
Removal of Ni(II) from electroplating rinse waters using cation-exchange resins: batch and column studies

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Abstract: The adsorption of Ni (II) from nickel electro plating rinse water has been attempted. Indion 225 and Dueolite C 20 cation-exchange resins through batch and column mode for the recovery of Ni (II), which showed a remarkable increase in sorption capacity. On the basis of isotherm analysis; more efficient adsorbent is chosen for column mode adsorption studies. The continuous-flow study was to investigate the effect of various process variables, like bed height, hydraulic loading rate on breakthrough and adsorption capacity. An attempt has also been made the data using Bohart–Adams approach to design the adsorption system.

Keywords: adsorption; ion exchange resins; Bohart–Adams model; regeneration.

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1 Introduction

The heavy and toxic metal contaminants in aqueous waste streams can cause serious water pollution problems in the world. Ni(II) has been identified as one of the hazardous pollutants. A higher concentration of Ni(II) in ingested water may cause severe damage to lungs, kidneys, gastro-intestinal distress, e.g., nausea, vomiting, diarrhoea, pulmonary fibrosis, renal oedema, and skin dermatitis. It is also a known carcinogen (Axtell et al., 2003). As nickel was used in a number of industries including electroplating, batteries manufacturing, mining, metal finishing and forging, Ni(II) exists in waste-water streams from industries such as electroplating, non-ferrous metals mineral processing, dye industries, porcelain enamelling, and steam-electric power plants (Yu and Kaewsarn, 2000). Various technologies have been developed over the years to remove toxic metal ions from water; the most important among them include filtration, chemical precipitation, electro-deposition, and membrane systems. All these technologies have advantages and limitations. However, these methods are not efficient in removing heavy metals of different concentrations and are relatively expensive to achieve within legal limits (Namasivayam and Sangeetha, 2006). The ion-exchange technique is a feasible and effective method to recover heavy metals from solutions (Dabrowski et al., 2004) and is a proven technology for the removal of Ni(II) from the rinse water of nickel electroplating and it was found that the removal of heavy metal using a cation-exchange resin has good

potential for industrial waste-water treatment. The present work also throws some light on the probable mechanism of the process, especially the role of mass transfer on the kinetics of Ni(II) removal by the cation exchange resin. Ion exchange techniques were recommended by many researchers as the appropriate choice for the recovery of heavy metals from rinse water and for the reuse of the treated water. The ion exchange resins used were prepared from the synthetic polymers such as styrene divinyl benzene copolymers. They are in sulphonated form and are strongly acidic cation exchangers and exhibit high affinity for heavy metals.

In the present investigation, batch mode adsorption studies were conducted using two types of commercially available cation ion exchange resins viz., Indion 225 and Dueolite C 20. After assessing the adsorption potential of the two adsorbents (Indion 225 and Dueolite C 20) with respect to the Ni(II) removal, the more efficient resin was selected for column mode studies.

2 Materials and methods

2.1 Materials

All the chemicals used were of analytical reagent grade and obtained from SD Fine Chemicals, Mumbai. The ion exchange resins, Indion 225 and Dueolite C 20, were procured from Ion Exchange India Ltd, Mumbai, and used for the present study; its characteristics are given in Table 1. The adsorbate is the Ni(II) ions contained in rinse water, which is synthetically generated in a laboratory by carrying out nickel plating using the setup shown in Figure 1.

Table 1 Characteristic properties of ion exchange resins

<i>Parameter</i>	<i>Indion 225</i>	<i>Dueolite C 20</i>
Matrix	Styrene divinyl benzene copolymer-gel structure	Cross linked polystyrene
Functional groups	Sulphonic acid	Sulphonic acid
Physical form	Moist translucent golden yellow coloured beads	Amber translucent beads
Ionic form as shipped	Sodium, Na ⁺	Sodium, Na ⁺
Moisture holding capacity	42–48%	46.2–57%
Apparent density	840 g L ⁻¹	825 g L ⁻¹
Uniformity coefficient	1.7 (maximum)	1.46 (maximum)
Total exchange capacity	2 meq mL ⁻¹	2.05 meq mL ⁻¹
Fine content	0.3 mm	0.45 mm
Coarse beads	1.2 mm	0.54 mm
pH range	0–14	0–14
Specific gravity	–	1.28

Dotted lines indicate the make-up solutions for the plating bath

NICKEL PLATING

SPRAY RINSE

DRAGOUT

RINSE WATER

Tank Layout with work Flow indicated by arrows

The electrolytic cell is comprised of a set of electrodes, viz. copper sheet cathode and nickel anode, placed in the acidic nickel laden solution. An electric current is applied across the electrodes and through the solution. In the acidic nickel bath solution (pH value is 4.8), the copper sheets of surface area $7.5 \times 5.0 \text{ cm}^2$ (of 2 mm thick) comprising the work piece and the nickel metal sheets of surface area as $6.5 \times 5 \text{ cm}^2$ (of 5 mm thick) were used as cathode and anode, respectively. The experiment was carried out at a fixed current density (0.024 A/cm^2). The cathode was pretreated and pickling was done for three minutes to remove dust and rust from the surface. When current was passed, the positively charged metal ions were drawn to the negatively charged cathode where they deposited onto the surface. The electroplating was done in the acidic bath for 10 min. One litre tanks containing distilled water were used to rinse the cathode after electroplating. The rinsing was done for 10 s for each tank. The rinse water collected in the first tank (spray rinse and drag out) was not taken for adsorption studies, as It will be used as make up solution for evaporation loss during plating. The other rinse waters collected containing heavy metal concentrations from 14.3 mg L^{-1} , 26.2 mg L^{-1} , 33.6 mg L^{-1} , 43.1 mg L^{-1} , and 53.1 mg L^{-1} were used for further experiments. The characteristic properties of rinse water concentration of 53.1 mg L^{-1} is tabulated in Table 2.

Table 2 Characteristic properties of generated rinse water

<i>Parameters</i>	<i>Contents/Characters</i>
Nickel (mg L ⁻¹)	53.1
pH	7.6
Total Hardness (mg L ⁻¹)	362
Total dissolved solids (mg L ⁻¹)	916
Sodium (mg L ⁻¹)	83
Potassium (mg L ⁻¹)	42
Chloride (mg L ⁻¹)	255
Sulphate (mg L ⁻¹)	516
Fe (mg L ⁻¹)	0.082

2.3 Batch adsorption studies

In each isotherm experiment, a known quantity 0.2 g for Indion 225 and 0.1 g for Dueolite C 20 of adsorbent contacted with 50 mL adsorbate solution (12.3 mg L⁻¹ – 53.1 mg L⁻¹ and room temperature at 32°C) in a conical flask at desired pH and room temperature. The batch setup was shaken in a rotary shaker (ORBITEK, Chennai, India) at constant agitation speed of 150 rpm. At various time intervals, the flasks were successively removed, the liquid was separated from the resin and the remaining concentration of Ni(II) in solution was analysed in an atomic absorption spectrophotometer (Perkin Elmer AA700 model). The experiment was continued till there was no change in the concentration of Ni(II) in the solution.

The concentration of Ni(II) ions retained in the resin phase, q_e (mg g⁻¹) was calculated by using the following equation.

$$q_e = \frac{(C_o - C_e)V}{W_s} \quad (1)$$

where C_o is the initial concentration of Ni(II) ions in the solution and V is the volume of the solution in litres and W_s is the mass of the resin dosage (g). The equilibrium adsorption capacity q_e (mg g⁻¹) was calculated using C_e , the equilibrium concentration of Ni(II) ions in the solution, after 24 h. Each experiment was carried out in duplicate. Ni(II) concentration was analysed using an atomic absorption spectrophotometer (Perkin Elmer AAS, model AA700).

Equilibrium adsorption isotherms were prepared by plotting the mass of nickel adsorbed per mass of resin as a function of residual concentration of Ni(II) at equilibrium. The nickel adsorption capacities of Indion 225 and Dueolite C 20 cation exchange resins were then compared using the following isotherms:

2.3.1 Langmuir Isotherm

The well known expression for the Langmuir isotherm (Langmuir, 1916) is given by the equation (2) and is valid for monolayer sorption onto a surface with a finite number of identical sites:

$$q_e = \frac{Q_o b C_e}{(1 + b C_e)} \quad (2)$$

where C_e is the heavy metal concentration at equilibrium (mg L^{-1}), Q_o and b is the Langmuir constants related to the maximum adsorption capacity and bonding energy of adsorption, respectively. Q_o and b can be determined from the linear plot of C_e/q_e vs. C_e .

2.3.2 Freundlich Isotherm

The Freundlich isotherm model (Freundlich, 1906) assumes neither homogeneous site energies nor limited levels of sorption. The Freundlich equation has the general form:

$$q_e = K_f C_e^{1/n} \quad (3)$$

where K_f relates to sorption capacity and n is sorption intensity. Equation (3) can be linearised in logarithmic form and the Freundlich constants can be determined.

2.3.3 Redlich-Peterson isotherm

The three parameter Redlich-Peterson model (Redlich and Peterson, 1959) has been proposed to improve the fit by the Langmuir or Freundlich equation and is given by equation (4)

$$q_e = \frac{K_{RP} C_e}{(1 + a_{RP} C_e^\beta)} \quad (4)$$

where K_{RP} , a_{RP} and β are the Redlich Peterson parameters. The exponent β lies between 0 and 1. When $a_{RP} \rightarrow 0$ isotherm is linear and if $\beta \rightarrow 1$ the isotherm obeys Langmuir. Further, when $a_{RP} C_e^\beta \gg 1$, the model reduces to the Freundlich isotherm, the Langmuir–Freundlich model.

2.3.4 Sips model

This is essentially a Freundlich isotherm which approaches an adsorption maximum at high concentrations of adsorbate. An equation, mathematically equivalent to the Sips Model equation (Nitta et al., 1984), can also be obtained by assuming that the surface is homogeneous, but that the adsorption is a cooperative process due to adsorbate–adsorbate interactions. The following relation represents this model:

$$q_e = \frac{K_s C_e^{\beta_s}}{1 + a_s C_e^{\beta_s}} \quad (5)$$

where K_s is the Sips model isotherm constant, a_s is the Sips model constant and β_s is the Sips model exponent. When $a_s \rightarrow 0$ the isotherm is Freundlich and if $\beta \rightarrow 1$ the isotherm obeys the Langmuir model.

The mean values of the duplicate of each concentration were plotted and fitted to the above isotherms. All the model parameters were evaluated using MATLAB software.

2.4 Column mode adsorption studies

The experimental arrangement shown in Figure 1 consists of a borosilicate glass column with 10 mm as internal diameter, packed with the chosen cation exchange resin. The effluent passing through the column was discharged into sample collecting units below the column using a peristaltic pump. Sampling points were also provided before and after the column for drawing the effluent samples at regular intervals. To increase the adsorption capacity of the cation exchange resin, it was soaked in 0.1 M HCl for a day and thoroughly rinsed and packed up to the desired bed height. The column was kept submerged throughout the runs to avoid air entrapment in the bed. The operation was in down-plug flow mode which was confirmed by trace experiments. The effluents and influents were collected in the same intervals. All the sorption experiments were carried out at room temperature only. (32°C). The Bohart–Adams model was used to predict the performance.

3 Results and discussion

3.1 Equilibrium adsorption isotherms

Analysis of the equilibrium data is important to develop an equation which accurately represents the results and which could be used for design purposes. Since sorption is a time dependant phenomenon, it is essential that the kinetic study should have been performed at specified concentrations (generated during rinsing operation), so as to establish the time at which equilibrium between the sorbate and sorbent is attained. Figures 2 and 3 show the amount of sorbate adsorbed at equilibrium and concentration of sorbate in solution.

Figure 2 Variation of concentration of Ni(II) ions in solution with time due to adsorption by Indion 225

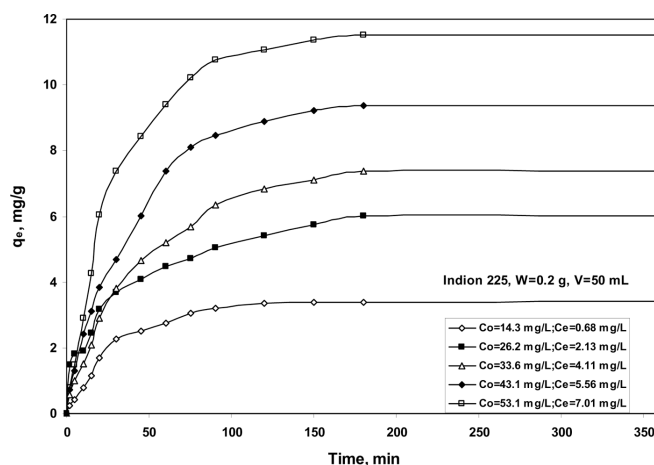
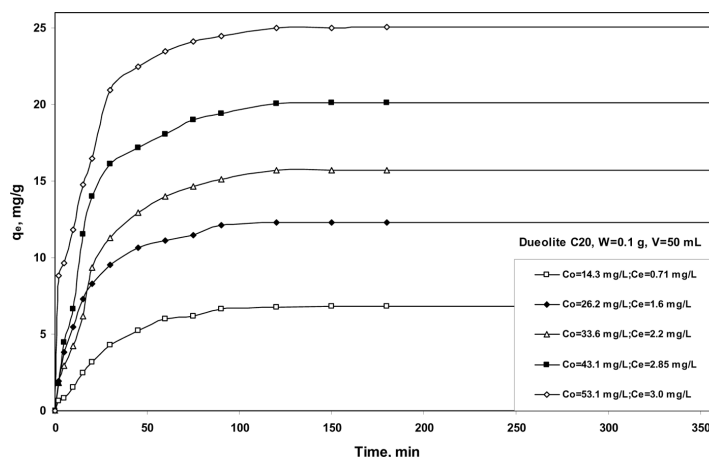


Figure 3 Variation of concentration of Ni(II) ions in solution with time due to adsorption by Dueolite C 20

Several isotherm equations have been used for the equilibrium modelling of sorption systems. The most widely used two parameter adsorption isotherms were the Langmuir and Freundlich isotherms. In addition to the above isotherms, Redlich-Peterson and Sips isotherms (were known as three parameter models) were also used for analysis. The isotherms relate the metal uptake per unit weight of adsorbent q_e to the equilibrium adsorbate concentration in the bulk fluid phase. For each isotherm, for a given initial Ni(II) concentration Indion 225 and Dueolite C 20 cation exchange resins were taken. An adsorption isotherm is characterised by certain constants whose values express the surface properties and affinity of the sorbent and are used to find the adsorption capacity of the sorbate. The Langmuir, Freundlich, Redlich-Peterson and Sips adsorption constants evaluated from the isotherms for two different resins and their correlation coefficients are also presented in Table 3. High regression correlation coefficients (greater than 0.9) were found for both the resins studied, suggesting that all models are suitable for describing the sorption equilibrium of Ni(II) in the studied concentration. The applicability of all the isotherm models to the Ni(II)-cation exchange resin system implies that both mono-layer sorption and heterogeneous surface conditions exist under the experimental conditions used. The sorption of Ni(II) ions on the resin is thus complex, involving more than one mechanism. From Table 3, the magnitude of K_f and n ; the Freundlich constants, showed easy uptake of Ni(II) from the aqueous solution with high adsorptive capacity of the Dueolite C 20 rather than that of Indion 225. Table 3 also indicated that n is greater than unity, indicating that Ni(II) ions are favourably adsorbed by both cation exchange resins. While the Freundlich model does not describe the saturation behaviour of the sorbent, Q_o , the mono-component Langmuir constant represents the mono-layer saturation at equilibrium. The other mono-component Langmuir constant b corresponds to the concentration at which a Ni(II) ion amount of $Q_o/2$ is bound and indicates the affinity for the binding of Ni(II) ions. A high b value indicates a high affinity. Values of Q_o and b for two different exchange resins were calculated from the Langmuir plots and the results are also tabulated in Table 3. The maximum capacity Q_o determined from the Langmuir isotherm defines the total capacity of the sorbent for Ni(II). The value of Q_o obtained for Dueolite C 20

(i.e., maximum uptake and equal to 45.98 mg g^{-1}) appears to be higher in comparison with the uptake obtained by Indion 225 while the value of b is lower than that of Indion 225 resin. A higher value of b also implied strong bonding of Ni(II) to Indion 225 at this concentration. The relevant adsorption parameters were also calculated according to the three-parameter isotherm of Redlich-Peterson using the least-squares method for Ni(II) ions and are tabulated in Table 3 for two different resins. The Redlich-/Peterson constant K_{RP} and Sips constant K_S indicated that the sorption capacity of Dueolite C 20 is more than that of Indion 225. It is to be noted that β normally should lie between 0 and 1, indicating favourable adsorption. With regard to the Redlich-/Peterson model the value of β obtained is negative for both the resins. Hence, the applicability of the Redlich-Peterson isotherm for present case is very much doubtful. In respect of the Sips isotherm, the value of β obtained is positive and the isotherm approaches the Freundlich form. Figures 4–7 present the Langmuir, Freundlich, Redlich-Peterson and Sips isotherm plots for Ni(II) ions adsorption on the ion exchange resins using the generated electroplating Ni(II) solutions, using MATLAB software, which shows the high value of the coefficient of correlation for both the adsorbents, indicating that the models fit well. The application of the Freundlich, Redlich-Peterson and Sips model to the isotherm data resulted in better R^2 correlation coefficients ($R^2 = 0.9$) indicating good agreement between experimental and predicted data. Also, the comparison clearly shows that Dueolite C 20 cation exchange resin is more effective for heavy metals removal. But Dueolite C 20, showing higher adsorption capacity and regression coefficients, was chosen for further column analysis.

Figure 4 Langmuir isotherm for the adsorption of Ni(II) by ion exchange resins Indion 225 and Dueolite C 20

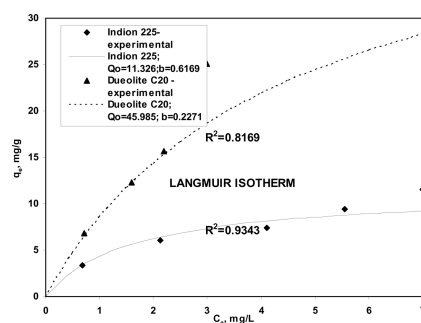


Figure 5 Freundlich isotherm for the adsorption of Ni(II) by ion exchange resins Indion 225 and Dueolite C 20

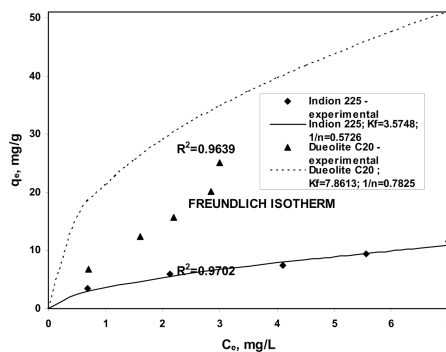
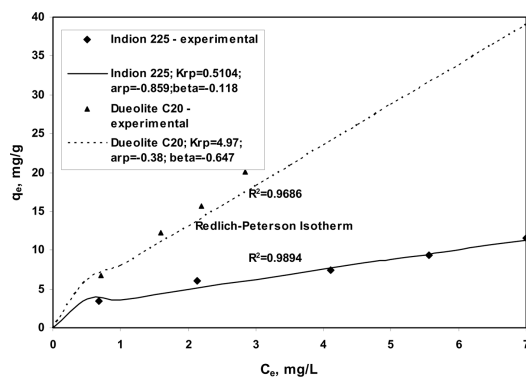
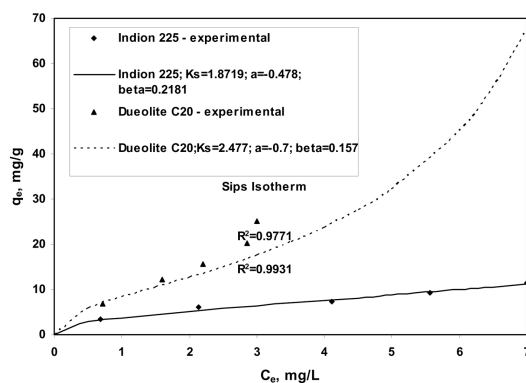


Figure 6 Redlich-Peterson isotherm for the adsorption of Ni(II) by ion exchange resins Indion 225 and Dueolite C 20**Figure 7** Sips model for the adsorption of Ni(II) by ion exchange resins Indion 225 and Dueolite C 20**Table 3** Isotherm parameters for Langmuir, Freundlich, Redlich–Peterson, Sips models

Isotherm	Indion 225			Dueolite C 20		
	Parameters		R^2	Parameters		R^2
LANGMUIR	Q^o	b	0.8169	Q^o	b	0.9343
	11.326	0.6169		45.985	0.2271	
FREUNDLICH	K_f	n	0.9702	K_f	n	0.9639
	3.5748	0.5726		7.8613	0.7825	
REDLICH-PETERSON	K_{RP}	a_{RP}	0.9894	K_{RP}	a	0.9686
	0.5104	-0.859		4.97	-0.38	
SIPS MODEL	K_S	a	0.9931	K_S	a	0.9771
	1.9719	-0.478		2.477	-0.7	

3.2 Column studies

Using the peristaltic pump the adsorbate was eluted through the column for the desired pumping flow rate of 6 ml min^{-1} to different bed heights, also varying the hydraulic

loading rate from $4.58 \text{ m}^3\text{h}^{-1}\text{m}^{-2}$ to $7.64 \text{ m}^3\text{h}^{-1}\text{m}^{-2}$. The bulk adsorption takes place in the adsorption zone where the concentration of the influent started rising, this is known as the break point. The breakthrough curve was plotted, giving the ratio of effluent and feed (influent) concentrations C_e/C_o and time (h) for varying operating conditions. The approach of Treybal (1980) has been adopted for calculating the column capacity for the removal of Ni(II). Breakthrough, expressed in mg of Ni(II) adsorbed per gram of adsorbent, was calculated using equation (6)

$$\begin{aligned} \text{Breakthrough capacity, } Q_{0.5} &= \text{metal adsorbed on adsorbent bed (mg)/ mass of} \\ &\quad \text{adsorbent in bed (g)} \\ &= \text{breakthrough time (h) (at 50\%)} \times \text{flow} \\ &\quad \text{rate (h}^{-1}\text{)} \times \text{feed Concentration (mg L}^{-1}\text{)} \times \text{mass of} \\ &\quad \text{adsorbent in bed (g)} \end{aligned} \quad (6)$$

Table 4 shows the column adsorption capacity for Ni(II) onto the adsorbent for varying operating variables: bed height, flow rate and constant feed concentration. The column capacity for Ni(II) adsorption for the bed height of 0.1–0.2 m, hydraulic loading rate of $3.81 \text{ m}^3\text{h}^{-1}\text{m}^{-2}$ and $4.58 \text{ m}^3\text{h}^{-1}\text{m}^{-2}$ and the constant feed concentration of 53.1 mg L^{-1} for breakthrough concentration were found to be 46.57 mg/g . From comparison of adsorption capacity from batch mode and column experiments, we can see that the less-stirred property in column mode increased the Ni(II) adsorption capacity on Dueolite C 20. Hence, the heavy metal sorption strongly depends on the solution chemistry of the metals and competing ions in the adsorbent. The excess amount of light metal ions (Na^+ and K^+) and total hardness in the generated effluent may have influenced the Ni(II) binding. However, (Volesky and Schiewer, 1999) inferred that light metals generally bind less strongly than heavy metal ions and, therefore, they do not strongly interfere with heavy metals binding.

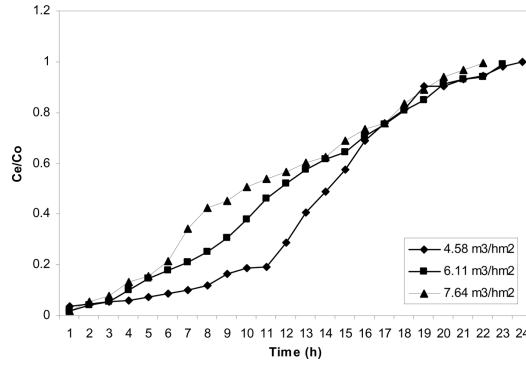
Table 4 Column adsorption and desorption capacity at 50% breakthrough constants

Parameters		Adsorption			Desorption		
Initial concentration (mg L ⁻¹)	Bed height (m)	Hydraulic loading rate (m ³ h ⁻¹ m ⁻²)	Break through time (h) (50%)	Adsorption capacity (mg g ⁻¹)	Hydraulic loading rate (m ³ h ⁻¹ m ⁻²)	Break through time (h) (50%)	Desorption capacity (mg g ⁻¹)
53.1	0.1	4.58	12.5	46.57	3.81	5.5	17.07
53.1	0.15	4.58	17	43.27	3.81	8	16.96
53.1	0.2	4.58	20.5	35.98	3.81	10	14.62

3.2.1 Effect of hydraulic loading rate

The breakthrough experiments were conducted at a bed height of 0.1 m, at constant feed concentration of 53.1 mg L^{-1} with hydraulic loading ranging from ($4.58 \text{ m}^3\text{h}^{-1}\text{m}^{-2}$, $6.11 \text{ m}^3\text{h}^{-1}\text{m}^{-2}$ and $7.64 \text{ m}^3\text{h}^{-1}\text{m}^{-2}$). The results were plotted in Figure 8 which shows that the breakthrough time decreases from 14.5 h to 10 h as hydraulic loading rate increases from $4.58 \text{ m}^3\text{h}^{-1}\text{m}^{-2}$ to $7.64 \text{ m}^3\text{h}^{-1}\text{m}^{-2}$. This behaviour is due to the fact that increase in HLR causes increase in zone speed and also results in decreasing the time required to achieve breakthrough. The same results were cited in removal of lead (II) by adsorption using treated granular activated carbon (Goel et al., 2005).

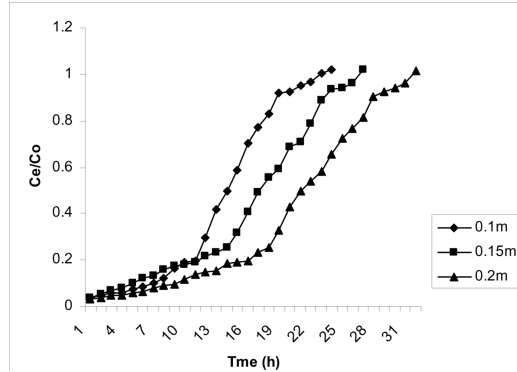
Figure 8 Breakthrough curve for different hydraulic loading rates at constant bed height and constant feed concentration



3.2.2 Effect of bed height

The experiments were conducted at different bed heights of 0.1 m, 0.15 m and 0.2 m at a hydraulic loading rate of $4.58 \text{ m}^3 \text{ h}^{-1} \text{ m}^{-2}$. Where the bed height increases, the length of the bed through which the effluent passes increases. The increase in the total adsorptive capacity of the bed results in a decrease in the solute concentration of the effluent, as shown in Figure 9.

Figure 9 Breakthrough curve for different bed heights and at constant feed concentration and hydraulic loading rate



3.3 Modelling of column study results

Based on surface reaction theory equilibrium is not instantaneous (Eckenfelder, 1989). According to the following equation the performance of the continuous column studies can be predicted by,

$$t = \frac{N_o X}{C_o V} - \ln \left[\frac{C_o}{C_e} - 1 \right] \times \frac{1}{C_o K} \quad (7)$$

where t is the time to break point (h), C_o the influent concentration (mg L^{-1}), C_e the concentration breakthrough at time t (mg L^{-1}), N_o the adsorption capacity (mg L^{-1}),

X is the depth of the column (m), V is the linear flow rate (mg h^{-1}), K is the rate constant ($\text{L mg}^{-1} \text{h}^{-1}$).

The simplified Bohart Adams model is

$$t = aX + b \quad (8)$$

where

$$a = \frac{N_o}{C_o V} \quad (9)$$

and b in equation (10) is given by

$$b = \ln \left[\frac{C_o}{C_e} - 1 \right] \times \frac{1}{C_o K}. \quad (10)$$

From the iso-removal lines given in Figure 10 for different breakthroughs, the Bohart–Adams parameters were calculated. Iso-removal lines were plotted for three different bed heights i.e., 0.1, 0.15 and 0.2 m with a constant influent concentration of 53.1 mg L^{-1} . The breakthrough times with desired breakthrough concentrations exhibit linearity with bed depth. The slope (a) and intercept (b) from the iso-removal lines were used to calculate the adsorption capacity (N_o) and adsorption rate constant (K), respectively. The calculated Bohart–Adams model constants for the adsorption of Ni(II) on to Dueolite C 20 are presented in Table 5 and will be used to design the column.

Figure 10 Iso-removal lines for 20%, 40% and 60% breakthrough for different bed heights at constant feed concentration and constant hydraulic loading rate

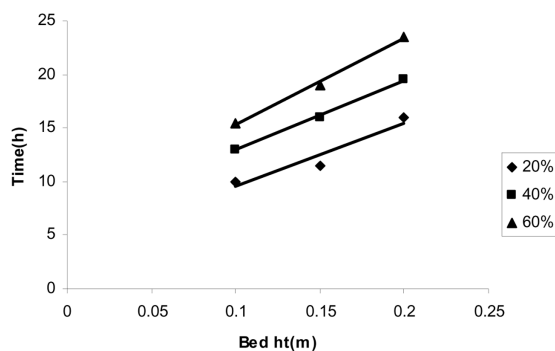


Table 5 The calculated Bohart–Adams model constants for the adsorption of Ni(II) by ion exchange resins Indion 225 and Dueolite C 20

Iso-removal percentage (%)	a (hm^{-1})	b (h)	N_o (mg L^{-1})	K ($\text{Lh}^{-1} \text{mg}^{-1}$)	R^2
20	60	−3.5	4863.96	−0.003	0.9246
40	65	−6.41	5269.29	−0.002	0.998
60	80	−7.33	6485.28	−0.0004	0.9948

Using the linear equation the necessary bed height for a preselected time period can be directly calculated until a defined break through concentration (Lehman et al., 2001). The slope constant for a different flow rate can be directly calculated by multiplying the original slope (a) by the ratio between the original (V_o) and the new flow rates (V_n).

Therefore

$$a_{\text{new}} = a_{\text{old}} \left[\frac{V_o}{V_n} \right] \quad (11)$$

Similarly, the equation can be developed for the initial concentration (53.1 mg L⁻¹) and can be modified to be applied for another concentration (18 mg L⁻¹)

$$a_{\text{new}} = a_{\text{old}} \left[\frac{C_o}{C_n} \right] \quad (12)$$

$$b_{\text{new}} = b_{\text{old}} \left[\frac{C_o}{C_n} \right] \left[\frac{\ln(C_n - 1)}{\ln(C_o - 1)} \right] \quad (13)$$

where C_o and C_n are the original and new feed concentrations. Based on equations (11)–(13) breakthrough time was predicted for a new feed concentration and flow rate using the Bohart–Adams model constants and the results are presented in Tables 6 and 7, respectively. The correlation prediction has been found to agree well for the case of changed flow rate and bed height. Hence, the developed model and the constants evaluated can be employed for the design of adsorption columns over any range of flow rates and bed heights.

Table 6 Predicted breakthrough time based on Bohart–Adams model for the new feed concentration

Break point (%)	a_{old}	b_{old}	C_o (mg L ⁻¹)	C_n	C_o/C_n	a_{new}	b_{new}	Bed height (m)	Predicted time (h)	Observed time (h)
60	80	-7.33	53.1	18	2.95	236	-17.99	0.1	5.6	15.5
40	65	-6.41	53.1	18	2.95	191.7	-15.73	0.1	3.44	13
20	60	-3.5	53.1	18	2.95	177	-8.59	0.1	9.1	10

Table 7 Predicted breakthrough time based on Bohart–Adams model for the new flow rate

Break point (%)	a_{old}	b_{old}	V_o	V_n	V_o/V_n	a_{new}	Bed height (m)	Predicted time (h)	Observed time (h)
60	80	-7.33	4.58	2.5	1.832	146.56	0.1	7.32	15.5
40	65	-6.41	4.58	2.5	1.832	119.08	0.1	5.49	13
20	60	-3.5	4.58	2.5	1.832	109.92	0.1	7.49	10

3.4 Column Regeneration Studies

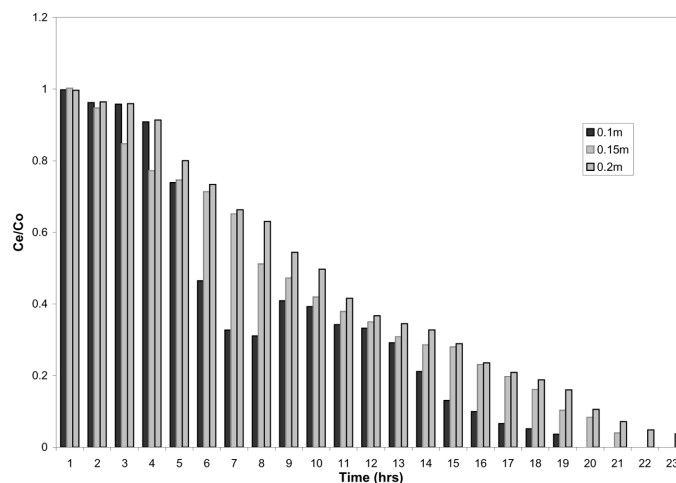
Reusability of adsorbent material is a crucial important in industrial practice. Hence, the aim is to remove the loaded metal ions from the column in the smallest possible volume of an eluting solution. In the present study, the elution of Ni(II) adsorbate from

the rinse electroplating wastewater was carried out using 0.1 M hydrochloric acid in different adsorbent heights with a linear flow rate of $3.81 \text{ m}^3 \text{ h}^{-1} \text{ m}^{-2}$, the results were shown in Figure 11, where the total Ni(II) desorption capacity was found to be 17.07 mg g^{-1} to 14.6 mg g^{-1} for 0.1 m–0.2 m bed height. This is because the exchangeable H^+ ions were more with the metal ions in the HCl solution. The regeneration efficiency (Gupta and Sharma, 2002), was calculated using equation (14) and it was found to be 36.66% and 40.65%. Also, it was noted that there was no major decrease in bed height.

$$RE\% = \frac{A_r}{A_o} \times 100. \quad (14)$$

In the above equation A_r is the adsorptive capacity of the regenerated column and A_o is the original capacity of the virgin adsorbent. The overall achievement of the adsorption process is achieved by the concentration factor, (Volesky and Schiewer, 1999), which is defined as the ratio of the total volume of effluent treated (in sorption process) to the total volume of desorbent used (in elution process). The concentration factor for the generated electroplating effluent for different bed heights 0.1 m, 0.15 m and 0.2 m was calculated and found to be 1.26, 1.28 and 1.39, respectively. These results show that as the bed height increases the concentration factor also increases.

Figure 11 Regeneration of column using 0.1M HCl for desorption of Ni(II) ions at different bed heights and same flow rate



4 Conclusions

The electroplating Ni(II) effluents were generated in lab scale and the characteristics of the effluents were analysed. Hence, the removal of Ni(II) from the generated effluents was studied using two cation exchange resins. The isotherm study identified that Dueolite C 20 is a suitable ion exchange resin for the removal of Ni(II) from electroplating effluents in batch and column mode operations. Column studies data have shown good agreement with the predicted results obtained by application of the Bohart–Adams model.

The constants evaluated from the Bohart–Adams model can be employed for the design of adsorption columns over a range of feasible flow rates and bed heights. The adsorbed Ni(II) ions can be effectively eluted with the use of HCl 0.1 M concentrations with the regeneration efficiency of 40.65%.

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