

ORIGINAL RESEARCH PAPER

## ADSORPTIVE REMOVAL OF NICKEL (II) USING LUFFA CYLINDRICA: EFFECT OF NaCl CONCENTRATION ON EQUILIBRIUM AND KINETIC PARAMETERS

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**Abstract:** In this study, biosorption of Nickel (II) from saline solutions by *Luffa Cylindrica*, was studied as a function of pH, initial Nickel (II) and NaCl concentrations in a batch system. The sorbent exhibited the maximal Nickel (II) uptake at pH 6 in the absence and in the presence of increasing concentration of NaCl. Equilibrium uptake increased with the Nickel (II) concentration up to 100 mg·L<sup>-1</sup> and diminished considerably in the presence of increasing concentrations of salt up to 50 g·L<sup>-1</sup>. At 100 mg·L<sup>-1</sup>, initial Nickel (II) concentration, *Luffa Cylindrica* 23.35 mg·g<sup>-1</sup> of Nickel (II) without salt medium. When NaCl concentration was raised to 50 g·L<sup>-1</sup>, this value dropped to 13.55 mg·g<sup>-1</sup> of Nickel (II) at the same conditions resulting in 41.98 % decrease in biosorption capacity. The equilibrium sorption data were analyzed by using Freundlich and Langmuir models. Freundlich was the most suitable adsorption model for describing the biosorption equilibrium data of Nickel (II) both individually and in salt-containing medium. Pseudo-second-order kinetic model also fitted well to both systems, viz. Nickel (II) and Nickel (II) + NaCl. Isotherm constants varied due to the level of salt were expressed as a function of initial NaCl concentration.

**Keywords:** biosorption, isotherm, *Luffa Cylindrica*, nickel, kinetics

## INTRODUCTION

Considerable research has been carried out in developing cost-effective heavy metal removal techniques. Physicochemical methods, such as chemical precipitation, chemical oxidation or reduction filtration, electrochemical treatment, application of membrane technology, evaporation recovery, solvent extraction and ion-exchange processes, have been traditionally employed for heavy metal removal from industrial wastewater. However, these techniques may be ineffective or extremely expensive, especially when the metals are dissolved in large volumes of solution at relatively low concentrations (around 1 - 100 g·mL<sup>-1</sup>) [1].

Biosorption utilizes the ability of certain materials to accumulate heavy metal from aqueous solutions by either metabolically mediated or physicochemical pathways of uptake [2]. Biosorption has distinct advantages over conventional methods of treatments: the process does not produce chemical sludge; it is more efficient and easy to operate. A major advantage of biosorption is that it can be used in situ, and with proper design that may not need any industrial process operations and can be integrated with many systems in the most eco-friendly manner [3]. Recently, many researchers have interested to find the cheap natural alternative adsorbents such as lignocellulosic materials especially the olive pits/stones [4], date stones [5] peach pits and almond shells [6]. As consequently, this strategy reduces significantly the treatment cost and contributes to a sustainable development. In this paper, we have used the *Luffa Cylindrica*, an agricultural waste abundantly available in the south of Algeria (Laghouat region) as an adsorbent to remove Nickel (II) from the water [7].

The ability of *Luffa Cylindrica* as an adsorbent for Nickel (II) has been understudied. In addition, the roles of salts on metal biosorption by this biosorbant have not been investigated. Besides, industrial wastewater generally contains different kinds of chemical compounds, which may significantly affect metal biosorption, including soluble salts such as sodium chloride. Thus, the effect of the concentration of NaCl salt on the equilibrium and kinetics of the nickel (II) biosorption kinetics on *Luffa Cylindrica* was studied.

### Technical information

Adsorption is a well-known equilibrium separation process. Equilibrium data, commonly known as adsorption isotherms, are basic requirements for the analysis and design of adsorption systems. The parameters of isotherm models and the underlying thermodynamic assumptions of the models often provide information on the adsorption mechanisms, the surface properties and the capacity or affinity of the adsorbent. One of the difficulties in describing the adsorption equilibrium of metal ions from waste streams is that wastewaters contain not one, but many components. If mono-component adsorption models could describe the equilibrium of metal ion in the presence of other components, such as salt, the individual isotherm parameters changed due to the level of salt can be related to initial NaCl concentration and these expressions may be useful to define the equilibrium data in salt-containing solutions. To discover the sorption capacity of *Luffa Cylindrica* for Nickel (II) in the absence and in the presence of changing concentrations of salt, the experimental data points were fitted to the Langmuir, Freundlich. Which are the most frequently used equations in the literature

describing the non-linear equilibrium between adsorbed metal on the cells ( $q_{eq}$ ) and metal ion in solution ( $C_{eq}$ ) at a constant temperature.

### Langmuir adsorption isotherm

Langmuir sorption model that was originally developed to describe the gas-solid phase adsorption of activated carbon has traditionally been used to quantify and contrast the performance of different sorbents and the model serves to estimate the maximal uptake values where they cannot be reached in the experiments. The empirical Langmuir equation which is valid for monolayer sorption onto a completely homogeneous surface with a finite number of identical sites and with negligible interaction between adsorbed molecules is given by Equation 1 [8]:

$$q_{eq} = \frac{Q_0 \cdot bC_{eq}}{1 + bC_{eq}} \quad (1)$$

Where  $q_{eq}$  is the amount of metal ion bound per gram of dried *Luffa Cylindrica* at equilibrium ( $\text{mg} \cdot \text{g}^{-1}$ ), and  $C_{eq}$  is the residual (equilibrium) metal concentration left in solution after binding ( $\text{mg} \cdot \text{L}^{-1}$ ). The parameters  $Q_0$  and  $b$  is Langmuir constants related to maximum adsorption capacity and bonding energy of adsorption, respectively, which are functions of the characteristics of the system as well as time.

### Freundlich adsorption isotherm

The Freundlich isotherm model assumes neither homogeneous site energies nor limited levels of sorption. The Freundlich model is the earliest known empirical equation and is shown to be consistent with exponential distribution of active sites, characteristic of heterogeneous surfaces. It is expressed by the following Equation 2 [9]:

$$q_{eq} = K_f + C_{eq}^{\frac{1}{n}} \quad (2)$$

where  $K_f$  and  $n$  are the mono-component Freundlich constants characteristic of the system.  $K_f$  and  $n$  are indicators of biosorption capacity and biosorption intensity, respectively.

On the other hand, two simplified kinetic models, including pseudo-first-order [10] and pseudo-second-order [11], were used to test the biosorption kinetics of Nickel (II) in the absence and in the presence of salt. The pseudo-first-order rate expression is generally expressed as follows (Equation 3):

$$\frac{dq}{dt} = K_1(q_{eq} - q) \quad (3)$$

Where  $K_1$  is the rate constant of first-order sorption ( $\text{min}^{-1}$ ),  $q$  is the metal ion uptake by unit mass of sorbent at any time ( $\text{mg} \cdot \text{g}^{-1}$ ). After integration and applying boundary conditions,  $t = 0$  to  $t = t$  and  $q = 0$  to  $q = q_t$ ; the integrated form of eqn. (3) becomes a linear function and model parameters of  $q_{eq}$  and  $k_1$  may be obtained from  $\log(q_{eq} - q)$  vs.  $t$  plot.

The pseudo-second-order equation is also based on the sorption capacity of the solid phase and on the assumption that the sorption processes involves chemisorption

mechanism and for Nickel (II) both singly and in the mixture are expressed as follows (Equation 4):

$$\frac{dq}{dt} = K_2(q_{eq} - q) \quad (4)$$

Where  $K_2$  is the rate constant of second-order biosorption ( $\text{g}\cdot\text{mg}^{-1}\cdot\text{min}^{-1}$ ). For the same boundary conditions, the integrated form of equation (4) gives a linear relationship. The values of  $q_{eq}$  and  $K_2$  can be estimated from the slope and intercept of the  $t/q$  against  $t$  plot.

## MATERIALS AND METHODS

### Sorbent preparation

The *Luffa Cylindrica* collected from a local farmland in Laghouat region (Algeria) is used in this study. This material was cut into small pieces and washed several times with double distilled water in order to eliminate the impurities such as the sand and dust. After that, the material was dried at 105 °C for 120 min to evaporate the humidity. The obtained material was ground using a grinder of type Janke and Kunkel IKA labortechnik to improve its specific area. Finally, the powder was sieved at different diameters between 0.063 and 0.5 (diameter uses less than 0.063 mm).

### Preparation of Nickel (II) and salt solutions for biosorption

All the chemicals used were of analytical grade. Synthetic stock solutions of Nickel (II) ( $1 \text{ g}\cdot\text{L}^{-1}$ ) (E. Merck) and salt ( $100 \text{ g}\cdot\text{L}^{-1}$ ) (E. Merck) were prepared by dissolving weighted amount of the hexahydrate nickel chloride  $\text{NiCl}_2\cdot 6\text{H}_2\text{O}$  and NaCl in distilled water, separately. For single Nickel (II) and binary Nickel (II)-salt mixture studies, desired combinations of Nickel (II) and salt were obtained by diluting stock solutions of these components and mixing them in the test medium. Before mixing with biosorbent solution, the *pH* of each test solution was adjusted to the required value (*pH* was measured using *pH* meter (ORION model 420A) Thermo Scientific). ACS reagent grade  $\text{H}_2\text{SO}_4$ , NaOH and buffer solutions (E. Merck) were used to adjust the solution *pH*. The ranges of initial concentrations of Nickel (II) and salt prepared from stock solutions varied from 10 to 100  $\text{mg}\cdot\text{L}^{-1}$  and 0 to 50  $\text{g}\cdot\text{L}^{-1}$ , respectively.

### Biosorption studies

Biosorption experiments were carried out using batch technique in 250 mL Erlenmeyer flasks containing 100 mL of Nickel (II) or Nickel (II)-salt mixture. Synthetic solutions at desired level of each component were adjusted at *pH* 6. The flasks were agitated at 300 rpm constant shaking rate for 180 min to ensure that equilibrium was reached. The contents were filtered, and the metal ion or metal-salt mixture bearing solution were analyzed for the remaining Nickel (II) ions. Studies were performed at a constant temperature of  $25 \pm 1$  °C.

All the biosorption experiments were repeated twice to confirm the results. The data were the mean values of the duplicates. The Nickel (II) uptake by *Luffa Cylindrica* quantity,  $q$  ( $\text{mg}\cdot\text{g}^{-1}$ ) was determined according to the following Equation 5:

$$q_t = \frac{(C_0 - C_{\text{res}})}{m} \cdot V \quad (5)$$

Where  $C_0$  is the initial Nickel (II) concentration ( $\text{mg}\cdot\text{L}^{-1}$ ),  $C_{\text{res}}$  is the residual Nickel (II) concentration at any time ( $\text{mg}\cdot\text{L}^{-1}$ ),  $V$  is the volume of solution (L) and  $m$  is the mass of the sorbent (g). At equilibrium,  $C_{\text{res}}$  is equal to  $C_{\text{eq}}$  and  $q$  is equal to  $q_{\text{eq}}$ .

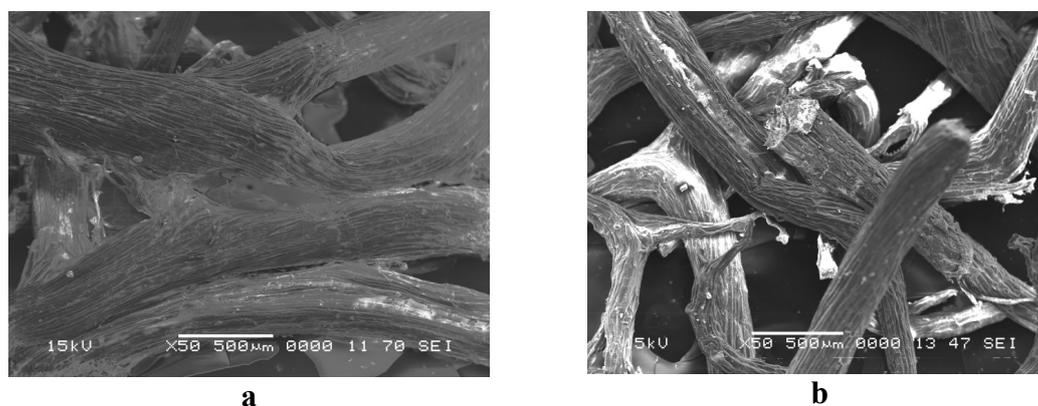
### Material characterization

The characterization was realized to explore the structure of the material. The surface morphology of the material was carried out using Scanning Electron Microscope (SEM) model XL-3 CP, Philips.

## RESULTS AND DISCUSSION

### Characterisation of *Luffa Cylindrica*

The morphology of *Luffa Cylindrica* surface was analyzed by scanning electron microscopy before and after Nickel loading (Figures 1 a and b). The *Luffa Cylindrica* before exposure were smooth and had certain dimensions, after their exposure to Nickel ions solution, they become destroyed and swollen, and their surface becomes meanders. This may be due to Nickel ions precipitated around the *Luffa* surface and linked with their functional groups. Also, these changes were probably caused when the samples were exposed to heavy metal solution; the metal ions replaced some of the cations initially present in the cell wall matrix and created stronger crosslinking. Due to ion-exchange mechanism, the heavy metal ions occupied the available free binding sites [12].



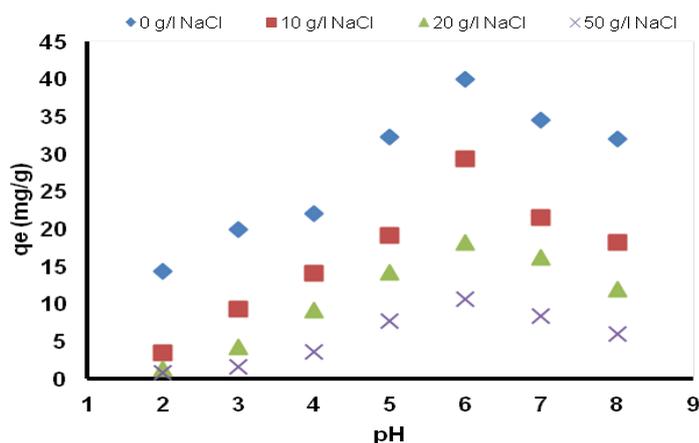
**Figure 1.** SEM micrograph of *Luffa Cylindrica* cell wall (a) before and (b) after Ni (II) adsorption from aqueous solution

## Effect of initial pH on Nickel (II) biosorption in the presence and in the absence of salt

Earlier studies on heavy metal biosorption have shown that pH is an important parameter affecting the biosorption process [13, 14].

To find the suitable pH for the effective biosorption of Nickel (II) ions by *Luffa Cylindrica*, experiments were carried out at different initial solution pH values (2.0 - 8.0) and at different initial NaCl concentrations (0 - 50 g·L<sup>-1</sup>). The variation of equilibrium Nickel (II) uptake with initial pH is given in Figure 2 at about 100 mg·L<sup>-1</sup> constant metal ion concentration. As seen from the figure, the highest uptake values were found at pH 6.0 (40 mg·g<sup>-1</sup>) and the biosorption of Nickel (II) decreased with further increase in pH for all the NaCl concentrations tested.

Various reasons might be attributed to the metal adsorption behavior of the biosorbent relative to solution pH. The cell wall of *Luffa Cylindrica* contains a large number of surface active sites. The pH dependence of metal uptake is related to these active sites and also to the metal solution chemistry [15]. The speciation of Nickel (II) in the working solutions was obtained by Visual MINETQ programme which showed that the dominant Nickel (II) species at pH > 9.3 is Ni(OH)<sub>2</sub> and Ni(OH)<sup>-3</sup> and at pH < 9.3 is Ni<sup>2+</sup> and Ni(OH)<sup>+</sup>, and therefore, at lower pH, there is a competition effect between the H<sub>3</sub>O<sup>+</sup> ions and Nickel (II) ions. Metal ions that could associate with the cell wall ligands would have to compete with the H<sub>3</sub>O<sup>+</sup> ions for the active sites. At low pH values, the concentration of H<sub>3</sub>O<sup>+</sup> far exceeds that of Nickel (II) ions, and hence, these ions occupy the binding sites on the cell walls, leaving Nickel (II) ions free in solution. With increasing pH, more ligands, such as amino and carbonyl groups, would be exposed leading to attraction between these negative charges and the positively charged Ni<sup>2+</sup> and Ni(OH)<sup>+</sup> ions hook up the free binding sites. Hence, the metal uptake increased on the surface of the adsorbent with the increase in pH.



**Figure 2.** Effect of pH and increasing NaCl concentration on equilibrium Ni (II) sorption capacity of *Luffa Cylindrica* ( $C_0$ : 100 mg·L<sup>-1</sup>, LC quantity: 1 g, temperature: 25 ± 1°C, agitation rate: 300 rpm).

Industrial effluents contain not only heavy metals but also salts. NaCl concentration is proportional to the ionic strength of aqueous solution. Ionic strength, besides pH, is one

of the important factors that influence the equilibrium uptake [16]. Although the ionic strength or the salinity did not affect the maximal  $pH$  of biosorption, it influenced the Nickel (II) uptake antagonistically. The Nickel (II) uptake decreased with increasing the salinity of the aqueous solution at all  $pH$  values studied (Figure 2). At  $pH$  6.0, Nickel (II) removal decreased from 40 to  $10.69 \text{ mg}\cdot\text{g}^{-1}$  resulted in 37.7 % reduction in biosorption capacity. This behavior may be due to the inhibition effect of salt on the permeability of cell membrane for Nickel (II) ions and relative competition between sodium ions and Nickel (II) species [17]. Since the highest Nickel (II) sorption was observed at  $pH$  6.0 in the absence and in the presence of salt, all further biosorption studies were carried out at this  $pH$ .

### **Effect of initial Nickel (II) concentration**

The initial metal concentration plays an important role in the process of biosorption [18]. With increase in initial Nickel (II) concentration, there is an increase in biosorption capacity of *Luffa Cylindrica* both individually and in combination with different concentrations of salt as shown in Table 1.

In the absence of salt, when the initial Nickel (II) concentration increased from 10 to  $100 \text{ mg}\cdot\text{L}^{-1}$  approximately, the adsorption capacity increased from  $7.98$  to  $23.35 \text{ mg}\cdot\text{g}^{-1}$  due to the increase in the number of metal ions competing for the available binding sites in the sorbent surface. But Nickel (II) concentration above  $100 \text{ mg}\cdot\text{L}^{-1}$  did not increase the biosorption significantly and biosorption yield showed even a decrease indicating saturation of all the binding sites at higher concentration levels as shown in Table 1. Same pattern was observed for Nickel (II) salt combinations. Nickel (II) removal yield was the maximum at the lowest concentration of Nickel (II) ( $10 \text{ mg}\cdot\text{L}^{-1}$ ) due to higher number of active sites attained than at higher concentrations of Nickel (II).

### **Effect of salt concentration**

Table 1, also, indicates the effect of NaCl concentration on the uptake of Nickel (II) ions by *Luffa Cylindrica* at different initial Nickel (II) concentrations. The results demonstrate that in the absence of salt, the biosorbent showed good ability for the Nickel (II) biosorption. When NaCl concentration increased up to  $50 \text{ mg}\cdot\text{L}^{-1}$ , there was significant decrease in biosorption of Nickel (II) indicating an antagonistic effect of salts on Nickel (II) biosorption.

The decrease in biosorption ability of the biosorbent with increasing salt concentration may be a result of biosorption mechanisms. NaCl concentration could markedly influence the biosorption presumably due to the competition between sodium ions (present in salt used to change the ionic strength of solution) and Nickel (II) ions for the same binding sites in the biosorbent surface [19, 20]. Another reason is that ionic strength increases, the activity of biosorbent (active sites) and metal activity decreases, so the adsorptive capacity of biosorbent decreases. According to surface chemistry theory, when two phases, for example, *Luffa Cylindrica* particles and metal species in aqueous solution, are in contact, they are bound to be surrounded by an electrical double layer owing to electrostatic interaction. If the adsorption mechanism is significantly the electrostatic attraction, adsorption decreases with increase in ionic strength. Some

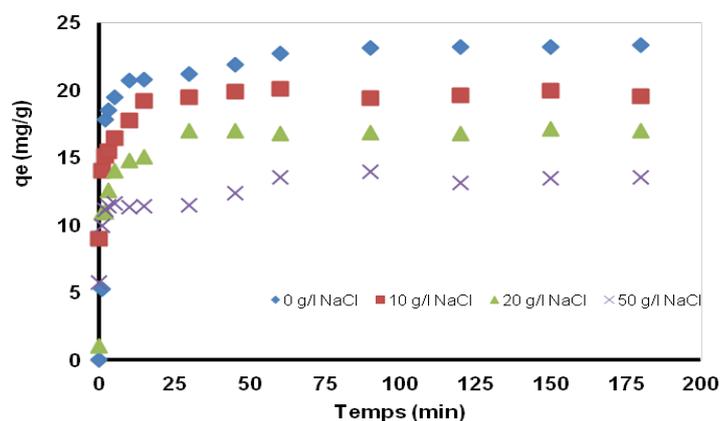
inorganic anions, such as chloride, may form complexes with some metal ions and therefore affect the adsorption process adversely [21, 22].

**Table 1.** Equilibrium uptakes removal of nickel (II) at different NaCl concentrations

$C_{0Ni(II)}$ [mg·L <sup>-1</sup> ]	$C_{0 NaCl} = 0 \text{ g·L}^{-1}$	$C_{0 NaCl} = 10 \text{ g·L}^{-1}$	$C_{0 NaCl} = 20 \text{ g·L}^{-1}$	$C_{0 NaCl} = 50 \text{ g·L}^{-1}$
	$q_{eq}$ [mg·g <sup>-1</sup> ]	$q_{eq}$ [mg·g <sup>-1</sup> ]	$q_{eq}$ [mg·g <sup>-1</sup> ]	$q_{eq}$ [mg·g <sup>-1</sup> ]
10	7.98	4.78	4.27	1.35
50	15.22	13.21	9.2	6.62
100	23.35	19.57	17	13.55

### Biosorption kinetics

Kinetics of sorption describing the pollutant(s) uptake rate is useful for defining the efficiency of sorption and feasibility of adsorbent for its use in water pollution control [23]. Hence, the kinetics of Nickel (II) removal both individually and in salt-containing medium has been carried out to understand the Nickel (II) adsorption behavior of the biosorbent. For this purpose, Biosorption capacity ( $q$ ) with initial Nickel (II) concentration of about 100 mg·L<sup>-1</sup> was plotted as a function of time at varying salt levels (Figure 3).



**Figure 3.** Biosorption kinetics of Ni (II) under increasing NaCl concentration ( $C_0 = 100 \text{ mg·L}^{-1}$ ,  $m = 1 \text{ g}$ , temperature:  $25 \pm 1^\circ\text{C}$ , agitation rate = 300 rpm)

The time and salt concentration dependent, similar shaped biosorption curves were obtained. The presence of salt in solution did not influence the dynamic uptake process of Nickel (II). The extent of Nickel (II) removal enhanced with increasing contact time at all salt concentrations studied. However, the rise in salt concentration resulted in a decrease in metal uptake.

For Nickel (II) and salt concentrations studied, initial sorption of Nickel (II) occurred much more rapidly and the majority of Nickel (II) uptake took place within the first 5 min of contact due to vacant sites available at the initial stage of biosorption, and thereafter, it proceeded at a slower rate and finally attained saturation called the equilibrium time. The data in Figure 3 indicated that the contact time required to reach equilibrium was very short, and the first 30 min of adsorption was sufficient to achieve equilibrium for all cases. The equilibrium time was also found to be independent of salt

concentration. Based on these results, the contact time was fixed at 40 min for the rest of the batch experiments to make sure that equilibrium was reached in all cases.

### Application of kinetic models

The sorption data were analyzed in terms of pseudo-first-order and pseudo-second-order type kinetics. The first-order rate constant ( $k_1$ ) and  $q_{eq}$  values were determined from the plots of linearized form of the pseudo-first-order model (eqn. (3)) at all Nickel (II) and salt concentrations studied for the initial 30 min (data not shown) and are presented in Table 2 along with the corresponding linear regression coefficients. The first-order rate constants decreased slightly with increasing the initial concentration of Nickel (II) and increased with increasing the salt concentration. The correlation coefficients were found to be above 0.9, but the calculated values of  $q_{eq}$  obtained from Lagergren plots were not equal to the experimental  $q_{eq}$  values, suggesting the insufficiency of the model to fit the kinetic data for the cases examined.

Using the linearized form of eqn. (4), second-order adsorption rate constants ( $k_2$ ) and equilibrium uptake values ( $q_{eq}$ ) were determined from the slope and intercept of the  $t/q$  against  $t$  plots (data not shown). The values of the parameters  $k_2$  and  $q_{eq}$  and of corresponding correlation coefficients are also presented in Table 2. The results indicated that both the initial Nickel (II) and salt concentrations also affected the second-order rate constants. The rate constants decreased with increasing Nickel (II) concentration. The correlation coefficients obtained greater than 0.99 and the adequate fitting of theoretical and experimental  $q_{eq}$  values for all Nickel (II) salt combinations suggest the applicability of second-order kinetic model based on the assumption that the rate-limiting step may be the chemisorption in explaining the kinetics of biosorption for the entire sorption period. This indicated that pseudo-second-order kinetic model describes the kinetics adequately in the concentration ranges studied.

**Table 2.** Pseudo-first and pseudo-second-order kinetic constants at different Ni (II) and NaCl concentrations at pH 6 and  $25 \pm 1^\circ\text{C}$

Salt concentration	$C_0$ [mg·L <sup>-1</sup> ]	$q_{eq,exp}$ [mg·g <sup>-1</sup> ]	First-order			Second-order		
			$k_1$ (1/min)	$q_{eq,cal}$ [mg·g <sup>-1</sup> ]	$R^2$	$K_2$ [g mg <sup>-1</sup> ·min <sup>-1</sup> ]	$q_{eq,cal}$ [mg·g <sup>-1</sup> ]	$R^2$
0 g·L <sup>-1</sup> NaCl	15	8.24	0.201	10.11	0.9619	0.047	8.30	0.9971
	50	15.69	0.168	20.10	0.9796	0.021	15.70	0.9972
	100	23.96	0.141	24.62	0.9767	0.007	23.98	0.9989
10 g·L <sup>-1</sup> NaCl	15	6.99	0.216	7.21	0.9602	0.055	6.91	0.9972
	50	13.43	0.173	15.21	0.9741	0.032	13.50	0.9965
	100	19.88	0.153	20.76	0.9651	0.011	19.90	0.9989
20 g·L <sup>-1</sup> NaCl	15	5.03	0.231	6.99	0.9726	0.067	4.91	0.9971
	50	9.6	0.197	11.89	0.9448	0.043	9.20	0.9989
	100	17.42	0.167	19.72	0.9726	0.016	17.43	0.9987
50 g·L <sup>-1</sup> NaCl	15	3.11	0.254	1.05	0.9628	0.083	2.99	0.9971
	50	6.87	0.219	6.07	0.9700	0.069	6.56	0.9979
	100	13.50	0.187	15.11	0.9661	0.020	13.52	0.9989

## Application of equilibrium models

For the investigation of salt effect on Nickel (II) biosorption, the Langmuir and Freundlich equations were applied to the equilibrium data obtained in both single Nickel (II) and Nickel (II) salt binary systems.

It was revealed that equilibrium Nickel (II) uptake increased with increasing initial metal concentration up to  $100 \text{ mg}\cdot\text{L}^{-1}$  for all cases studied. The curvilinear relationship between the amount of Nickel (II) adsorbed per unit weight of the *Luffa Cylindrica* and the residual Nickel (II) concentration at equilibrium suggests that saturation of cell-binding sites occurred at the higher concentrations of this metal ion. The equilibrium removal of Nickel (II) decreased with increasing salt concentration. The corresponding model parameters at different salt levels estimated by non-linear regression analysis were listed in Table 4 along with the linear regression coefficients. The values of linear regression coefficients were the criteria for the selection of the most suitable isotherm model.

On the basis of linear regression coefficients in Table 3, the Langmuir model best described the Nickel (II) sorption isotherm data. The model fitted the experimental data with higher linear regression coefficient suggesting the monolayer, homogeneous sorption in single as well as salt added binary systems.

The estimated coefficients of Freundlich model ( $K_F$  and  $n$ ) for Nickel (II) sorption in both single and binary systems are listed in Table 3. The  $n$  is an experimental parameter that varies with the degree of heterogeneity and is related to the distribution of bonded ions on the sorbent surface. In particular, the value of  $n$ , which is significantly higher than unity, indicated that Nickel (II) ions are favorably adsorbed under all the experimental conditions examined. The values of  $n$  at different salt concentrations also indicated that the salt added into biosorption medium affected the cadmium (II) biosorption intensity contrarily. From the table, the magnitude of  $K_F$  showed a relatively easy uptake of Nickel (II) ions from aqueous solution with high adsorptive capacity of the *Luffa Cylindrica* for Nickel (II) in the absence and in the presence of salt. The coexistence of salt at its any initial concentration increased  $K_F$  constant significantly. The maximum  $K_F$  value was 7.38 in the absence of salt and the value of  $K_F$  decreased to 1.23 with the addition of  $50 \text{ g}\cdot\text{L}^{-1}$  salt, which was consistent with the experimental observation.

Table 3 also shows the effect of coexistence of salt added at different levels on the Langmuir constants ( $Q^0$  and  $b$ ). As the Freundlich model does not describe the saturation behavior of the sorbent,  $Q^0$  represents the maximum capacity of the adsorbent for Nickel (II) or the monolayer saturation at equilibrium. As seen from Table 3, *Luffa Cylindrica* exhibited the maximum biosorption capacity ( $Q^0$ ) for single Nickel (II) biosorption. The addition of salt decreased the  $Q^0$  value of Nickel (II) biosorption notably. The presence of  $50 \text{ g}\cdot\text{L}^{-1}$  salt decreased the maximum Nickel (II) removal capacity of the *Luffa Cylindrica* from 24.55 to 14.44 mg/g compared with the monometal conditions. A high value of the other Langmuir parameter,  $b$ , indicates a steep desirable beginning of the isotherm that reflects the high affinity of the biosorbent for the sorbate. Its value is the reciprocal of the Nickel (II) concentration at which half of the saturation of the biosorbent is attained. The highest  $b$  value obtained for monometal conditions also decreased with the addition of salt indicating its negative effect on Nickel (II) biosorption.

**Table 3.** Evolution of the adsorption capacity as a function of the NaCl concentration in the case of the Langmuir and Freundlich models and under the experimental conditions (pH: 6, LC quantity: 1 g, temperature:  $25 \pm 1$  °C, stirring speed 300 rpm)

Models	Salt concentration [ $\text{g}\cdot\text{L}^{-1}$ ]			
	0	10	20	50
Langmuir:				
$Q^0$ [ $\text{mg}\cdot\text{g}^{-1}$ ]	24.55	20.90	18.33	14.44
b	0.28	0.23	0.19	0.11
$R^2$	0.9939	0.9960	0.9948	0.9919
Freundlich:				
$K_F$ [ $\text{mg}\cdot\text{g}^{-1}$ ]	7.38	5.33	2.11	1.23
n	3.44	2.62	2.02	1.74
$R^2$	0.9638	0.9638	0.9907	0.9931

## CONCLUSIONS

The purpose of this study was to find out the adsorption capacity of *Luffa Cylindrica* for Nickel (II) in the presence of mixed salts keeping in view the dual problems encountered in industrial effluent treatment. Different experiments performed with varying initial pH, initial Nickel (II) concentration and salt concentration revealed that pH 6, contact time 180 min and initial metal concentration of  $10 \text{ mg}\cdot\text{L}^{-1}$  were optimum for biosorption of Nickel. Pseudo-second-order equation, which fits the data well showed that there is good correlation between experimental and calculated value of  $q_{eq}$  explaining the biosorption kinetics based on the assumption that biomass biosorption of the metal is the rate-limiting step. A better correlation was found in the case of the Langmuir model of nickel (II) biosorption on *Luffa Cylindrica* in the presence and absence of NaCl salt. It was seen that the adsorption equilibrium data fitted very well to Langmuir model at all salt concentrations studied. It was found that Nickel (II) uptake capacity of this *Luffa Cylindrica* is higher in the absence of salt ( $Q^0 = 24.55 \text{ mg}\cdot\text{g}^{-1}$ ) than in the presence of  $50 \text{ g}\cdot\text{L}^{-1}$  salt ( $Q^0 = 14.44 \text{ mg}\cdot\text{g}^{-1}$ ). The *Luffa Cylindrica* still has a considerable potential for the uptake of Nickel (II) from saline waters due to salt level. This work can provide a useful data for the bioremoval of Nickel (II) ions from salt-bearing wastewaters by *Luffa Cylindrica*.

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