Removal of Ni(II) from water and wastewater using modified Duolite XAD-761 resin

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Complete mixing of cross-linked phenol-formaldehyde polymeric resin (Duolite XAD-761) with anionic surfactant - sodium dioctyl sulphosuccinate (SDOSS) and EDTA-disodium salt (Chelating agent) in an aqueous solution led to the formation of a modified resin. FT-IR studies showed that the immobilization of the extractants results from hydrophobic interaction between the alkyl group of the extractants and phenyl group of the support, and also from other mechanisms like polar or electrostatic forces. The modified resin was used in batch adsorption experiments for the removal of Ni(II) were carried out as a function of agitation time, pH, adsorbent dosage and adsorption capacity. Adsorption data could be interpreted by Langmuir and Freundlich equations. The results showed that the adsorption kinetics of Ni(II) on modified XAD-761 resin could be best described by the pseudo-second-order model. SEM studies revealed the morphological observations of the pure resin, modified resin and Ni(II) adsorbed modified resin. The adsorbent was also tested for the removal of Ni(II) from synthetic wastewater.

Keywords: Ni(II) adsorption, Duolite XAD-761, SDOSS, EDTA, FT-IR, SEM, Adsorption isotherms, Kinetics

The increased use of heavy metals has resulted in an increased flux of metallic substances in different environmental segments. The metals are of special concern due to their recalcitrant and persistency properties in nature. It is well established that heavy metals interfere with functional groups of essential enzymes even at very lesser concentration. Ni(II) containing wastewaters are common as nickel is used in a number of industries including electroplating, batteries manufacturing, mining, metal finishing and forging. The higher concentration of Ni(II) in ingested water may cause severe damage to lungs, kidneys, vomiting, diarrhea, pulmonary fibrosis, renal edema and skin dermatitis. Conventional methods of Ni(II) removal from wastewaters include chemical precipitation, coagulation/flocculation, complexation, sequestration, electrochemical deposition, biological treatment. However, these methods have considerable disadvantages including imperfect metal removal, high reagent or energy requirement or generate large amount of toxic sludge, which is to be disposed in additional steps.

Solvent impregnated resins have been extensively used for separating and recovering valuable metals. Among the separation methods porous resins impregnated with extracting solvents have offered many advantages over the use of liquid-liquid extraction, due to characteristics of the solid phase. These advantages include good selectivity, preconcentration factor, binding energy and mechanical stability, easy regeneration for multiple sorption-desorption cycles and good reproducibility in the sorption characteristics. The porous XAD resins exhibit many striking features such as stable chemical structures, high porosity and surface areas and great adsorption capacities. Amberlite XAD series resins have been widely used for the solid phase extraction of heavy metals. Immobilization of chelating agents onto polymeric resins was used for the extraction of heavy metals from aqueous solution.

Separation methods using surfactant micelles as separation media have been extensively studied. The sorption of a surfactant on the external surface of a natural zeolite and coconut coir pith for heavy metal removal has been studied. The performance of the polyoxyethylene-type nonionic surfactant loaded on Amberlite XAD-4 for the collection of precious metals from water has been evaluated. Studies have shown that surfactants in combination with a complexing agent have greater capability of extracting heavy metals from contaminated soil and joint application of surfactants and EDTA improved the removal of Cd and Cr from municipal sludge. The sorption of precious metal on a
macroporous resin Amberlite XAD-4 impregnated with non ionic surfactant- trioctylamine (TOA) has been studied. It has been noticed that Duolite XAD-761 resins are macroporous organic polymers with a high surface area, good mechanical stability, chemically homogeneous non-ionic structure, easy regeneration for multiple sorption-desorption cycles with good reproducibility in the sorption characteristics. Hence, Duolite XAD - 761 has been chosen for current investigations.

In this present study, attempts were made to prepare a solvent-impregnated resin with Duolite XAD-761 by using aqueous solution of non-hazardous sodium dioctyl sulphosuccinate (SDOSS) and EDTA-disodium salt (Chelating agent) for the separation of Ni(II) from the aqueous solution. The capability of the modified resin for the removal of nickel from aqueous solutions has been evaluated.

Experimental Procedure

Instrumentation

The AAS of Electronic Corporation India Ltd (Hyderabad, India), model- SL 163, with air-acetylene burner was used for the determination of Ni(II) concentration. The FT-IR spectrum was recorded with a NICOLET 380 FT-IR model. Scanning electron microscopic (SEM) studies were performed using JOEL-6360 instrument. The pH was measured with an Elico (Hyderabad, India) pH meter (model LI-120 digital). A thermally controlled mechanical shaker with a speed of 200 rpm was used for metal ion-chelating resin equilibration.

Reagents and Solutions

All the reagents used in the present study were of AR grade. The stock solution of Ni(II) was prepared by dissolving an appropriate amount of NiSO₄·6H₂O (BDH, Mumbai, India) in distilled water. The working solution of Ni was adjusted to a desired pH with 0.1 M HCl or NaOH. Duolite XAD-761 (surface area, 150-250 m²/g and mean size, 0.56-0.76 mm) was procured from Rohm Hass (Philadelphia, PA, USA). The properties of the resin are given in Table 1. The SDOSS and EDTA-disodium salt (S.D fine chem, Mumbai, India) were used as such for the preparation of chelating resin.

Preparation of adsorbent

The resin Duolite XAD-761 was purified with a 50% ethanol - water solution containing 4 M HCl to remove inorganic impurities and monomeric material. After that, the resin was rinsed thoroughly with distilled water to eliminate chloride ions. For the impregnation purposes, a dry method was followed. 1 g of pure Duolite XAD-761 resin was well mixed with equal ratio (1:1) mixture of 20 mL of 66.6% (v/v) water – ethanol mixture containing 2 g of SDOSS and 20 mL of water containing 2 g of EDTA (Disodium salt) and beads were left in the mixture for 24 h. The polymeric beads were separated from the solution by filtration, then washed with water and dried at 50°C. The amount of impregnated complex was calculated from the material balance (from a mixture of SDOSS and EDTA). The amount of ligand impregnated onto dry resin was found to be 156 mg g⁻¹.

Batch experiments

100 mL of Ni(II) solution with desired concentration adjusted to a desired pH were taken in polythene bottles of 300 mL capacity and 0.2 g of modified Duolite XAD-761 resin was added to it. The solutions were agitated for a predetermined period at 30±1°C and then resin particles were separated by filtration and the filtrate was analyzed for Ni(II) by AAS. Adsorption isotherm and kinetic studies were carried out with different initial concentrations of Ni(II) by maintaining the modified resin dosage at constant level. Adsorption isotherm studies were made after completing a period of 24 h.

Results and Discussion

Both surfactant and EDTA-disodium salt (a chelator) were individually loaded on Duolite XAD-761 and then tested for Ni(II) adsorption. However, individually loaded resins could not remove the Ni(II) from the solution effectively. The initial

<table>
<thead>
<tr>
<th>Table 1— Physical and chemical properties of Duolite XAD-761</th>
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<td>Physical and chemical properties</td>
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<tr>
<td>Duolite XAD-761</td>
</tr>
<tr>
<td>Matrix</td>
</tr>
<tr>
<td>Surface area (m²/g)</td>
</tr>
<tr>
<td>Specific gravity</td>
</tr>
<tr>
<td>Particle size (mm)</td>
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<tr>
<td>Polarity</td>
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<tr>
<td>Porosity (mL/g)</td>
</tr>
<tr>
<td>Average pore diameter (Å)</td>
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<tr>
<td>Operating pH range</td>
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</table>

Source: Information provided by the manufacturer, Rohm and Hass Co., Philadelphia, Pa
studies indicated that percentage of removals were found to be 80% for surfactant loaded resin (4 mg/g) and 50% for EDTA-disodium salt loaded resin (2.5 mg/g) for an initial Ni(II) concentration of 10 mg/L and for a modified resin dosage of 0.2 g/100 mL respectively. When the complex of surfactant and EDTA loaded on Duolite XAD-761 was used, the results showed that both surfactant and EDTA could stimulate the adsorption of Ni(II) from aqueous solution. It may be due to their unique characteristics, such as surface charge and sorption energy of the solution or exchange heavy metal on the solid surface. Hence, the effect of both the surfactant and EDTA (disodium salt), on the polymer has been evaluated in the present study.

**FTIR of Duolite XAD-761 resin, modified resin and Ni(II) loaded resin**

The FT-IR spectra of pure Duolite XAD-761 resin, modified resin and Ni(II) adsorbed modified resin are shown in Figs 1 to 3. The IR spectrum of the Duolite XAD-761 resin (Fig. 1) exhibits a broad band at 3506 cm\(^{-1}\), which is indicative of hydroxyl groups bound to the resin. A smaller absorption due to – CH\(_2\) – linkages also appears at 2921 cm\(^{-1}\). A band due to phenolic C-O stretching vibrations is also visible at 1145 cm\(^{-1}\) and absorptions due to aromatic vibrations can also be seen at 1647 cm\(^{-1}\) (C=C stretching) and 1474 cm\(^{-1}\) (C-H bending).

The IR assignment of modified Duolite XAD-761 resin (Fig. 2) displays absorption band at 1732 cm\(^{-1}\) attributed to C=O stretching in ester and absorption band at 1094 cm\(^{-1}\) corresponds to C-O stretching in ether are also observed. A band at 1064 cm\(^{-1}\) attributed to C-N stretching as in amine is observed. The absorption band at 2925 cm\(^{-1}\) corresponds to CH\(_3\) stretching and another band at 2856 cm\(^{-1}\) attributed to CH\(_2\) stretching are also observed. A significant peak at 1356 cm\(^{-1}\) attributed to asymmetric stretching of SO\(_3\)Na group and other absorption band at 665 cm\(^{-1}\) correspond to C-S symmetric stretching in sulphate are also observed. These observations suggest that the physical adsorption of the extractants by Duolite XAD-761 polymeric resin is achieved partly through hydrophobic interaction between the hydrophobic alkyl part of the extractant and the phenyl group of the support and partly through other mechanisms such as polar or electrostatic forces.

The IR spectra of Ni(II) adsorbed modified resin (Fig. 3) shows slight change of frequencies of the functional groups compared with the spectrum of the modified resin. The absorption frequencies of C=O stretching in ester and C-O stretching in ether are also shifted to 1738 and 1098 cm\(^{-1}\) respectively. The absorption band of SO\(_3\)Na asymmetric stretching is shifted to 1362 cm\(^{-1}\). The absorption band of C-N stretching is shifted to 1071 cm\(^{-1}\). In addition, the absorption frequency of C-S stretching is also shifted to 672 cm\(^{-1}\). These observations suggested that the heavy metal ion is incorporated in polymeric resin through interaction with active groups of the modified resin.
SEM studies

SEM is used to study the morphology and surface characteristics of adsorbent material\(^\text{30}\). In this work, SEM is used to study the morphological changes on the surface of adsorbent resin in its various forms (such as pure, impregnated and Ni(II) loaded modified resin), which are shown in Fig. 4(a-c). The morphology of the impregnated and Ni(II) loaded resins show some important observations. Coverage of the surface of the resins due to the impregnation of the complex of the SDOSS - EDTA and adsorption/loading of Ni(II), presumably leading to formation of white layer (cloud) of uniform thickness and coverage may be visualized.

Effect of agitation period

Figure 5 represents the effects of agitation time on the removal of Ni(II) by the modified resin sorbent. The removal increases with time and attains equilibrium at 180 min for an initial Ni(II) concentration of 10 mg/L and for a sorbent dosage of 0.2 g/100 mL (99.9% removal of Ni(II)).

Effect of pH

The most important single parameter influencing the sorption capacity is the pH of adsorption medium\(^\text{31}\). The initial pH of adsorption medium is related to the adsorption mechanisms onto the adsorbent surface from water and reflects the nature of the physicochemical interaction of the species in solution and the adsorptive sites of adsorbents\(^\text{4}\). The effect of removal of Ni(II) by sorbent for pH ranging between 1 and 10 is shown in Fig. 6. It could be seen that quantitative removal of Ni(II) is achieved by the modified resin (5.0 mg/g) over the pH range of 5.0 - 7.0 for an initial Ni(II) concentration of 10 mg/L and for a modified resin dosage of 0.2 g/100 mL.

When the initial pH of the medium was adjusted to the higher values, Ni(II) precipitation is observed because of the existence of OH\(^-\) ion in the adsorption medium at a pH greater than 8.0 and consequently the removal process is decreased. At very low pH values, the surface of sorbent would also be surrounded by the hydronium ions which reduce the Ni(II) interaction with binding sites of the modified resin sorbent. Moreover the stability of the SDOSS-EDTA complex which was adsorbed on the surface of the polymer matrix might be reduced with the result the adsorption of the metal ion decreases at low pH.

Adsorption isotherm

Adsorption isotherm can be used to describe how solutes interact with adsorbent and so are critical in optimizing the use of adsorbent. Two commonly used isotherms the Langmuir and Freundlich isotherms have been applied for this study. The Langmuir equation is given as

\[
\frac{C_e}{q_e} = \frac{1}{Q_0b} + \frac{C_e}{Q_0} \quad \ldots (1)
\]
where $C_e$ is the equilibrium concentration (mg/L), $q_e$ is the amount adsorbed at equilibrium (mg/g) and $Q_0$ and $b$ are Langmuir constants related to adsorption capacity and energy of adsorption, respectively. The linear plot of $C_e/q_e$ versus $C_e$ (Fig. 8) shows that the adsorption obeys the Langmuir model. $Q_0$ and $b$ (Intercept: 0.0158 for distilled water and 1.8 for tap water) were determined from the slopes and intercept respectively and found to be 34.50 mg/g and 6.89 mg/g and 0.0674 mg/L for distilled water and tap water after an equilibration time of 24 h respectively. The essential characteristics of Langmuir isotherm can be expressed in terms of a dimension less constant separation factor or equilibrium parameter $R_L$ which is defined as

$$R_L = \frac{1}{1+bC_0}.$$  

Here, $b$ is Langmuir constant and $C_0$ is the initial concentration of Ni(II). Separation factor shows the nature of adsorption process, and its value indicate the sorption process could be favourable, linear, unfavorable, when $0 < R_L < 1$, $R_L = 1$, $R_L > 1$, respectively. The $R_L$ values were found to be 0.0178 for distilled water and 0.0422 for tap water showing the sorption of Ni(II) on modified XAD-761 resin is favourable at pH 5. The correlation coefficient values ($R^2$) were found to be 0.997 and 0.845 for Ni(II) sorption for distilled water and tap water respectively. Based on $R^2$ values, Langmuir model seems to be more agreeable indicating the formation of monolayer sorption.

The Freundlich isotherm is represented by the equation

$$\log x/m = \log K_F + 1/n \log C_e$$  

where $C_e$ is the equilibrium concentration (mg/L) and $x/m$ is the amount adsorbed per unit weight of adsorbent. The linear plots of $\log (x/m)$ versus $\log C_e$ are show that the adsorption obeys the Freundlich
isotherm (Fig. 9). The $K$ and $n$ values are calculated from the intercepts and slopes, respectively. The values of adsorption capacity ($K$) for resin were found to be 8.20 and 1.42 in distilled water and tap water, respectively. The values of adsorption intensity ($n$) were found to be 5.64 and 2.15 in distilled water and tap water, respectively. The values of $1 < n < 10$ show favourable adsorption of Ni(II) on the sorbent. The decrease in the adsorption capacity in tap water may be due to the presence of common cations available in tap water which may be competing for the adsorption sites on the modified resin. The correlation coefficient values ($R^2$) were found to be 0.973 and 0.783 for Ni(II) sorption for distilled water and tap water respectively. The $R^2$ values indicated that the Freundlich model does not well fit with the experimental data when compared with Langmuir model.

Adsorption kinetics

In order to clarify the adsorption kinetics of Ni (II) ion onto modified Duolite XAD-761 resin three kinetic models, such as reversible first order, Lagergren’s pseudo-first-order and pseudo-second-order models were applied to the experimental data.

Reversible first order rate equation is given as,

$$\ln(1-U_t) = -kt$$

where $U_t = (C_o-C_t) / (C_o-C_e)$

$C_o$, $C_t$, and $C_e$ are the concentration in mg/L of Ni(II) initially at any time $t$ and at equilibrium, respectively. The straight line plot of $\ln(1-U_t)$ versus $t$ indicates the applicability of first order kinetics (Fig. 10). The straight line portions of the curves were used for calculating the slope values which give the overall rate constant $K$ of the process. The forward ($k_1$) and backward ($k_2$) rate constants are calculated using the following equation.

$$K = k_1 + k_2$$
$$k_2 = (k_1/k_c)$$
$$K = k_1(1+1/k_c)$$

$k_c$ is the equilibrium constant. The kinetic data are furnished in Table 2. It is evident that the forward rate constant is much higher than the backward rate constant suggesting that the rate of adsorption is clearly dominant. As the concentration decreases the overall rate constants and forward rate constants also increases due to effective capture of metallic ions by the surfactant-EDTA complex present on the polymer matrix. The correlation coefficient values ($R^2$) for reversible first order kinetics of Ni(II) sorption are also given in Table 2 and found to be lower than pseudo–second order values.

The linearized form of the pseudo-first-order rate equation of Lagergren is given as$^{34}$,

$$\ln (q_e - q_t) = \ln q_e - k_1 t$$

Fig. 10—Reversible first order kinetic fits for the adsorption of Ni(II)

Table 2—Rate constants for the adsorption of Ni(II) by reversible first order kinetics

<table>
<thead>
<tr>
<th>Concentration of Ni(II) (mg L$^{-1}$)</th>
<th>$K$ Overall (rate constant, (h$^{-1}$))</th>
<th>$k_1$ Forward rate constant, (h$^{-1}$)</th>
<th>$k_2$ Backward rate constant, (h$^{-1}$)</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1.2300</td>
<td>1.2500</td>
<td>0.1050</td>
<td>0.934</td>
</tr>
<tr>
<td>7</td>
<td>2.7450</td>
<td>2.5600</td>
<td>0.1850</td>
<td>0.965</td>
</tr>
<tr>
<td>5</td>
<td>3.7840</td>
<td>3.5060</td>
<td>0.2780</td>
<td>0.970</td>
</tr>
<tr>
<td>3</td>
<td>5.2460</td>
<td>4.8335</td>
<td>0.4125</td>
<td>0.917</td>
</tr>
</tbody>
</table>
where $q_e$ and $q_t$ are the amount of the metal ions adsorbed (mg/g) at equilibrium and $t$ (min), respectively and $k_1$ is the pseudo-first-order equilibrium rate constant (1/min). A plot of $\ln (q_e - q_t)$ versus $t$ gives straight line with slope of $k_1$ and an intercept of $\ln q_e$. It confirms the applicability of the pseudo-first-order rate equation (Fig. 11).

The pseudo-second-order model rate equation may be expressed as\textsuperscript{35}

\[
\frac{t}{q_t} = \frac{1}{k_2q_e^2} + \frac{t}{q_e}
\]  

... (5)

where $k_2$ is the pseudo-second-order adsorption rate constant (g/mg/min). A plot of $(t/q_t)$ versus $t$ also produces straight line with slope of $1/q_e$ and intercept of $1/k_2q_e^2$. It indicates the applicability of pseudo-second-order model (Fig. 12).

In order to compare quantitatively the applicability of kinetic models in fitting to data, the percent relative deviation ($P$), given by the following equation was calculated

\[
P = 100 \sum \left\{ \frac{[q_{e\text{ (exp)}} - q_{e\text{ (theo)}}]}{q_{e\text{ (exp)}}} \right\} \]  

... (6)

where $q_{e\text{ (exp)}}$ is the experimental value of $q_e$ at any value of $C_{ce}, q_{e\text{ (theo)}}$ the corresponding theoretical value of $q_e$ and $N$ is the number of observations. It is found that lower the value of percentage deviation ($P$), better is the fit. It is generally accepted that when $P$ value is less than 5, the fit is considered to be excellent\textsuperscript{36}. The results have been analyzed using Eqs (4) and (5). The experimental data fitted well in both the equations. The values of $q_{e\text{ (theo)}}$ calculated from these models are compared with experimental values $q_{e\text{ (exp)}}$ in Table 3. It is found that values of $q_{e\text{ (theo)}}$ calculated from the pseudo-first-order kinetic model differed appreciably from the experimental values $q_{e\text{ (exp)}}$. The percent relative deviation ($P$) is also very high. On the other hand, values of $q_{e\text{ (theo)}}$ are found to be very close to $q_{e\text{ (exp)}}$ when pseudo-second-order rate equation was applied. The percent relative deviation ($P$) is well within the range and also the values of correlation coefficients ($R^2$) are very high to pseudo-second-order kinetics when compared with pseudo-first-order. The $P$ value cannot be found out for reversible first order kinetics. These results indicated that the adsorption of Ni(II) onto modified XAD-761 resin is governed by pseudo-second-order kinetics predominantly.

The free energy of adsorption ($\Delta G^0$) can be related with the equilibrium constant $K$ (L mol$^{-1}$), corresponding to the reciprocal of the Langmuir constant, $b$, by the following equation\textsuperscript{37,38}

\[
\begin{array}{cccc}
\text{Table 3} & \text{Pseudo-first-order and pseudo-second-order kinetic constants for the adsorption of Ni(II) on modified XAD-761 resin} \\
\hline
\text{Metal} & \text{Conc.} & \text{Pseudo-first-order kinetic} & \text{Pseudo-second-order kinetic} \\
& (mg/L) & k_1 (1/min) & q_{e\text{ (theo)}} (mg/g) & q_{e\text{ (exp)}} (mg/g) & R^2 & P & k_2 (g/mg/min) & q_{e\text{ (theo)}} (mg/g) & q_{e\text{ (exp)}} (mg/g) & R^2 & P \\
\hline
\text{Ni(II)} & 3 & 0.1435 & 5.0530 & 2.90 & 0.964 & 74.24 & 0.0229 & 3.01 & 2.90 & 0.996 & 3.86 \\
& 5 & 0.1168 & 8.3310 & 4.95 & 0.968 & 68.30 & 0.0161 & 5.12 & 4.95 & 0.998 & 3.43 \\
& 7 & 0.0518 & 5.6010 & 6.90 & 0.979 & 18.82 & 0.0091 & 7.18 & 6.90 & 0.998 & 4.18 \\
& 10 & 0.0308 & 17.300 & 9.85 & 0.818 & 75.63 & 0.0026 & 10.20 & 9.85 & 0.991 & 3.55 \\
\end{array}
\]
where \( R \) is the universal gas constant (8.314 J mol\(^{-1}\) K\(^{-1}\)) and \( T \) is the absolute temperature (K). Gibbs free energy change \( \Delta G^0 \) was calculated to be -28.90 ± 5 kJ mol\(^{-1}\) based upon three sets of data. Negative value of \( \Delta G^0 \) indicated the feasibility of the process and spontaneous nature of the adsorption. However, the removal mechanism of Ni(II) adsorption is not well understood. It may further be added that the modified XAD-761 resin extracts Ni(II) solution by ion exchange/chelation through electrostatic attraction.

**Desorption studies**

Desorption studies were conducted to recover the Ni(II) from the modified resin. Attempts were made to desorb Ni(II) from the spent resins using sodium chloride (1 – 5%). The values are shown in the Table 4. Results showed that 99% of Ni(II) desorbed from the resin under optimum concentration of 3% NaCl. After the extraction of Ni(II) on modified resin, it was washed completely with distilled water. The adsorption capacity of this material was again tested and about five cycles of operation was carried out. Results showed that adsorption capacity of NaCl regenerated resin was maintained over the range 99-92% even up to five cycles of operation. Results indicate that 3% NaCl is best suitable for regeneration and recovery of valuable nickel ion.

**Application to wastewater**

Experiments with synthetic wastewater have been carried out to elucidate the adsorption capacity of the modified resin. Results in Table 5 give the characteristics of the synthetic wastewater applied for this study before and after treatment. The effect of modified resin dosage on the removal of Ni(II) has been carried out under optimum time and pH. Figure 13 shows the removal of Ni(II) as a function of sorbent dosage for an initial concentration of 63 mg/L. It has been observed that 97% removal of Ni(II) could be achieved with a sorbent dose of 0.9 g/100 mL.

**Conclusion**

Surfactant (SDOSS) and EDTA (disodium salt) complex – impregnated on Duolite XAD-761 resins were found to be useful for adsorption of Ni(II) from aqueous solution. Separation media was prepared by mixing the resins in aqueous solution of anionic surfactant and EDTA. Thus, without chemical synthesis, chelating functionality was easily introduced on solid surface. FTIR investigations show that the immobilization of the extractants on the Duolite XAD-761 polymeric resin is achieved partly through hydrophobic interaction between the hydrophobic alkyl part of the extractant and the phenyl group of the support and partly through other mechanisms such as polar or electrostatic forces. The adsorption of Ni(II) on the modified resin follows first order reversible kinetics. Desorption of Ni(II) could effectively be achieved with 3% NaCl from the modified resins. Batch studies demonstrated that modified resin showed excellent removal of Ni(II) in

![Fig. 13— Effect of resin dosage on adsorption of Ni(II) from wastewater [(Ni(II) concentration=63 mg/L, pH=5.0, Equilibrated time=3 h)]](image-url)
the presence of common impurities in wastewater and a complete recovery of nickel ion also could be achieved.

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