



A Polymeric Adsorbent for Removal And Recovery of Nickel From Aqueous Media

Sulu Ortamdan Nikelin Uzaklaştırılması ve Geri Kazanımı İçin Polimerik Bir Adsorban

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ABSTRACT

The Interpenetrating Polymer Network (IPN) structure was obtained by gamma radiation of solution of polyethylene glycol (PEG) (35000MW) in an acrylonitrile (AN) to 14 and 60kGy doses were amidoximated with hydroxylamine solution at optimum amidoximation conditions. Effects of pH (2-10) and mNi/mIPN ratio (0.002-0.5) in Ni²⁺ adsorption were examined by batch process and optimum values were determined as 8 and 0.4 for both doses, respectively. Also, the effect of flow rate to Ni²⁺ adsorption was examined by the reflux flow process with a fixed-bed reactor at room temperature. Optimum flow rate is determined as 6 mL/s at optimum pH. Ni²⁺ adsorption studies were carried out in batch (pH= 6 and 8) and flow (pH= 8) systems. Maximum adsorption values reached for irradiated to 14 and 60kGy doses and amidoximated IPNs were given as 105 and 99 mgNi/gIPN in batch system (pH=6), 378 and 361 mgNi/gIPN in batch system (pH= 8) and 891 and 673mgNi/gIPN in flow system (pH= 8), respectively. Maximum elution efficiency was obtained for HCl as being 99.5% and 66.1% for IPNs irradiated to 14 and 60kGy doses and amidoximated, respectively. FTIR results showed that HCl caused structural deformation. Minimum elution efficiency was obtained for (NH₄)₂CO₃ as being 60.1% and 58.2% for IPNs irradiated to 14 and 60kGy, respectively, by the minimum deformation.

Key Words

IPN, nickel, adsorption, elution.

Öz

Çiçe-geçmiş Polimer Ağı (IPN) yapı, polietilen glikol (PEG) (35000MW) çözeltisinin akrilonitril (AN) içerisinde 14 ve 60 kGy dozlarına gama ışınımla elde edilmiş ve optimum amidoksimesyon koşullarında hidrosilamin çözeltisi ile amidoksimesleştirilmiştir. Ni²⁺ adsorpsiyonunda pH (2-10) ve mNi/mIPN oranının (0.01-0.5) etkisi kesikli sistemde incelenmiş ve her iki doz için sırasıyla en uygun değer 8 ve 0.4 olarak belirlenmiştir. Ayrıca, akış hızının Ni²⁺ adsorpsiyonuna etkisi sabit yataklı bir reaktör ile geri akışlı sistemde oda sıcaklığında incelenmiştir. En uygun akış hızı, en uygun pH'da 6 mL/dk olarak belirlenmiştir. Ni²⁺ adsorpsiyon çalışmaları, kesikli (pH= 6 ve 8) ve akışlı (pH= 8) sistemde gerçekleştirilmiştir. 14 ve 60kGy dozlarına ışınlanmış ve amidoksimesleştirilmiş IPN'lerin en yüksek adsorpsiyon değerleri sırasıyla, kesikli sisteminde, pH= 6 için 105 ve 99 mgNi/gIPN pH= 8 için 378 ve 361 mgNi/gIPN, akışlı sistemde; pH= 8 için 891 ve 673 mgNi/gIPN olarak saptanmıştır. En yüksek elüsyon verimi, 14 ve 60kGy dozlarına ışınlanmış ve amidoksimesleştirilmiş IPN'ler için sırasıyla %99.5 ve %66.1 olarak HCl ile elde edilmiştir. FTIR sonuçları, HCl'nin yapısal deformasyona neden olduğunu göstermiştir. En düşük deformasyonla 14 ve 60kGy'ye ışınlanan IPN'ler için elüsyon verimi %60.1 ve %58.2 olarak (NH₄)₂CO₃ ile elde edilmiştir.

Anahtar Kelimeler

IPN, nikel, adsorpsiyon, elüsyon.

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INTRODUCTION

The presence of nickel ions in the aqueous media has been of great concern because of its toxic nature, binds to nucleic acids and causes mutation. In spite of this property, nickel is a heavy metal that must be recovered due to its technological importance. Researchers improved so many adsorbent based on organic [1-14], inorganic [15-18] and biologic [19-21] for adsorption process. Required parameters for the improved adsorbent are selective for metal ions, the ability for low concentration adsorption, high adsorption capacity, regenerable and economic [1]. Researches are direct to novel polymeric adsorbents with ion exchange or/and chelating resin to obtain all these parameters. Polyacrylamidoxime resins are determined as a feasible adsorbent for the removal and recovery of metal ions from aqueous media because of high adsorption capacity and ability to regeneration [1-21].

Both the amidoxime group and hydrophilic group contained adsorbents cover more metal ions than only amidoxime group contained. Because of this, among amidoxime, amide, carboxyl and hydroxyl groups, the amidoxime group is least hydrophilic. In adsorption, aqueous solution diffusion that is rate determined step is faster to the more hydrophilic polymer. In this respect adsorption increases according to the type and amount of hydrophilic group [1-3,5,7-10].

In this study, a new polymeric adsorbent bearing both hydrophilic groups and amidoxime groups synthesized as IPNs based on polyethylene glycol(PEG) and acrylonitrile(AN) which is developed to remove low concentrations of heavy metals in aqueous media. The IPNs which were developed for removal and recovery of low concentrations of uranium [1] from aqueous media were used for the same purpose for Ni²⁺ ions at two different radiation doses.

MATERIALS and METHODS

Materials

In this study for preparation of IPNs poly(ethylene glycol)(PEG, 35000MW) (H(OCH₂CH₂)_nOH) (Merck), acrylonitrile(AN) (H₂C=CHCN) (Merck) and N,N-dimethylformamide (DMF) (HCON(CH₃)₂) (Merck) were used at high purity. For amidoximation of IPNs, sodium hydroxide (NaOH) (Merck) and hydroxylamine hydrochloride hexahydrate (NH₂OH.HCl.6H₂O) (Aldrich) were used. For adsorption experiments, nickel solutions were prepared by dissolving appropriate amounts of nickel (II) nitrate hexahydrate (Ni(NO₃)₂.6H₂O) (BDH) in distilled water. Sodium diethyldithiocarbamate trihydrate (C₅H₁₀NNaS₂.3H₂O) (Merck) was used as a complexing agent. For elution experiments, hydrochloric acid (%37) (HCl) (Merck), sulfuric acid (%98) (H₂SO₄) (Merck), nitric acid (%65) (HNO₃) (Merck) and ammonium carbonate ((NH₄)₂CO₃) (RDH) were used. NaOH and HCl were used for pH adjustment.

Preparation of IPNs

For the preparation of IPNs, the solution of poly(ethylene glycol)(PEG35000MW) (1 g) in acrylonitrile(AN) (3 ml) irradiated to two different doses, 14 (14 IPN) and 60kGy (60 IPN), with 60Co-γ radiation source (5.0kGy.h⁻¹ radiation dose rate) at room temperature. The actual irradiation reaction is given in Figure 1. These IPNs were washed into N, N-dimethylformamide (DMF) for 24h and were dried at 40°C to constant mass. The IPNs having a conversion ratio of 60% (14 IPNs) and 70% (60 IPNs) were cut in a cylindrical shape (3mm diameter and 3 mm height) and prepared for use in the amidoximation reaction [1].

Amidoximation of IPNs

The cyano(CN) groups of 14 and 60 IPN were changed into an amidoxime (HONCNH₂) group by reacting with hydroxylamine(NH₂OH) solution at a molar ratio of NH₂OH/CN=1.5 in aqueous media at 70°C and pH=7

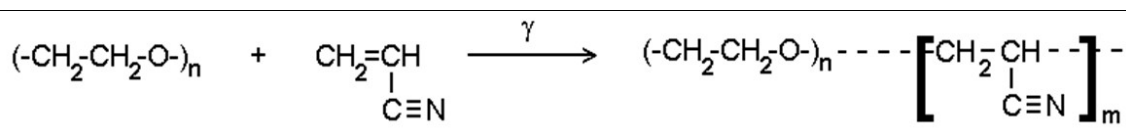


Figure 1. Irradiation reaction to obtain IPN from polyethylene glycol and acrylonitrile.

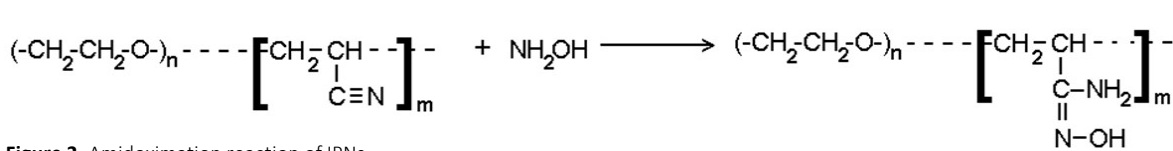


Figure 2. Amidoximation reaction of IPNs.

by 2 hours and amidoximated IPNs were obtained (14A and 60A IPNs). The reaction is shown in Figure 2. The amidoximated IPNs were washed with distilled-deionized water for 24hrs and then dried to constant mass at 40°C [1].

The Effect of pH on the Adsorption of Ni²⁺

14A and 60A IPNs (20 mg) were put into 10ml 50ppm Ni²⁺ solution at room temperature for 24hrs. The solution pH was adjusted with NaOH and HCl as 2, 4, 6, 8 and 10. The concentration of Ni²⁺ ions in the solution was determined using UV-Vis spectrometer.

The Effect of mNi/mIPN Ratio on the Adsorption of Ni²⁺

14A and 60A IPNs were put into 5 ml of 100 ppm Ni²⁺ solution at pH=8 and room temperature for 24 hrs. Samples with mNi/mIPN ratios ranging from 0.002 to 0.5 were prepared. The concentration of Ni²⁺ ions in the solution was determined using UV-Vis spectrometer.

The Effect of Flow Rate on the Adsorption of Ni²⁺

14A IPNs (10 mg) were used in 100 ml and 100ppm Ni²⁺ stock solution at flow rates of 3 and 6ml/s at room temperature. Fiber glass (20 mg) was used as a filling material for the fixed-bed reactor in the reflux flow process. To ensure the continuous flow in the process, the Velp Scientifica Type SP311 model peristaltic pump was used.

The Adsorption of Ni²⁺ in Batch and Flow Systems

In the batch system, for investigation of Ni²⁺ ions adsorp-

tion, 14A and 60A IPNs (20mg) were added into a tube containing 10ml Ni²⁺ solutions at a known concentration for 24 hrs at room temperature. Experiments occurred at an optimum mNi/mIPN ratio of 0.4 and two different pH values (seawater pH⁸ and solution pH⁶).

In the flow system, for investigation of Ni²⁺ ions adsorption, 14A and 60A IPNs (10mg) were used in reflux flow process with a fixed-bed reactor at room temperature, the optimum flow rate as 6 mL/s and optimum pH value determined as 8. The reservoir volume of the flow system was 100 ml.

The pH was adjusted to 8 with NaOH. Ni²⁺ solutions were prepared by diluting 1000ppm stock solution of Ni²⁺, obtained by dissolving nickel (II) nitrate hexahydrate in distilled-deionized water. For the determination of adsorption, concentrations of Ni²⁺ were varied between 20-1000 ppm for the batch system and 25-400 ppm for the flow system. The concentration of Ni²⁺ ions in the solution was determined using by UV-Vis spectrometer.

The Elution of Ni²⁺ in Batch Systems

Adsorption of nickel ions on 14A and 60A IPNs (5mg) was performed in 20 ml 100 ppm Ni²⁺ solution for 24 hours at an optimum mNi/mIPN ratio of 0.4 and pH = 8. IPNs were washed into distilled-deionized water for 24hrs and then dried to constant mass at 40°C.

The 14A and 60A IPNs dried after the nickel adsorption were eluted with selected eluents (Table 1). For elution experiments, the eluent concentration was 1M and the

Table 1. The post-processing IPN codes.

Process		Code		
Irradiation	Amidoximation	Eluent	14kGy	60kGy
Done	-	-	14	60
Done	Done	-	14A	60A
Done	Done	HCl	14AH	60AH
Done	Done	H ² SO ⁴	14AHS	60AHS
Done	Done	HNO ³	14AHN	60AHN
Done	Done	(NH ⁴) ² CO ³	14ANC	60ANC
Done	Done	NaOH	14ANa	60ANa

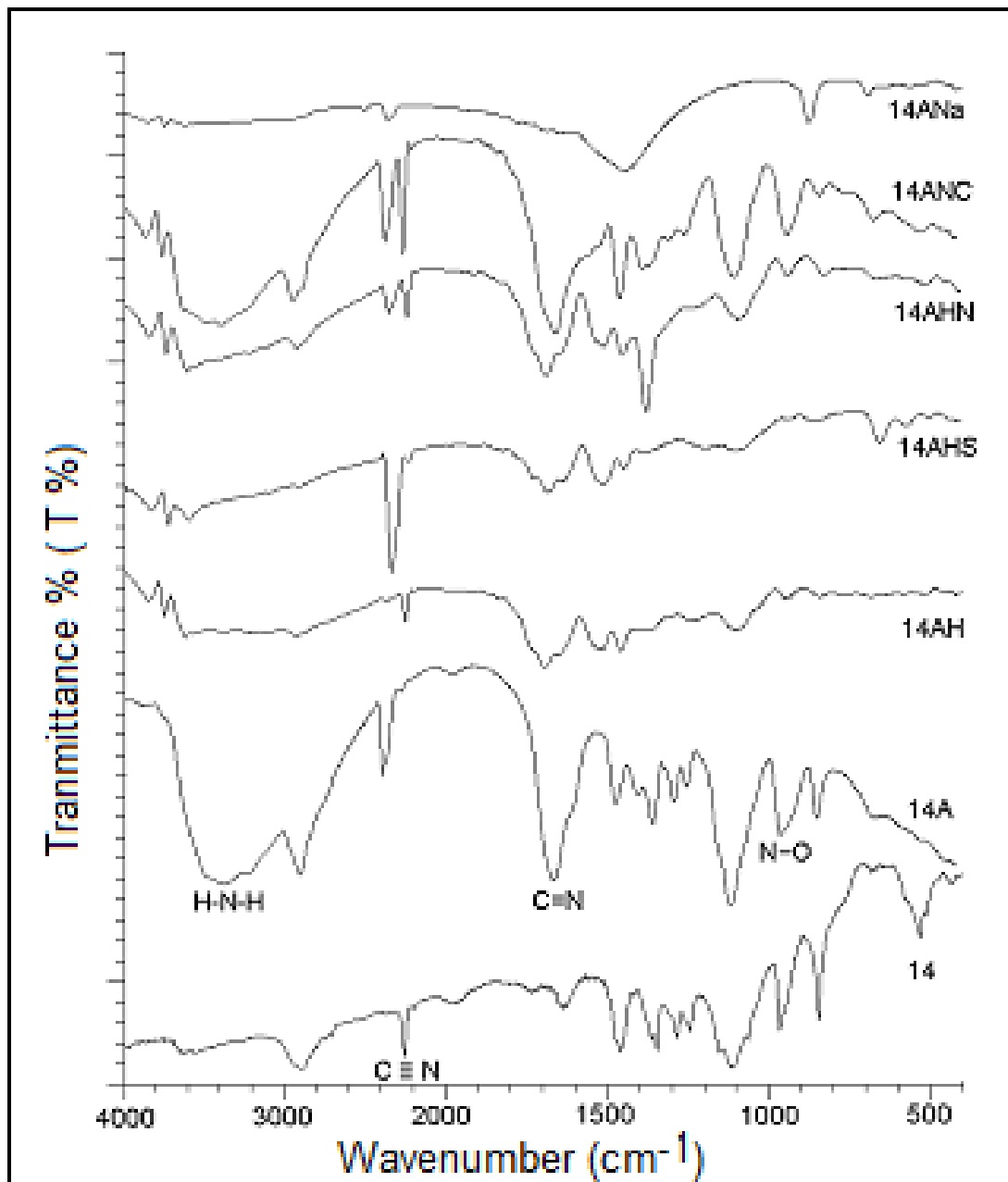


Figure 3. FTIR spectra of the IPNs irradiated to 14kGy dose (14), amidoximated (14A) and eluted after adsorption (14AH, 14AHS, 14AHN, 14ANC and 14ANa).

elution volume was 10 ml. The codes of the IPNs after elution are given in Table 1. The concentration of Ni^{2+} ions in eluent solution were determined using on UV-Vis spectrometer. Eluted IPNs structures were determined with FTIR spectrophotometer.

Determination of Ni^{2+} Concentration and Characterization of IPNs

After adsorption and elution, the equilibrium concentration

of Ni^{2+} ions in solution was determined using UV-Vis spectrometer (Shimadzu UV1201V model) at 426nm with sodium diethyl-dithiocarbamate as a complexing agent (pH=4). The percent of Ni^{2+} eluted from IPN (Elution efficiency, E, %) and the amount of Ni^{2+} adsorbed were determined by Eqn. 1 and 2, respectively:

$$E = 100 \times ((C_0 - C_e) / C_0) \quad \text{Eqn. 1}$$

$$Q = ((C_0 - C_e) \times V / M) \quad \text{Eqn. 2}$$

where C_0 and C_e are the initial and equilibrium concentrations of Ni^{2+} ions (mg/L), M is the mass of adsorbent (g), V is the volume of sample (L), and Q is the amount of Ni^{2+} ions adsorbed per mass of adsorbent (mg/g) [14].

After irradiation, amidoximation and elution, the change in the structure of the IPNs was determined using FTIR spectrophotometer (Shimadzu FTIR 8300) at between 400-4000 cm^{-1} intervals.

RESULTS and DISCUSSION

Characterisation of IPNs

14 and 60 IPNs obtained in white colour and homogeneously have a hard structure. Their hardness was increased

with increasing radiation dose due to crosslinking. In the FTIR spectra of PEG-AN irradiated to 14 and 60kGy doses, the peak of nitrile ($C\equiv N$) group at $2242cm^{-1}$, which is the characteristic stretching band of nitrile and the peak strength, was increased with increasing radiation dose due to conversion (%). The peak of $1100cm^{-1}$ and symmetric peaks in its two sides is called fingerprint zone and corresponding to $[-CH_2-CH_2-]$ structure in the chain (Figure 3 and 4, 14 and 60 spectra). End of this reaction, IPNs have no functional group (amidoxime group) and do not chelate with metal ions but could be adsorbed only by swelling [1].

In the FTIR spectrum of 14A and 60A IPNs, appeared H-N-H ($3360-3390 cm^{-1}$), N-O ($940 cm^{-1}$), C=N ($1652 cm^{-1}$) peaks and disappeared $C\equiv N$ ($2242cm^{-1}$) peak show that the cy-

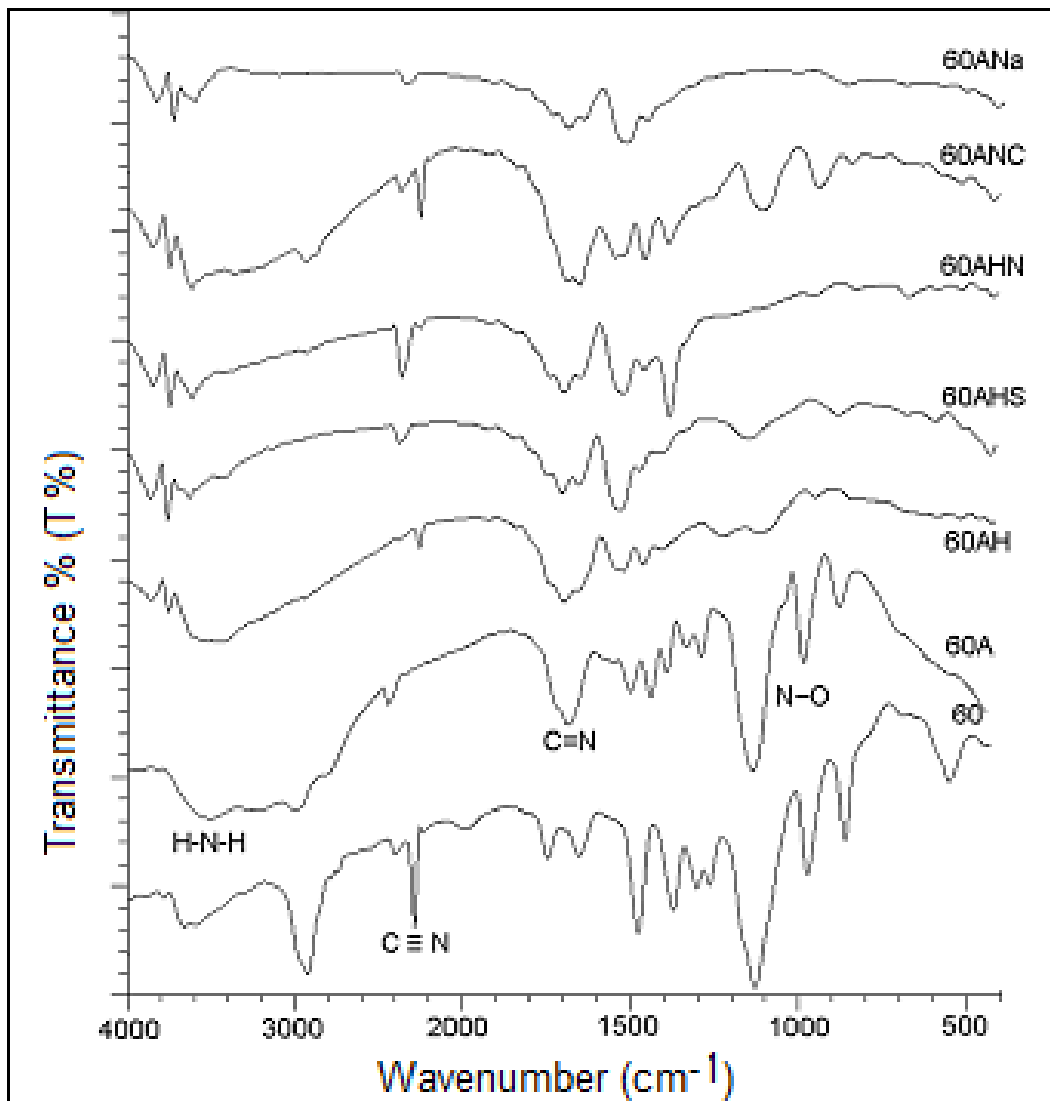


Figure 4. FTIR spectra of the IPNs irradiated to 60kGy dose (60), amidoximated (60A) and eluted after adsorption (60AH, 60AHS, 60AHN, 60ANC and 60ANa).

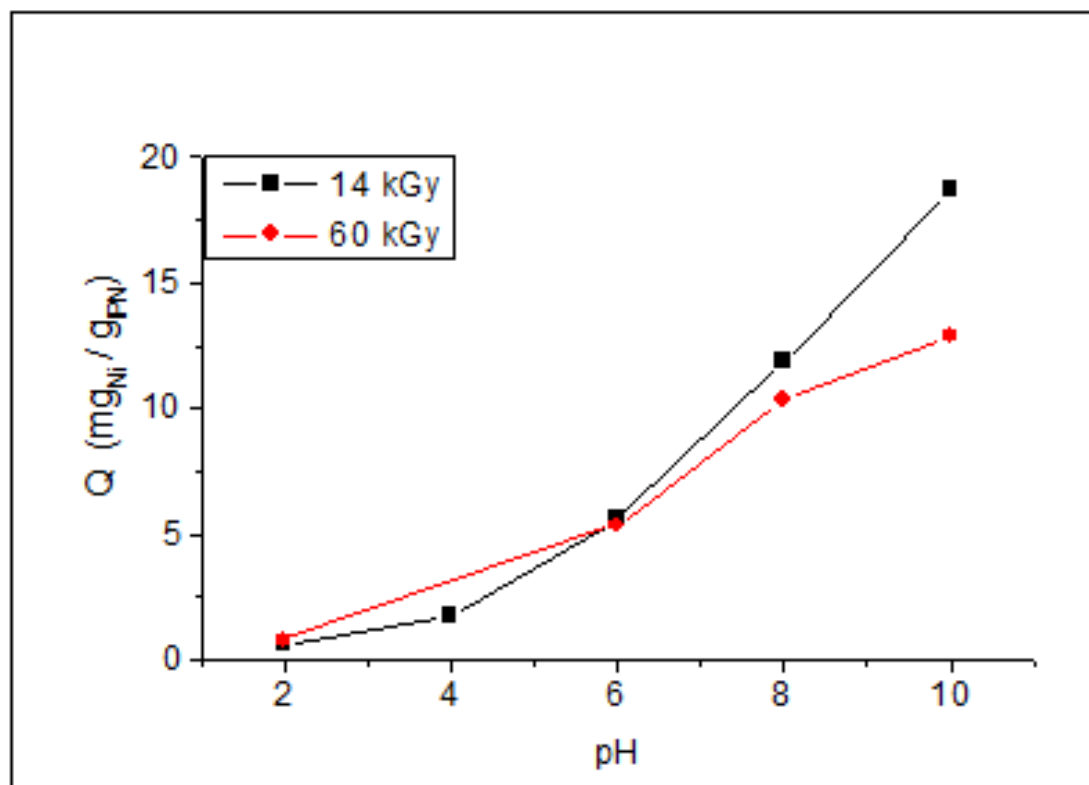


Figure 5. The effect of pH on the adsorption of Ni²⁺ ions (C₀=100ppm, room temperature and batch system).

no group of IPNs was changed into amidoxime group by reacting with hydroxylamine in both radiation dose (Figure 3 and 4, 14A and 60A spectra). The peak strength of C=N in 14A spectrum is more than in 60A spectra. This result shows that the amidoxime group in 14A IPNs was formed more in 60A IPNs and amidoximation was decreased with increasing radiation dose. After the amidoximation reaction, the IPNs have both amidoxime functional groups for chelating with heavy metal ions and hydrophilic groups providing swelling in aqueous media [1].

Five post-elution samples of IPNs irradiated to a dose of 14kGy are seen in the comparative FTIR spectrum, and all of these eluted IPN constructs are partially degraded, except for 14ANC (Figure 3 and Table 1). In the 14AH and 14AHN spectra, C=N peaks indicated that the structure of IPNs returned before amidoximation. 14ANA spectrum shows that the chain structure is degraded due to disappearing C=N peak and fingerprint zone. The comparative FTIR spectra of irradiated to 60 kGy dose seven IPNs samples is shown in Figure 4 and sample codes are given Table 1. NH₂, NO and C=N peaks in all spectra correspond to amidoxime structure. NH₂ and C=N peaks were obtained in 60ANC and 60AH

IPNs spectra but peak strengths decreased. NO peak was obtained only in 60ANC sample spectra but peak strength decreased. As seen from the FTIR spectra, these changes in peaks show changes in IPN structures after elution.

For both doses (14 and 60kGy), the elution efficiency of HCl as the eluent was the maximum, but the amidoxime group in the IPN structure was degraded according to the FTIR spectrum. Although (NH₄)₂CO₃ as the eluent had the lowest elution yield, minimal structural degradation of IPNs occurred.

The Effect of pH on the Adsorption of Ni²⁺

For the adsorption of Ni²⁺ ions with irradiated and amidoximated IPNs (14A and 60A), adsorption medium pH was changed from 2 to 10. This pH range was selected due to the hydrolysis reaction possibility of the nickel ions out of this range. As a result of the experiments, the adsorption of Ni²⁺ ions with irradiated and amidoximated IPNs (14A and 60A) was increased with rising pH. For both doses irradiated IPNs minimum and maximum adsorption values were obtained at pH= 2 and pH= 10, respectively. Due to the decomposition of IPNs

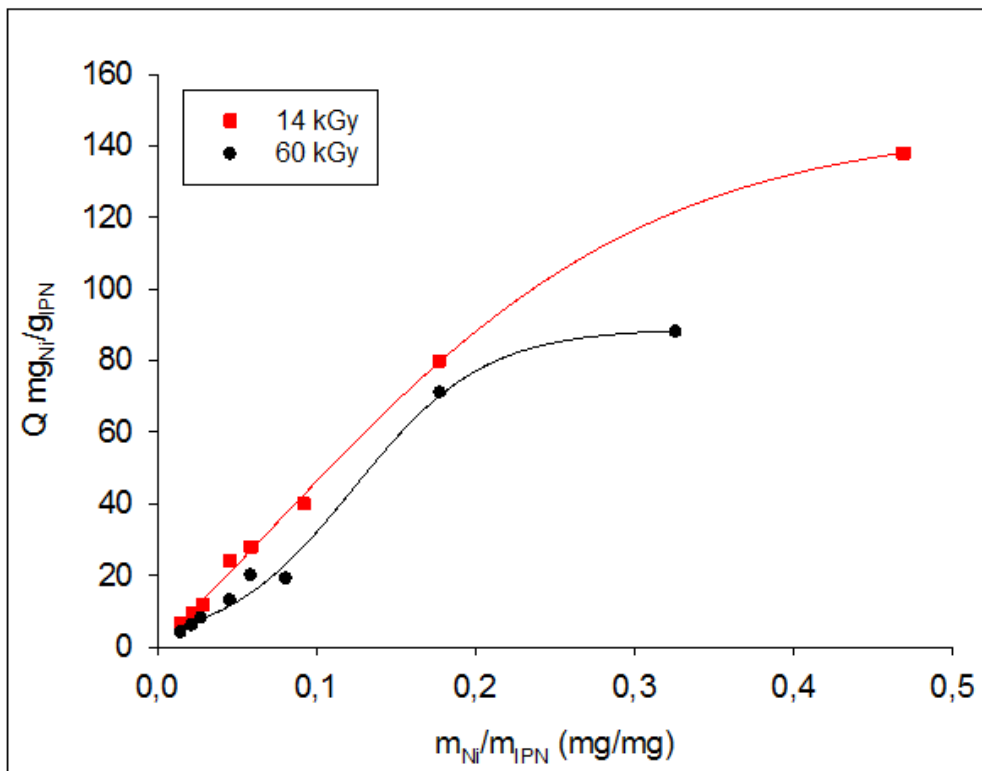


Figure 6. The effect of m_{Ni}/m_{IPN} ratio on the adsorption of Ni^{2+} ions ($C_0 = 100$ ppm, $pH = 8$, room temperature and batch system).

at $pH = 10$, the optimum pH was selected as 8 for further experiments (Figure 5). It was reported in the related literature that the pH of the adsorption medium is one of the most important parameters affecting the adsorption capacities [2,4,13]. Adsorption values of amidoxime group-containing adsorbents synthesized by radiation-based vaccination for nickel ions were investigated between pH 2 and 6 and the most suitable pH was determined to be 6 [2]. In another study, poly (ethylene terephthalate) fibres grafted with methacrylic acid for the pH effect on the nickel adsorption was carried out from 2 to 10 and 6 was selected as the optimum pH [4]. For the nickel ions adsorption onto the PEGMA-VI microspheres, adsorption medium pH was changed from 2 to 8 and high adsorption capacities were observed above pH 6 [13].

The Effect of m_{Ni}/m_{IPN} Ratio on the Adsorption of Ni^{2+}

The relationship between m_{Ni}/m_{IPN} ratio and nickel ion adsorption of IPNs (14A and 60A) is given in Figure 6.

The optimum m_{Ni}/m_{IPN} ratio for 14A and 60A IPNs was determined to be 0.4. At this ratio, the adsorption of Ni^{2+} ions with 14A IPNs was 1.5 times more than with 60A IPNs. This is thought to be due to the cross-linking ratio. Due to the low irradiation dose, the crosslinking ratio in 14A IPNs is lower than that found in 60A IPNs. Thus, 14A IPNs were more swollen and were able to adsorb more nickel ions than 60A IPNs (Figure 6). The change of the water content of the IPNs with the irradiation was reported in the related literature [1].

The Effect of Flow Rate on the Adsorption of Ni^{2+}

The effect of flow rate on nickel ion adsorption in the continuous system was realized with 14A IPNs and the results are given in Figure 7. The adsorbed Ni^{2+} ions increased with time in the IPN structure and the steady-state was reached after 40 minutes due to the filling of the active sites in the IPN. The adsorption of Ni^{2+} ions with 14A IPN at a flow rate 6 ml/s was 1.25 times higher at 3 ml/s. Thus, the optimal flow rate is determined to be 6 ml/s (Figure 7). In the related literature, some

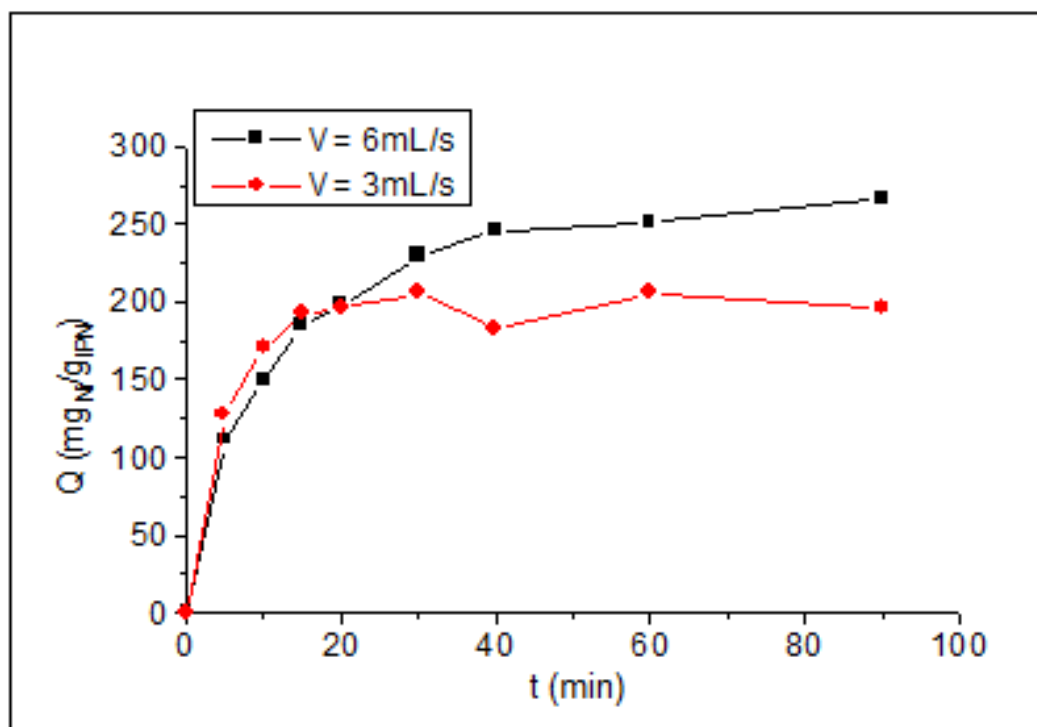


Figure 7. The effect of flow rate on the adsorption of Ni²⁺ ions (C₀=100ppm, pH=8, room temperature and flow system).

adsorbents have been reported to reach a steady-state [11-13]. The time to reach a steady-state in nickel ion adsorption was determined as 60 minutes in P[AAm/DAPB/DAMB] hydrogel [11], 40 minutes in polyethyleneimine (PEI)-attached poly(p-chloromethyl styrene) (PCMS) beads [12], 120 minutes in PEGMA-VI microspheres [13].

The Adsorption of Ni²⁺ at the Optimum Conditions

The adsorption isotherms for the 14A and 60A IPNs in batch (pH=6 and 8) and flow (pH=8) systems are shown in Figure 8. According to Gile's isotherms, the adsorption isotherms for 14A and 60A IPNs in batch system at pH=6 and 8 were fixed as S2 type; in flow system at pH=8 were fixed as L2 type and the correlation coefficients for Langmuir isotherms were determined as 0.96 and 0.95; for Freundlich isotherms were determined as 0.99 and 0.98, respectively. Similar results have been obtained in the studies in the related literature [14,15,21].

For each adsorption systems (batch; pH=6 and pH=8 and flow; pH=8), the adsorption of Ni²⁺ ions with 14A IPNs is greater than with 60A IPNs (Figure 8 and Table 2). This is thought to be due to the cross-linking ratio. Because of the increased radiation dose, the cross-linking rate in the

IPN structure is increased and therefore the swelling of the IPNs is reduced and the adsorption of Ni²⁺ ions is reduced accordingly. For the IPNs 14A and 60A in batch (pH=6 and 8) and flow (pH= 8) systems maximum adsorption value was obtained at pH= 8 (Figure 8 and Table 2). This may be due to non-amidoxime nitrile groups in the IPN structure. In the IPNs, the non-amidoximated nitrile group is hydrolysed and then the pH of the medium is increased to the carboxylic acid group. Meanwhile, the increase in the hydrophilic group in the structure causes the swelling of the IPNs and the adsorption of Ni²⁺ ions increases. Adsorption values for 14A and 60A IPNs in batch (pH = 6 and 8) and flow (pH = 8) systems were the highest values obtained in the flow system (Figure 8 and Table 2). This is considered to be an increase in the diffusion effect resulting from the flow rate. The solution and adsorbate in the flow system make more contact, and the flow causes a mixing effect similar to that in the batch system. This effect increases the diffusion rate and adsorption of Ni²⁺ ions. The highest adsorption values in the IPNs prepared for nickel adsorption reached in the flow system with 14A IPNs. For these 14A IPNs, the maximum adsorption value was obtained above 96% with a maximum adsorption capacity of about 900 mg_{Ni}/g_{IPN} at pH = 8 (Figure 8 and Table 2).

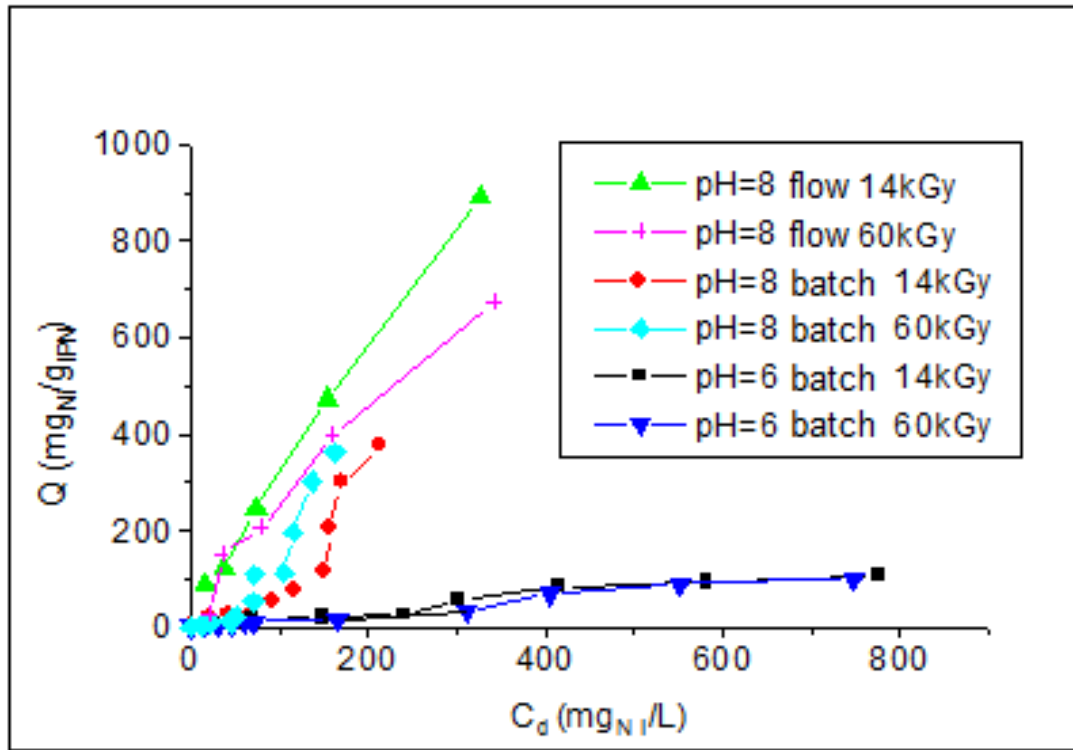


Figure 8. For radiated to 14 and 60kGy doses and amidoximated IPNs, the adsorption isotherms in batch (pH= 6 and 8) and flow (pH= 8) systems.

In the comparison of the obtained results with the related literature, it is also possible to find some polymeric adsorbents for the adsorption of nickel. The adsorption capacities of amidoxime-group-containing adsorbents synthesized by radiation-induced and poly(ethylene terephthalate) fibres grafted with methacrylic acid, were found as 29 mg/g [2] and 456 mg/g [4] for nickel ions, respectively. Nickel adsorption is more than 98% in the process of removing and recovering nickel ions with a chelating resin containing triethylenetetramine in the flow system [7]. The adsorption capacity of nickel ions from aqueous solutions by Poly[acrylamide/N,N-DAMB/N,N-DAPB] super absorbent hydrogel in batch system is determined as 95 mg/g [12]. The nickel adsorption value by PEGMA-VI microparticles reached 78 mg/g as maximum rate at pH 6 [13].

The Elution of IPNs

At the end of the adsorption studies, IPNs were eluted with various eluents to recover nickel from IPNs. The elution efficiency and eluent type obtained for the irradiated to 14 and 60kGy doses and amidoximated IPNs (14A and 60A) are given in Table 3. According to the data in the table, the maximum elution efficiency was obtained with HCl used as the eluent. For 14AH and 60AH IPNs, the elution efficiency of HCl was 99.46% and 66.06%, respectively. The minimum elution efficiency was observed with $(\text{NH}_4)_2\text{CO}_3$ used as the eluent. For 14ANC and 60ANC IPNs, the elution efficiency of $(\text{NH}_4)_2\text{CO}_3$ is 60.05% and 58.18%, respectively. As can be seen from Table 3, the elution efficiency values of 14A IPNs adsorbed nickel ions are greater than the values

Table 2. Maximum adsorption values for irradiated to 14 and 60kGy doses IPNs in batch (pH= 6 and 8) and flow (pH= 8) systems.

System	PH	Q (mgNi/gIPN)	
		14kGy	60kGy
Batch	6	105	99
Batch	8	378	361
Flow	8	891	673

Table 3. Elution efficiency of IPNs irradiated to 14 and 60kGy doses (% E).

Eluent type	14kGy E%	60kGy E%
HCl	99.46	66.06
H ₂ SO ₄	92.24	63.16
HNO ₃	83.02	58.03
(NH ₄) ₂ CO ₃	60.05	58.18
NaOH	71.22	48.53

obtained at 60A IPN. This is thought to result from the increased cross-linking with increasing radiation dose. Crosslinking in the IPN structure causes less swelling, resulting in a reduction in desorption of nickel.

It is also possible to find some polymeric adsorbents for the nickel desorption in comparison with the literature. The desorption capacity of poly(ethylene terephthalate) fibres grafted with methacrylic acid was found as 96.5% [4]. Nickel desorption is more than 99% in the process of removing and recovering nickel ions with a chelating resin containing triethylenetetramine [7]. The desorption capacity of poly[acrylamide/N,N-DAMB/N,N-DAPB] super absorbent hydrogel in batch system is determined as 85% [12]. The desorption efficiency of PEGMA-VI microparticles reached 99% [13].

Conclusion

As a result, IPNs irradiated to 14 kGy and optimally amidoximated to recover or remove Ni²⁺ ions should be used at pH=8 and in the flow system. By the way, maximum adsorption efficiency (%96.2) is reached. In addition to all the adsorbents developed so far, the main feature of amidoximated IPNs used in this study is that it can adsorb Ni²⁺ ions at low concentrations as well as high concentrations. This study indicates that amidoximated IPNs can be efficiently used as wastewater pH values between pH = 6 and 8. However, the nickel adsorption at pH = 8 is twice as much as the adsorption at pH = 6. In this respect, IPNs are also suitable for Ni²⁺ recovery from seawater with a pH of 8.3.

In addition to this the eluent, which prefers to use in the industry, must be obtained by processing condition. Where high desorption efficiency is desired, HCl may be selected as the eluent. Given the adsorbent cost, (NH₄)₂CO₃ can be selected as an optimum eluent. The adsorbents obtained in this study can be used as adsorbents for the recovery and removal of nickel from aqueous media.

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