

Evaluation of Sorption Mechanism of Pb (II) and Ni (II) onto Pea (*Pisum sativum*) Peels

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Abstract: The present study was carried out to know the sorption mechanism of Pb (II) and Ni (II) in aqueous solution using pea peels under the influence of sorbent dose, pH, temperature, initial metal ion concentration and contact time. SEM and FTIR were used for characterization of pea peels. The study showed that solution pH affects sorption process and the optimum pH for Pb (II) was 6.0 while for that of Ni (II) was 7.0. Pseudo-second order kinetic model was found to be the most suitable one to explain the kinetic data not only due to high value of R^2 (>0.99) but also due to the closeness of the experimental sorption capacity values to that of calculated sorption capacity values of pseudo second order kinetic model. It can be seen from the results that Freundlich isotherm explains well the equilibrium data ($R^2 > 0.99$). Sorption capacity of pea peels was 140.84 and 32.36 for Pb (II) and Ni (II) mg g^{-1} respectively. The positive value of ΔH° and negative values of ΔG° suggest that sorption of Pb (II) and Ni (II) onto pea peels is an endothermic and spontaneous process respectively.

Key words: pea peels, kinetics, thermodynamics, equilibrium

1 Introduction

The non-degradability, toxicity and bio-magnification of heavy metals made them a threat for human as well as ecosystem^{1,2}. Pollution due to heavy metals is the results of various anthropogenic and industrial activities such as paper mills, electroplating, fertilizer manufacturing, textiles, mining, battery manufacturing and metallurgic processing. Nowadays, the major global concern is the discharge of untreated industrial wastes containing heavy metals in the water bodies³. Among these heavy metals lead and nickel constitute profound environmental contamination. These metals cause various diseases like diarrhea, nausea, skin dermatitis, pulmonary fibrosis, vomiting, mental retardation, neuro-logical disintegration and brain damage in children⁴. In order to protect the public health, it is necessary to bring the concentrations of these heavy metal ions to their permissible levels or completely remove them from the industrial wastes before entering in to the running water⁵. In past various techniques have been applied for the treatment of wastewater containing heavy metal ions such as solvent extraction, activated carbon sorption, filtration, ion exchange, chemical precipitation, electrochemical processes and membrane separation processes⁶. However, these methods have some serious disad-

vantages such as environmentally disruption, generation of toxic sludge, insufficient removal of the target one and high cost of these methods⁷. Due to these drawbacks, the researchers have keen interest to employ low cost and abundantly available materials to treat contaminated water. One of the most attractive and alternative method is sorption; based on the utilization of biomaterial to remove contaminants⁸.

In the last decade, Pb(II) and Ni(II) containing wastewaters were treated using a variety of sorbents such as chemically modified brown algae⁹, *Pseudomonas aeruginosa*¹⁰, *Lysinibacillus* sp. BA2¹¹, *Bacillus laterosporus*¹², *Spirulina platensis*⁸, chemically modified brown macroalgae¹, seed husk of *Calophyllum inophyllum*¹³, *Penicillium simplicissimum*¹⁴, chitosan¹⁵, etc.

Peels of the pea is one of the abundantly available agricultural byproduct whose annual production is about 11.7 million tons throughout the world¹⁶. The literature survey implied that only dyes such as malachite green and methylene blue from aqueous solution were removed onto pea peels and but no data are available to show the removal of heavy metal ions using pea peels^{17,18}.

Therefore, the present study was conducted for the removal of Pb(II) and Ni(II) from aqueous solution using

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pea peels and various parameters were optimized for maximum sorption of these metal ions such as temperature, dose of sorbent, pH, initial metal ion concentrations and contact time. Scanning electron microscopy was used for characterization of the pea peels before and after sorption of Pb (II) and Ni (II). The sorption mechanism of Pb (II) and Ni (II) onto pea peels was evaluated by applying various models.

2 EXPERIMENTAL

2.1 Chemicals and reagents

Chemicals and reagents used in this research work were of analytical grade purity. The standard solutions of Pb (II) and Ni were prepared from their nitrate salts by dissolving required amount of lead nitrate and nickel nitrate in distilled water. Diluted solutions of these metal ions were prepared from the stock solutions using dilution formula. Britton Robinson buffer was used for the adjustment of pH of the solutions.

2.2 Instruments

Atomic absorption spectrophotometer (model Z-8200, Japan) was used for determination of Pb (II) and Ni (II) in residues. The suspensions of metal-biosorbent were shaken on an orbital shaker (model Heidolph Unimax 2010). Electrical grinder (Fritsch-Pulverisette 2, Japan) was used to grind peels of the pea. Solution pH was checked with pH meter (Model WTW-Inolab 720) and sorbent was weighed with electrical balance (Sartorius GC 2012).

2.3 Preparation of sorbent

The peels of pea were collected from restaurants and hotels in Faisalabad city. To remove impurities such as dirt particles, the peels of pea were first washed with tap water followed by distilled water. These materials were then sun dried and ground in a mixer grinder after drying and become powder. The larger particles were separated manually and crushed with pestle in a mortar and finally sieved. A known amount (10 g) of the pea peel powder was transferred in a beaker and distilled water was added till the materials are completely soaked in water. These materials were then kept overnight and the surface water was decanted. The decantation process was repeated till the decanted water become clear. At last, the pea peels powder was filtered followed by drying in oven at 100°C till weight of materials become constant. The materials were then transferred in a bottle and stored for further experiments.

2.4 Batch sorption procedure

Sorption experiments were conducted in batch system by introducing a known amount (0.1 g) of pea peels powder in separate Erlenmeyer flasks (250 mL) containing 10 mL of

Pb (II) and Ni (II) of solution has a concentration of 40 mg L⁻¹ at 303 K. The pH of Pb (II) and Ni (II) solutions was adjusted with Britton Robinson buffer of pH 6.0 and 7.0 respectively. The flask contents were agitated at 200 rpm for 60 minutes in a shaking incubator (SHIN SAENG, Shaking Incubator, Model No. SKIR-601, Made in Korea). The flask contents were filtered and the filtrates were transferred in volumetric flasks of capacity 25 mL followed by dilution up to marks with distilled water. Concentrations of Pb (II) and Ni (II) in these flasks were determined by atomic absorption spectrophotometer.

Percent sorption and sorption capacity of Pb (II) and Ni (II) were determined using the following two equations:

$$\% \text{ Sorption} = \left[\frac{C_i - C_f}{C_i} \right] \times 100 \quad (1)$$

$$q_e = \left[\frac{C_i - C_f}{m} \right] V \quad (2)$$

Where C_i is the initial concentration of metal ions ($\mu\text{g mL}^{-1}$) and C_f is the final concentration of metal ions ($\mu\text{g mL}^{-1}$), m is the amount of sorbent (g), q_e is the sorption capacity (mg g^{-1}) while V is the volume for sorption of metal ions solution (mL).

3 Results and Discussion

3.1 Characterization of pea peels

Scanning electron microscopic analysis of unloaded and metal loaded pea peel was carried out at 1000x magnification power. The morphology of Ni (II) and Pb (II) loaded pea peel at 1000x is depicted in Figs. 1 and 2 respectively. It can be seen from the figures that different micro pores are present at the surface of pea peel which are responsible for the sorption of metal ions. Surface porosity and irregularity was changed by sorption of Pb (II) and Ni (II), suggesting sorption of these metal ions onto pea peels. In case of Ni (II) loaded pea peel, the surface roughness decreased by the filling of micro pores by metal ions as shown in Fig. 2. The smoothness of the pea peels after sorption elucidated

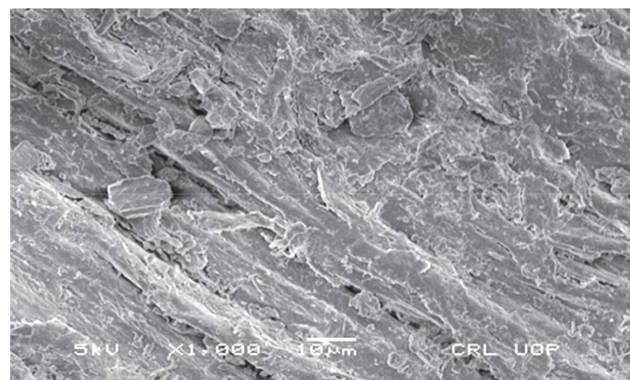


Fig. 1 SEM image of pea peels before sorption of Pb (II) and Ni (II).

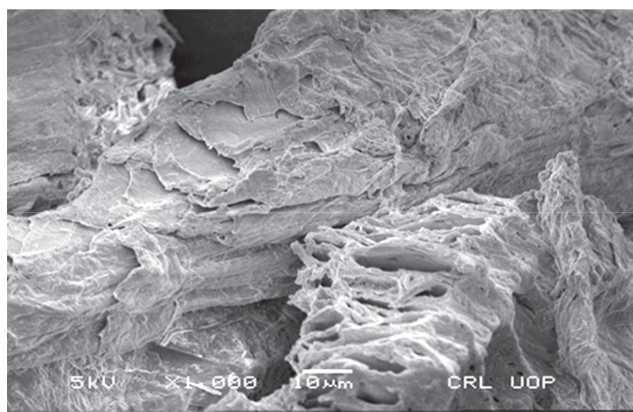


Fig. 2 SEM photograph of Pb(II) loaded pea peels.



Fig. 3 SEM image of Ni(II) loaded pea peels.

the sorption of Pb(II) and Ni(II) on the heterogeneous surface of sorbent. Similarly, in case of Pb(II) loaded pea peel the biomass roughness was changed which clarify the sorption phenomenon as shown in the Fig. 3.

The functional groups present on the surface of pea peels were identified with the help of Fourier transform infrared spectrophotometer by varying the frequencies from 4000 to 400 cm^{-1} as shown in Fig. 4. Peak at 3450 cm^{-1} in-

dicates the presence of hydroxyl groups of carboxylic acid, alcohol and phenol while peaks at 2900 cm^{-1} represent the presence of aliphatic C-H. The presence of peak around 1600 cm^{-1} indicates the presence of C-C stretching that can be attributed to the lignin aromatic C-C bond and the lignin structure may be further confirmed by the presence of a strong peak at above 1000 cm^{-1} of C-O. The presence of these functional groups is responsible for sorption of Pb (II) and Ni(II). Such type of results was also presented by other researchers with pea peels¹⁹. The specific surface area, pore volume and pore diameter of pea peels were found to be 310.51 m^2/g , 0.207 cm^3/g , and 32.55 Å respectively.

3.2 Effect of pH

Solution pH is considered as one of the most important factor which affects the sorption phenomenon. It significantly affects the interactions between the metal ion present in solution and the sites on sorbent surface and the sorption mechanism on the surface of sorbent²⁰. Therefore, pH of the solution was varied from 3-11 and keeping the other parameter constant at 303 K. Figure 5 showed that an increase in metal ion removal taken place as the solution pH increased and maximum sorption capacity for Pb (II) was obtained at pH 6.0 while that of Ni(II) was at pH 7.0. Low sorption capacities of these metal ions were observed at low pH because at this pH there is a competition between metal ions and hydrogen ion toward sorptive sites. As the pH increases, this competition decreases and maximum sorption of Pb(II) was achieved at pH 6.0 while and Ni(II) was obtained at pH 7.0. The figure also showed that after pH 7.0 a decrease in removal of these metal ions was observed. Perhaps this may be due to formation of hydroxides of these metal ions. The zero point charge (pH_{ZPC}) of the pea peels was determined to explain the effect of pH on sorption process of Pb(II) and Ni(II) in aqueous solution²¹. It has been given in the literature that favorable pH for adsorption of cation is greater than that of pH_{ZPC} while

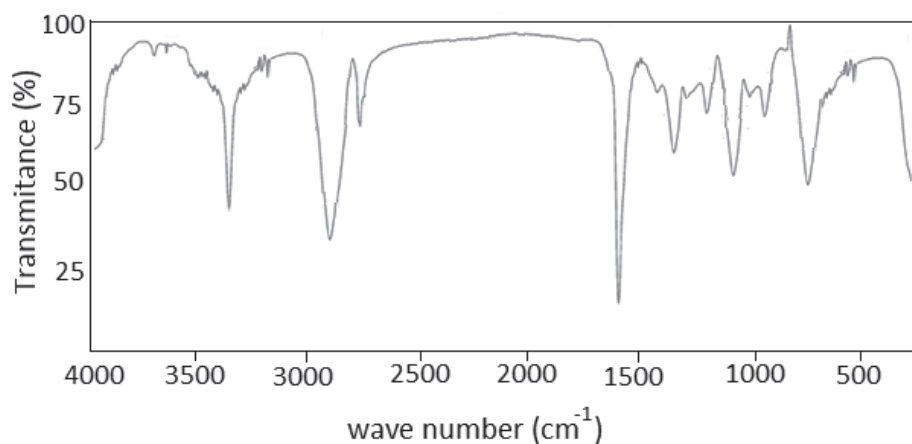


Fig. 4 FTIR analysis of pea peels.

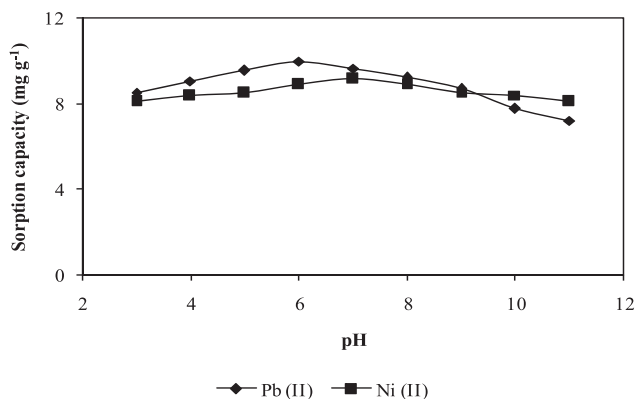


Fig. 5 Effect of pH on sorption capacity of pea peels for Pb(II) and Ni(II) (pH range 3-11, initial metal ion concentration $40 \mu\text{g mL}^{-1}$, sorbent dose 0.1 g, contact time 60 min, volume for sorption 25 mL, temperature 303 K).

for adsorption of anion, the favorable pH is less than that of pH_{ZPC} ²². The value of pH_{ZPC} for pea peels was found to be 5.5. It can be illustrated from the **Fig. 5** that sorption capacity increases with progress in pH and maximum sorption was achieved at pH greater than pH_{ZPC} . A high electrostatic attraction was found between metal ions (Pb(II) and Ni(II)) and sorbent at pH 6.0 and 7.0.

3.3 Effect of sorbent dose

The dose of sorbent is also one of the significant factors which affect the sorption phenomenon. Therefore, the dependence of Pb(II) and Ni(II) sorption on pea peel was carried out by changing the amount of pea peels from 0.1 to 0.9 g in a constant volume (25 mL) at 303 K and pH 6.0 and 7.0 respectively. **Figure 6** showed that as the dose of sorbent increases the sorption of these metal ions also increases. The figure showed that sorption capacity of Pb(II) increased from 7.597 mg g^{-1} to 8.212 mg g^{-1} while the sorption capacity of Ni(II) increased from 8.567 mg g^{-1} to 9.165 mg g^{-1} as the amount of sorbent dose was varied in the range of 0.1 to 0.9 g. It can be concluded that as the dose of sorbent increases the number of active sites also increases as a result an increase in sorption of these metal ions was observed. These types of results have been also achieved by various researchers.

3.4 Effect of contact time

Contact time is also among the factors which affects the sorption phenomenon. Therefore, contact time for sorption was varied from 10 to 70 min while keeping the other parameters constant (i.e. pH 6.0 for Pb(II) and pH 7.0 for Ni(II) at 303 K). It was noted that a very small increase was observed during sorption process with the progress of time. In the beginning of sorption process, the sorption sites of sorbent are opened and Pb(II) and Ni(II) interact

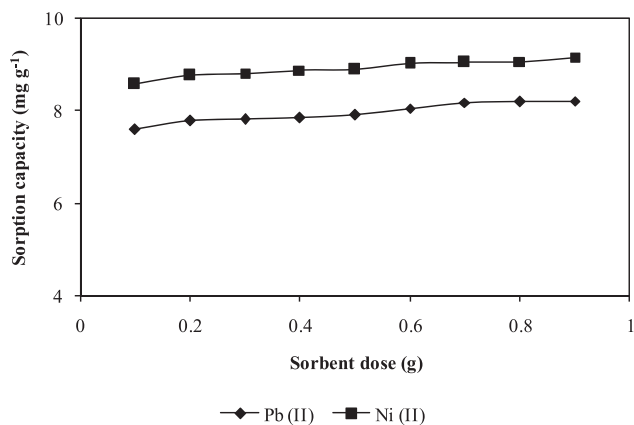


Fig. 6 Effect of sorbent dose on sorption capacity of pea peels for Pb(II) and Ni(II) (Sorbent dose range 0.1-0.9, initial metal ion concentration $40 \mu\text{g mL}^{-1}$, pH 6.0 for Pb(II) and 7.0 for Ni(II), contact time 60 min; volume for sorption 25 mL, temperature 303 K).

easily with the sites. Therefore, on the initial stage greater sorption was observed. Furthermore, it was also observed that with shaking of the reaction mixture greater uptake (9.7 mg g^{-1} of Pb(II) and 9.2 mg g^{-1} of Ni(II) respectively) was observed for the same equilibration time in contrast to contact time without shaking of the reaction mixture (8.8 mg g^{-1} of Pb(II) and 8.5 mg g^{-1} of Ni(II) respectively).

3.5 Sorption kinetics

Kinetic data have been employed to evaluate the sorption mechanism and dynamics of the process. During sorption different steps are involved. Among them first metal ions transfer to the surface of sorbent from solution, second metal ions transfer towards active sites and the third one is the diffusion of metal ions within the pores of particle. During sorption process a single step mentioned above or the combination of these steps are involved depending on different experimental parameters. A number of kinetic models are applied to know which step is more dominant but here we have applied four kinetic models which are commonly used to study kinetic data of Pb(II) and Ni(II). These include pseudo-first, Elovich, pseudo-second and intraparticle diffusion. The linear forms of each model are given in the following equations:

3.5.1 Pseudo-first-order

$$\log(q_e - q_t) = \log q_e - \frac{K_1 t}{2.303} \quad (3)$$

Where K_1 represents rate constant for pseudo-first order (min^{-1}) while q_t and q_e are the amounts of Pb(II) and Ni(II) sorbed per unit of sorbent (mg g^{-1}) at any given time (min) and at equilibrium respectively.

3.5.2 Pseudo Second Order

$$\frac{t}{q_t} = \frac{t}{q_e} + \frac{1}{K_2 q_e^2} \quad (4)$$

Where K_2 denotes rate constant for pseudo-second-order ($\text{g mg}^{-1} \text{ min}^{-1}$) while q_t and q_e are the amounts of Pb(II) and Ni(II) sorbed per unit of sorbent (mg g^{-1}) at any given time (min) and at equilibrium respectively.

3.5.3 Intraparticle Diffusion Model

Diffusion mechanism cannot identify by applying only the above two models but it's the intraparticle diffusion model which explains the diffusion of sorbate in to sorbent. This model is expressed as:

$$q_t = K_{int} t^{1/2} + C \quad (5)$$

In this equation C represents the thickness of the boundary layer while the rate constant is denoted by K_{int} ($\text{mol L}^{-1} \text{ min}^{-1/2}$).

In sorption process intraparticle diffusion could be the only controlling step if the line of the plot of $t^{1/2}$ of time versus the sorption capacity q_t is passes through the origin²³⁾. On the other hand if the line does not pass through the origin then some other processes will be involved along with this model. Our study showed that line did not pass through the origin suggesting that this model is not the only controlling step in the sorption process. Some other steps are involved along with intraparticle diffusion model. This table also shows that value of intraparticle diffusion rate constant is higher for Pb(II) as compare to Ni(II), suggesting that Pb(II) sorption is faster than Ni(II).

3.5.4 Elovich Equation

The Elovich equation describes the chemisorption process on heterogamous surface. This equation can be expressed in the following linear form:

$$q_t = \frac{1}{\beta} \ln(\alpha\beta) + \frac{1}{\beta} \ln(t) \quad (6)$$

In this equation α denotes the initial metal ions sorption ($\text{mg g}^{-1} \text{ min}^{-1}$) while β represents desorption rate (g min^{-1}) respectively.

Constant parameters of each model were calculated from linearized forms of respective equations and summarized in **Table 1**. The R^2 values of the pseudo-second-order kinetic model are higher as compare to other models, suggesting the fitness of the data in to pseudo-second-order. The table also showed that there is also a close agreement between the calculated sorption capacities and experimental sorption capacities of the pseudo-second-order, confirming the fitness of the data into pseudo-second-order.

3.6 Sorption isotherms

Isotherms illustrate a relationship between sorbate and sorbent at constant temperature. The isotherm can also be used for the prediction of sorption capacity of sorbent which helps for designing the sorption process²⁴⁾. Therefore, different isotherms were used to analyze the equilibrium data such as Tempkin, Radushkevich (D-R), Langmuir and Freundlich.

3.6.1 Freundlich Isotherm

According to this isotherm, the sorbent surface is heterogeneous i.e. various function groups are present on the surface of sorbent having different energies. This isotherm is expressed in the following linear form:

$$\log q_e = \log K_F + \frac{1}{n} \log C_e \quad (7)$$

Where K_F indicates the relative sorption capacity and is known as Freundlich constant (mg g^{-1}), $1/n$ indicates the heterogeneity of sorption sites, the concentration of Pb(II) and Ni(II) at equilibrium is represented by C_e ($\mu\text{g mL}^{-1}$)

Table 1 Kinetic parameters of the removal of Pb(II) and Ni(II).

Model	Parameters	Pb(II)	Ni(II)
Pseudo-first-order	q_e (mg g^{-1}) (exp)	8.815	9.345
	q_e (mg g^{-1}) (cal)	2.377	1.070
	K_1 (min^{-1})	0.040	0.003
	R^2	0.8884	0.9557
Pseudo-second-order	K_2 ($\text{g mg}^{-1} \text{ min}^{-1}$)	0.031	0.080
	q_e (mg g^{-1})	9.132	5.851
	R^2	0.9986	0.9944
Intraparticle diffusion	K_{int} ($\text{mg g}^{-1} \text{ sec}^{1/2}$)	0.286	0.185
	C	6.440	7.247
	R^2	0.9593	0.7803
	β (g mg^{-1})	1.287	1.846
Elovich equation	α ($\text{mg g}^{-1} \text{ min}^{-1}$)	863.764	86664.532
	R^2	0.9697	0.7656

while q_e denotes sorption capacity (mg g^{-1}).

3.6.2 Langmuir Isotherm

Langmuir isotherm considers a monolayer sorption on a surface having binding sites of equal energies and these sites have equal affinity toward metal ions. This isotherm also assumes that there is no transmigration of sorbed metal ions from one place to another on the surface of sorbent. Following is the linear form of this isotherm:

$$\frac{C_e}{q_e} = \frac{1}{K_1 Q_m} + \frac{C_e}{Q_m} \quad (8)$$

Where Q_m denotes monolayer sorption capacity (mg g^{-1}) while K_1 expresses Langmuir constant and associated to sorption free energy (L mg^{-1}).

3.6.3 Temkin Model

According to Temkin isotherm as the surface coverage increases, a linear decrease in heat of sorption takes place and assumes the interaction of sorbate and sorbent. The following equation is a linear form of this isotherm:

$$q_e = B_T \ln A_T + B_T \ln C_e \quad (9)$$

In the above equation A_T associated with maximum binding energy while B_T associated with heat of sorption.

3.6.4 Dubinin-Radushkevich (D-R) isotherm

Nature of sorption process that whether it is physical or chemical can be determined by fitting the experimental data in Dubinin-Radushkevich (D-R) isotherm while the surface will not be a homogeneous one²⁵. Following equation represents the linear form of this isotherm:

$$\ln q_e = \ln Q_m - K \epsilon^2 \quad (10)$$

In this equation K denotes the sorption energy and the theoretical saturation capability is represented by Q_m while ϵ denotes the Polanyi potential. The value of Polanyi potential is obtained by following equation:

$$\epsilon = RT \ln \left(1 + \frac{1}{C_e} \right) \quad (11)$$

The nature of sorption process can be revealed by mean free energy of sorption (E) and can be obtained as following:

$$E = \frac{1}{\sqrt{2K}} \quad (12)$$

Physical sorption has E value less than 8 kJ mol^{-1} while chemical sorption has E value between 8 to $16 (\text{kJ mol}^{-1})$ ²⁶.

The values of correlation coefficients and the other constant parameters are calculated from linearized forms of respective equations and summarized in **Table 2**. This table showed that Freundlich isotherm gave good fitness into the data due high values of R^2 among the studied isotherms. The maximum Pb(II) and Ni(II) sorption capacities (Q_m) were found to be $140.845 \text{ mg g}^{-1}$ and 32.362 mg g^{-1} respectively. The literature study reveals that Freundlich isotherm describes multilayer sorption on a heterogeneous surface which suggests physical sorption. The value of E shows that sorption of Pb(II) and Ni(II) onto pea peels is physical sorption because its value is less than 8 kJ mol^{-1} . It can be seen from **Table 3** that the result obtained in this study was found to be promising as compared with many reported literatures.

3.7 Effect of Temperature

The temperature of the reaction mixture was varied from 303 to 323 K to see the effect of temperature on sorption of Pb(II) and Ni(II) on pea peels while the other parameters were kept constant (i.e. pH 6.0 for Pb(II) and pH 7.0 for Ni(II)). It was observed that sorption of Pb(II) and Ni(II) onto pea peels is increased gradually with increase in temperature from 303 to 323 K, suggesting the endothermic nature of sorption process. Additionally, the endothermic

Table 2 Isothermal parameters of the removal of Pb(II) and Ni(II).

Model	parameters	Pb (II)	Ni (II)
Freundlich	$K_F (\text{mg g}^{-1})$	2.029	0.745
	n	0.890	0.592
	R^2	0.9669	0.9982
Langmuir	$K_1 (\text{L mg}^{-1})$	43.859	0.244
	$Q_m (\text{mg g}^{-1})$	140.845	32.362
	R^2	0.8745	0.9355
Tempkin	$A_T (\text{L g}^{-1})$	0.511	4.678
	$B_T (\text{mg L}^{-1})$	16.112	48.286
	R^2	0.9887	0.9885
	$Q_m (\text{mg g}^{-1})$	28.343	68.923
Dubinin-Radushkevich	K	3×10^{-6}	1×10^{-5}
	$E (\text{kJ mol}^{-1})$	0.408	0.223
	R^2	0.9581	0.9854

Table 3 A comparison of sorption capacities for various sorbents for Pb (II) and Ni (II).

Metal ion	Sorbent	Sorption capacity (mg g ⁻¹)	Reference
Pb (II)	Chemically modified brown algae	110.350	8
Ni (II)	Chemically modified brown algae	16.170	8
Pb (II)	Nonliving cell <i>Pseudomonas aeruginosa</i> ASU 6a	123.000	9
Ni (II)	Nonliving cell <i>Pseudomonas aeruginosa</i> ASU 6a	113.600	9
Pb (II)	<i>Lysinibacillus</i> sp. BA2	238.040	10
Ni (II)	<i>Bacillus laterosporus</i> (MTCC 1628)	44.440	23
Pb (II)	Pea peels	140.840	In the present study
Ni (II)	Pea peels	32.360	In the present study

mic nature of this process can also indicated by the value of free energy of sorption²⁷. At high temperature, an increase in thickness of the boundary layer occurs due to decreasing tendency of metal ions to escape from the surface of pea peels to the bulk solution. As a result, the sorption of Pb (II) and Ni (II) increases with increase in temperature.

3.8 Thermodynamic Study

The sorption mechanism of Pb (II) and Ni (II) onto pea peels was described using thermodynamic parameters such as free energy (ΔG°), enthalpy (ΔH°) and entropy (ΔS°). The following equations were used to calculate these parameters:

$$K_D = \frac{q_e}{C_e} \quad (13)$$

$$\Delta G^\circ = -RT \ln K_D \quad (14)$$

$$\ln K_D = -\frac{\Delta G^\circ}{RT} = -\frac{\Delta H^\circ}{RT} + \frac{\Delta S^\circ}{R} \quad (15)$$

Where C_e denotes the metal ion at equilibrium ($\mu\text{g mL}^{-1}$), q_e represents sorption capacity (mg g^{-1}) at equilibrium and K_D denotes distribution coefficient. The values of $\ln K_D$ were plotted against $1/T$ and the slope and intercept of this plot were used to calculate the values of ΔH° and ΔS° respectively. **Table 4** shows the values of these parameters.

This table showed that ΔG° is negative, suggesting the spontaneity and feasibility of the sorption of Pb (II) and Ni (II) onto pea peels. The values of Gibbs free energy are continuously decreases as the temperature increases which indicates that the sorption of both metal ions is favorable at high temperature. In solution, the metal ions mobility increases with temperature as a consequence, the high affin-

ity between metal ions and sorbent was observed at high temperature²⁸. The sorption of Pb (II) and Ni (II) onto pea peels is endothermic as indicated by the positive values of ΔH° . The values of ΔS° are positive for both metal ions suggesting that randomness at solid liquid interface increases during the process. Positive values of ΔS° also reflect the affinity of sorbent toward metal ions.

4 CONCLUSIONS

The present study was carried out to investigate the sorption mechanisms of Pb (II) and Ni (II) in aqueous solution using pea peels. The study showed that pH of the solution highly affects the sorption of Pb (II) and Ni (II) and maximum sorption of Pb (II) was obtained at pH 6.0 while Ni (II) was at pH 7.0. Kinetic data well fitted into pseudo-second order due high R^2 values as well as the closeness of experimental sorption capacity to that of calculated sorption capacity values of pseudo second order kinetic model. The isotherm studies showed that Freundlich isotherm is one of the best choices to explain the equilibrium data due to high values of correlation coefficients. Sorption capacity of pea peels was 140.84 and 32.36 for Pb (II) and Ni (II) mg g^{-1} respectively. The values of enthalpy and free energy indicate that the sorption process of Pb (II) and Ni (II) using pea peels is an endothermic and spontaneous process respectively.

Table 4 Thermodynamic parameters of the removal of Pb (II) and Ni (II).

Metal	ΔG° (kJ mol ⁻¹)			ΔH° (kJ mol ⁻¹)	ΔS° (kJ K ⁻¹ mol ⁻¹)
	303 K	313 K	323 K		
Pb (II)	0.059	0.082	0.214	5.448	0.017
Ni (II)	2.021	2.110	2.338	9.011	0.035

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