium (mg/g), $K_{1,ads}$ is the constant of pseudo first-order kinetic model (min$^{-1}$). The values of $K_{1,ads}$ and $q_e$

can be obtained from the slope and intercept of the plot of $\log(q_e - q_t)$ versus t respectively.

The pseudo-second-order kinetic model is based on the assumption of chemisorption of the adsorbate on the adsorbent (Naiya *et al*., 2009). The linear form of this model is given as

$$\frac{t}{q_t} = \frac{1}{K_{2,ads} \cdot {q_e}^{2}} + \frac{1}{q_e} \cdot t \tag{9}$$

where $K_{2,ads}$ is the constant of pseudo second-order kinetic (g mg$^{-1}$min$^{-1}$). The values of $K_{2,ads}$ and $q_e$ can be calculated from the slope and intercept of the plot of $\frac{t}{q_t}$ versus $t$.

The values of the parameters along with coefficient of determination for each model are tabulated in Table 4.

**Table 4:** Parameter values calculated using the pseudo first-order, pseudo second-order and intra-particle diffusion models for the biosorption of Ni(II) by tamarind bark.

| | First-order kinetic model | | | Second-order kinetic model | | | Intra-particle diffusion | |
|---|---|---|---|---|---|---|---|---|
| $q_{exp}$ (mg/g) | K $_{1,ads}$(min$^{-1}$) | $q_{eq}$(mg/g) | $R^2$ | K $_{2,ads}$(g mg$^{-1}$min$^{-1}$) | $q_{eq}$ (mg/g) | $R^2$ | $K_d$(mg/g min$^{0.5}$) | $R^2$ |
| 9.08 | 28.78x10$^{-3}$ | 1.458 | 0.956 | 41.03x10$^{-3}$ | 9.216 | 0.999 | 0.129 | 0.763 |

It is clear from the table that, the coefficient of determination of pseudo-second-order model was higher in comparison to pseudo-first-order model and the calculated experimental value of $q_e$ was close to that for pseudo-second-order kinetic model. This suggests that, the pseudo-second-order kinetic model fitted the biosorption kinetic data of Ni(II) onto tamarind bark better than the pseudo-first-order kinetic model. In accordance with pseudo-second-order kinetic model, the rate-limiting step of this sorption system may be chemisorption involving valency forces through sharing or exchange of electrons between sorbent and sorbate (Dundar *et al*., 2008). The low coefficient of determination value obtained for intra-particle diffusion model indicates that both surface adsorption and intra-particle diffusion are involved in this biosorption system. This consisted with results taken from the pseudo-second-order model that the chemisorption may be the rate-limiting step.

***-IR analysis:*** The pattern of sorption of metals onto plant materials is attributed to the active groups and bonds present on them (Krishnani *et al*., 2008). Plant cell walls, mainly consisting of polysaccharides, proteins and lipids, offer many functional groups such as carboxyl, carbonyl, hydroxyl and amino which can be involved in metal binding (Macfie and Welbourn., 2008). The FTIR spectra of tamarind bark before and after nickel adsorption are shown in Fig.5.

The IR spectrum of unloaded tamarind bark showed peaks at 3457-2218cm$^{-1}$ which is due to –NH stretching presenting amino group as well as –OH group bound to alcohol (Park *et al*., 2005). The bands that are observed at 2923 and 2856 cm$^{-1}$ suggest the presence of C-H group of aliphatic acids (Farinella *et al*., 2007). The peak observed at 1737 cm$^{-1}$ may be assigned to the vibration of C=O of the ester group (Kamala *et al*., 2005). The peak at 1647 cm$^{-1}$ was the result of CO stretching mode with NH deformation and was indicative of amide 1 (Mukhopadhyay., 2008). The peak at 1510 cm$^{-1}$ indicated the presence of C=C stretching of phenol aromatic ring (Guo and Lua., 2003). The peak at 1458 cm$^{-1}$ may be attributed to symmetric stretching vibration of C=O (Yuan *et al*., 2009). The band observed at 1321 cm$^{-1}$ can be ascribed to –COOH group.the bands in range of 1161 and 1052 cm$^{-1}$ can be assigned to the –CN stretching vibration of protein fractions (Kapoor and Viraraghavan., 1997). The peaks less than 1000 cm$^{-1}$ represents the "fingerprint" region which attributed to the phosphate group which is one of the functional groups of which nucleic acids are composed (Guibaud *et al*., 2003).

The IR spectrum of tamarind bark after nickel biosorption showed that the band at 3458 cm$^{-1}$ became more broader and showed the disappearance of bands at 3068, 3224, 3268 and 3318 cm$^{-1}$ due to change in nature of binding (Pradhan *et al*., 2007) after interaction with nickel ions. The bond intensity at 2923 and 2856 cm$^{-1}$ was broader after nickel biosorption. The peak at 1647 cm$^{-1}$ was not as sharp as found in unloaded biosorbent. The bond intensity at 520 and 611 cm$^{-1}$ decreased after nickel biosorption. The above observations indicated that the main functional groups involved in biosorption process were hydroxyl, carboxyl, amine and phosphate groups.

***- Reusability of Biosorbent:***

The regeneration of the biosorbents is of crucial importance in assessing their potential for commercial application (Sangi *et al*., 2008). Desorption of nickel from tamarind bark using 0.1 M HCl resulted in 75.17, 72.78, 70.46, 66.63 % recovery of metal ion from biosorbent in four consequent cycles. The biosorption efficiency of tamarind bark decreased by 15 % after the fourth cycle. These results showed that, the tamarind bark can be used repeatedly for the removal of Ni(II) with high efficiency.

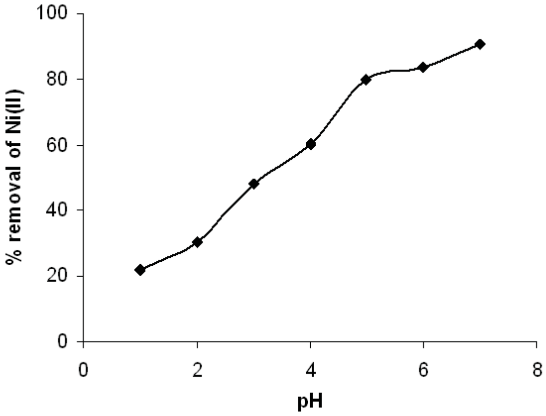

**Fig. 1:** Effect of solution pH on the biosorption of Ni(II) by tamarind bark (initial concentration of Ni(II) = 40 mg/l., concentration of biosorbent = 4 g/l, agitation speed = 200 rpm).

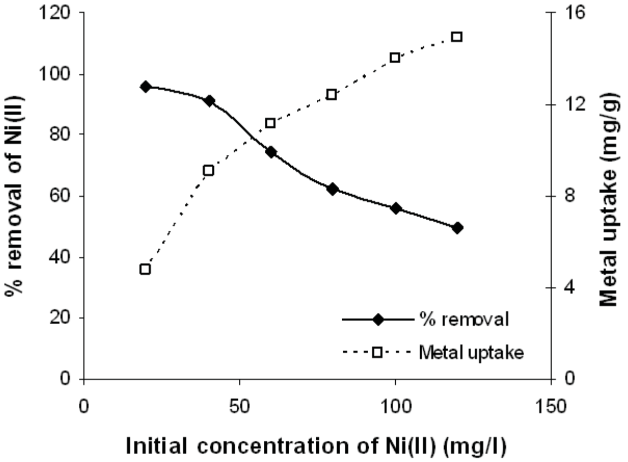

**Fig. 2:** Effect of initial metal concentration on the biosorption of Ni(II) by tamarind bark (pH = 7.0, concentration of biosorbent = 4 g/l, agitation speed = 200 rpm).

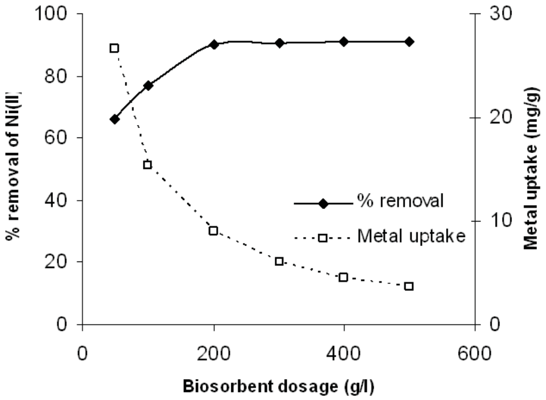

**Fig. 3:** Effect of biosorbent dosage on the biosorption of Ni(II) by tamarind bark (pH = 7.0, concentration of Ni(II) = 40 mg/l, agitation speed = 200 rpm)

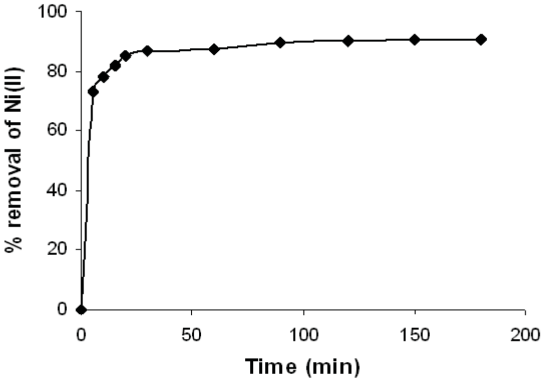

**Fig. 4:** Effect of contact time on biosorption of Ni(II) by tamarind bark (pH = 7.0, concentration of Ni(II) = 40 mg/l, concentration of biosorbent = 4 g/l, agitation speed = 200 rpm).

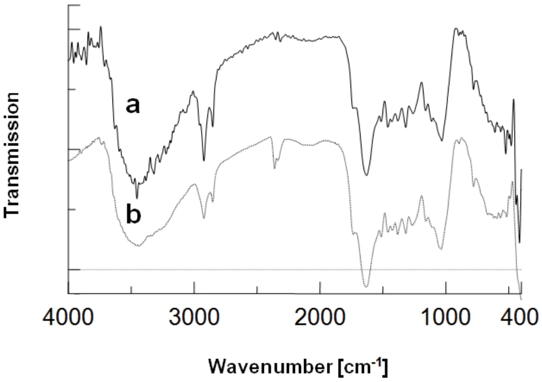

**Fig. 5:** FTIR spectrum of unloaded (a) and nickel-loaded (b) biomass.

### - *Application to Electroplating Wastewater:*

In order to assess the performance of tamarind bark for the removal of Ni(II) from electroplating wastewater, experiment was carried out under the conditions of pH 7.0 , contact time of one hours and biosorbent dosage of 8 g/l. The result showed 72.31 % removal of Ni(II) from wastewater. The remaining concentration of nickel in wastewater (49.17 mg/l) was treated under the conditions of first treatment. This stage resulted in the reduction of nickel concentration to 1.56 mg/l which meets the Indian standard for industrial wastewater discharge.

## *Conclusions:*

Tamarind bark was found to be an effective biosorbent for the removal of nickel from rinsing wastewater of plating factory. The results obtained from the present study revealed that the sorption efficiency was dependent on operating conditions such as pH, contact time, biomass dosage and initial metal concentration. As pH increased, the metal biosorption increased up to pH 7.0. Increases of biomass dosage lead to increase in nickel adsorption due to increase in the surface area. The adsorption isotherm of nickel by tamarind bark could be adequately described by Langmuir isotherm. The monolayer capacity was 15.34 mg/g. The $R_L$ values showed that the biosorption was favorable. The kinetic data was well described by pseudo second order kinetic. The intra-particle diffusion was not the rate limiting step in the biosorption process. The kinetic data also indicated that the equilibrium attained within the initial 30 minutes of contact time between the sorbate and sorbent. The FTIR analysis indicated that the functional group of hydroxyl, carboxyl, amine and phosphate were responsible for nickel binding. The results showed that the recovery of metal and the reusability of biosorbent are possible. The findings of this study revealed that tamarind bark powder is a promising biosorbent for the removal of nickel from contaminated wastewater.

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