Removal of Cu(II), Pb(II) and Cr(VI) ions from aqueous solution using amidoximated non-woven polyethylene-g-acrylonitrile fabric

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Abstract

Pre-irradiation method was applied to graft acrylonitrile (AN) onto non-woven polyethylene film. Graft yield reached 130% at 70 kGy radiation dose, 60% monomer concentration and 4 h reaction time when H₂SO₄ was used as an additive. The modification of AN grafted films with hydroxyl amine hydrochloride was done for the preparation of amidoxime adsorbent. The constructed adsorbent was characterized using FTIR, DMA and SEM. The amidoxime adsorbent was used for adsorption of Cu(II), Pb(II) and Cr(VI). Adsorption capacity was investigated under different conditions: contact time, pH and initial metal ion concentration. The optimum condition for maximum adsorption was found to be contact time 72 h and initial metal concentration 500 ppm for all the metal ions studied and pH 5.2 for Cu(II), 5.4 for Pb(II), 1.5 for Cr(VI). Kinetic adsorption data was elucidated using pseudo-first-order and pseudo-second-order equations. The equilibrium experimental data of metal adsorption matched Langmuir isotherm model. From the Langmuir equation, the monolayer saturation adsorption capacity (highest adsorption capacity) of the adsorbent was found to be 74.62 mg/g for Cu(II), 107 mg/g for Pb(II) and 156.25 mg/g for Cr(VI). The thermodynamics of metal adsorption was also investigated. Furthermore, desorption and reuse of the adsorbent film was studied. The results suggest that the adsorbent can be effective for adsorption of Cu(II), Pb(II) and Cr(VI).

Keywords Polyethylene · Acrylonitrile · Amidoxime · Adsorption

Introduction

Recently, due to discharge of different heavy metals from various industries water pollution has become a massive problem. Non-biodegradability and tendency to accumulate in living organisms made heavy metals more hazardous than other pollutants. Heavy metals generally found in waste water from different industries include Copper, Silver, Zinc, Cadmium, Gold, Mercury, Lead, Chromium, Iron, Nickel, Tin, Arsenic, Selenium, Molybdenum, Cobalt, Manganese, Aluminum etc [1]

Heavy metals are threat to the environment and human health [2, 3]. Heavy metals are responsible for the damage to the central nervous system, kidneys, skin, teeth, liver or lungs [4]. Intake of some heavy metals at high levels may even result in death. The non-bio-degradable nature of heavy metals makes the removal more important and challenging [5, 6]. The fast development of different industries such as paints and pigments, mining, mineral processing, metallurgical operation, glass production, mining operation, metal plating, and battery manufacturing process increasing the demand for most heavy metals. At the same the environmental regulations on discharge heavy metals are becoming stricter. Hence development of efficient and effective techniques for treatment of wastewater containing soluble heavy metals becoming crucial.

The common technologies utilized to treat industrial wastewaters are precipitation, ion exchange, membrane processes, evaporation, chemical oxidation or reduction, solvent extraction, coagulation, complexation, ion exchange, foam flotation, electro-deposition, cementation or membrane operations. But, most of these techniques are very expensive or technically

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complicated, and applicable only in special cases of wastewater treatment [7].

It is necessary to develop cost effective alternative technologies or sorbents for treatment of metals contaminated waste streams. Adsorption process has demonstrated as an effective process for industrial waste water treatment that offers major benefits like the low cost, easy operation, and reusability. In addition, selective adsorption of some heavy metals is possible by some adsorbents [7]. Many researches has been conducted on removal of toxic metals, dyes etc. using adsorption process [8–14].

Researchers are always looking for an alternative metal adsorbent and grafted polymers have become their center of attention recently [15–25]. The method by which functional monomers are covalently bonded to the backbone polymer chain is called ‘Grafting’. Graft polymerization is highly beneficial since it allows incorporating different functions possessed by the grafted monomer to the parent polymer while maintaining the mechanical properties of the parent polymer [26, 27]. Radiation-induced grafting technique is superior to all other methods used for initiating graft copolymerization like ionizing radiation, ultraviolet light, plasma treatment, decomposition of chemical initiators, oxidation of polymers etc., due to its extensive penetration into the polymer matrix and its quick and homogeneous formation of radicals [28].

Non-woven polyethylene has been chosen as the base polymer to construct metal adsorbent. Many researchers have considered single or binary monomer grafted polyethylene (PE) film for adsorption of heavy metal ion [29–32]. Amine-type adsorbents were synthesized from polyethylene fabric and investigated for selective uranium adsorption [33]. Chelating hollow fiber membranes were prepared by radiation-induced grafting of glycidyl methacrylate onto a polyethylene hollow fiber membrane followed by its subsequent amination and the adsorption characteristics of Pb^{2+} and Pd^{2+} for the chelating hollow fiber membranes were studied [34]. Adsorption of the uranyl ions on an amidoxime-based polyethylene nonwoven fabric was investigated [35]. Dimethylaminoethylmethacrylate (DMAEMA) grafted polyethylene/polypropylene (PE/PP) nonwoven fabric was prepared by radiation-induced graft polymerization and studied for the removal of phosphate [36].

The present study emphasizes on the creation of a new adsorbent by radiation-induced grafting of acrylonitrile (AN) onto non woven polyethylene (PE) films and its application in Cu(II), Pb(II) and Cr(VI) removal. AN was grafted onto PE film using the pre-irradiation method. H_2SO_4 was added to the monomer solution to enhance the graft yield. The modification of AN grafted films with hydroxyl amine hydrochloride was done for the preparation of amidoxime adsorbent. The prepared adsorbent has been used to adsorb Cu(II), Pb(II) and Cr(VI) ion from aqueous solution. Adsorption capacity was studied under various conditions: contact time, pH and

initial metal ion concentration. Investigation of desorption and reuse of the adsorbent film was also done.

Experimental

Materials and reagents

A non-woven polyethylene (PE) fabric obtained from Kurashiki MFG Co. was used as a trunk polymer for graft polymerization. Monomer acrylonitrile (BDH, England) was used to graft onto trunk polymer. Methanol, sodium carbonate, sulphuric acid and acetone were obtained from Merck, Germany. Hydroxyl amine hydrochloride was supplied by Sigma Aldrich, USA. Copper (II) sulfate pentahydrate (Merck, Germany), lead (II) acetate trihydrate (Merck, Germany) and potassium dichromate (Techno pharmchem, India) were used for metal adsorption study.

Instrument and apparatus

The PE films were characterized using FTIR (ATR) spectrophotometer (8400S Shimadzu Japan) between 700 and 4000 cm^{-1} range (resolution 4 cm^{-1} , number of scans: 20 times). The dynamic mechanical property of the adsorbent was investigated from 20 to $170\text{ }^{\circ}\text{C}$ at a heating rate of $4\text{ }^{\circ}\text{C}/\text{min}$ having a vacillating frequency of 1 Hz using dynamic mechanical analyzer (DMA), Triton technology TTDMA, UK. The morphological study of the adsorbent was done by using scanning electron microscopy (SEM) of Model JEOL 6400 at an accelerating voltage of 20 kV. The SEM specimens were sputter coated with platinum. The metal-ion concentrations in the solutions were analyzed by absorption spectrophotometer (AA-6800) of SHIMADZU Japan. Co-60 gamma ray was the radiation source. It is a 90 kCi Cobalt-60 Batch Type Panoramic Irradiator (Board of Radiation and Isotope Technology (BRIT), India). Activity was 68.63 kCi and dose rate was 13.7 kGy/h .

Grafting of AN onto the non-woven PE films by gamma radiation

The non-woven PE films were irradiated using the Co-60 gamma radiation source at 70 kGy radiation dose at an ambient temperature. The irradiated PE films were preserved at dry-ice condition until further use. The monomer solution was prepared by the addition of 60% AN and H_2SO_4 (2% of AN) to methanol. The monomer solution was bubbled with argon gas for removal of dissolved oxygen. The de-aerated monomer solution was streamed into glass bottle consisting irradiated PE films. After filling the glass bottle with monomer solution fully, it was tightly closed with a lid for avoiding intrusion of oxygen from the air into the monomer solution

present in the bottle. Next, in a water bath of temperature 80 °C, the grafting reaction was carried out for 4 h. After that, the AN-g-PE fabric was washed with methanol for eliminating residual monomer and homopolymer of AN. The degree of grafting was calculated by the following formula:

$$\text{Degree of grafting (\%)} = [(W_1 - W_0)/W_0] \times 100 \quad (1)$$

Where, W_1 is the dry weight of grafted PE film and W_0 is the dry weight of PE film.

Amidoximation of nitrile group of AN grafted PE film

80 g/L aqueous solution of hydroxyl amine hydrochloride was prepared in distilled water by stirring with the help of a glass rod. It was neutralized by adding sodium carbonate. The AN grafted PE (AN-g-PE) films were positioned into the aqueous solution of hydroxyl amine hydrochloride and heated in water bath at 80 °C for 4 h. The films were then washed thrice with the help of distilled water for removing the residual salts and were dried in air. The conversion of nitrile group of AN-g-PE film was calculated as follows:

$$C_n = [(W_2 - W_1)/W_1] \times [M_0/M_1] \times 100 \quad (2)$$

Where, W_1 is the weight of the grafted PE film before the reaction, W_2 is the weight of the grafted film after the reaction, M_0 is the molecular weight of the acrylonitrile monomer (53 g/mol) and M_1 is the molecular weight of the hydroxyl amine (33 g/mol) [37].

Metal ion adsorption by amidoximated PE film

The amidoximated PE films were immersed in 50 ml aqueous solutions of Cu(II), Pb(II) and Cr(VI) at room temperature (25 °C). At different pH, contact time and initial metal ion concentration, the adsorption process was carried out. pH of the solutions were adjusted by HCl and NaOH solution. The metal-ion concentrations of the solutions before and after adsorption were measured using atomic absorption spectro-photometer. The metal ion uptake capacity of the film was calculated using the following formula:

$$Q = V(C_1 - C_2)/W, \quad (3)$$

Where, Q is the adsorption amount (mg/g of adsorbent), W the weight of the amidoximated PE film (g), V the volume of solution (L), and C_1 and C_2 are the concentrations (mg/L) of metal ion before and after adsorption respectively.

Desorption of metal ions

The desorption of Cu(II) and Pb(II) ions from the adsorbent films were carried out by treating with 2 M aqueous solution of HCl for 2 h. The desorption of Cr(VI) ions from the

adsorbent films were carried out by the treatment with 2 M aqueous solution of NaOH for 20 h. Desorption percentage was calculated using the following equation:

$$\begin{aligned} \text{Percent desorption} \quad (4) \\ = (\text{Ions desorbed (mg)}/\text{Ions adsorbed (mg)}) \times 100 \end{aligned}$$

Results and discussion

Grafting of AN on PE film

Pre-irradiation method was employed for grafting of AN on non-woven PE film in the present study. In this technique, the polymer backbone is first irradiated so that it can form free radicals. After that, the irradiated polymer substrate is treated with the monomer as a solution in an appropriate solvent. The massive advantage of using pre-irradiation method is that it is comparatively free from the homo-polymer formation because the monomer is not exposed to radiation. In the present research, the graft yield obtained was 130% for 70 kGy radiation dose, 60% monomer concentration using H_2SO_4 (2% of AN) as an additive for 4 h reaction time.

Conversion of nitrile group of AN

The AN-g-PE films were allowed to react with hydroxylamine hydrochloride for conversion of the nitrile group to amidoxime group. The conversion of nitrile group to amidoxime group is 80% at 80 g/L of hydroxylamine hydrochloride solution, pH 7 and 4 h reaction time.

FTIR (ATR) analysis of PE, AN-g-PE and amidoxime-PE films

Polyethylene constitutes an infinite chain of CH_2 groups. So, the characteristic features of the FTIR spectrum of PE film (Fig. 1) are its C-H stretching vibrations. Two peaks denoting C-H asymmetric and symmetric stretching vibrations are observed at 2910 and 2845 cm^{-1} respectively. In the spectrum of AN-g-PE (Fig. 1), the intensity of both these peaks is slightly increased while the 2910 peak shifts towards a lower wavenumber (2902 cm^{-1}). Moreover, a new peak (2245 cm^{-1}), representing the nitrile group also appeared in the spectrum. The spectra exhibited some changes after amidoximation of the nitrile group of AN-g-PE film which is shown in the Amidoxime-PE spectrum (Fig. 1). The peak corresponding to nitrile group (2245 cm^{-1}) is noticeably decreased due to the conversion of nitrile to amidoxime and shifts towards higher wavenumber (2300 cm^{-1}). Moreover, the characteristic peaks of amidoxime can be observed at 910 cm^{-1} (assigned to

Fig. 1 FTIR spectrum of non-woven PE, AN grafted non-woven PE (AN-PE) and amidoximated non-woven PE (Amidoxime-PE)

N-O) and 1236 cm^{-1} (assigned to the bending vibration of the amine group N-H). A broad peak was also observed around 3726 and 3032 cm^{-1} (assigned to O-H). These results suggest that the conversion of the nitrile group to the amidoxime group has been successfully done. [38, 39]

Dynamic mechanical analysis (DMA) of PE, AN-g-PE and amidoxime-PE films

The storage modulus of PE, AN-g-PE and amidoxime-PE film with change of temperature is revealed through Fig. 2. The initial value of storage modulus for amidoxime-PE film is greater than that of PE film and AN-g-PE film. It is visible, that the glassy transition region for AN-g-PE film obtained in

the temperature extending from $50\text{ }^{\circ}\text{C}$ to $120\text{ }^{\circ}\text{C}$. On the contrary, the glassy transition region for PE film ranges between $20\text{ }^{\circ}\text{C}$ and $110\text{ }^{\circ}\text{C}$. Glass transition region for amidoxime-PE film obtained in the temperature range $50\text{--}150\text{ }^{\circ}\text{C}$. It is also observed that there is a sharp decline of modulus for AN-g-PE in the glassy region, a fluctuating decline of modulus for amidoxime-PE in the glassy transition region and a slow decline of modulus for PE curve in the glassy region.

Scanning Electron microscopy of PE, AN-g-PE and amidoxime-PE films

The nonwoven fibers were characterized by SEM to compare the physical appearance of PE, AN-g-PE and amidoxime-PE

Fig. 2 Storage modulus of PE, AN-g-PE and amidoxime-PE film

Fig. 3 **a** SEM image of non-woven PE. **b** SEM image of AN grafted non-woven PE. **c** SEM image of amidoximated AN grafted non-woven PE

fabrics. The SEM image of PE, AN-g-PE and amidoxime -PE fabrics are shown in Fig. 3(a), (b) and (c) respectively. The SEM image of AN grafted PE shows change in the physical appearance and also slight increase in the average diameter of fibers that offer additional physical evidences for the grafting. The SEM image of amidoxime-PE shows significant change in physical appearance and large increase in average diameter that provide evidences for the modification.

Cu(II), Pb(II) and Cr(VI) adsorption by amidoxime-non woven PE films

The amidoximated non-woven PE films were analyzed for adsorption of Cu(II), Pb(II) and Cr(VI) from aqueous solution. The effect of contact time of Cu(II), Pb(II) and Cr(VI) adsorption were investigated. The amidoxime-non woven PE films were put inside the aqueous solutions of Cu (II) (at pH 5.2, initial concentration 300 ppm), the aqueous solutions of Pb (II) (at pH 5.4, initial concentration 500 ppm) and the aqueous solutions of Cr(VI) (at pH 1.5, initial concentration 100 ppm) separately at room temperature (25 °C). The concentrations of the Cu(II), Pb(II) and Cr(VI) ions in solutions were measured

at regular intervals. The experimental data found are shown in Fig. 4. It can be inferred that the Cu(II), Pb(II) and Cr(VI) adsorption rate is quick at the beginning, and gradually reaches plateau towards equilibrium with maximum adsorption of 67 mg/g for Cu(II), 107 mg/g for Pb(II) and 100 mg/g for Cr(VI). The adsorption of Cu(II), Pb(II) and Cr(VI) ions reached equilibrium value after the duration of 72 h.

Cu(II), Pb(II) and Cr(VI) adsorption by the amidoxime-non woven PE film were fitted with the pseudo-first-order and pseudo-second order kinetic models. The pseudo-first-order and pseudo-second-order equations [40, 41] are articulated by the following equation:

$$\log (Q_e - Q_t) = \log Q_e - (k_1 / 2.303) t \quad (5)$$

$$t/Q_t = 1 / (k_2 Q_e^2) + t/Q_e \quad (6)$$

where Q_t and Q_e are the amount of metal adsorbed (mg/g) at any time and equilibrium time, respectively, k_1 is the rate constant (1/h) of the first-order adsorption and k_2 (g /h.mg) is the rate constant of second-order adsorption. The pseudo-first-order rate constants could be measured experimentally by plotting $\log (Q_e - Q_t)$ against t as shown in Fig. 5. The

Fig. 4 Cu(II), Pb(II) and Cr(VI) adsorption capacity of the amidoxime adsorbent against standing time

Fig. 5 Pseudo 1st order plot for Cu(II), Pb(II) and Cr(VI) adsorption

experimental and theoretical Q_e value, first-order rate constant and the correlation coefficients (R^2) are given in Table 1. From the results it can be observed that the experimental Q_e value and the Q_e value calculated from first-order kinetic model are not in agreement with each other. Pseudo-second-order rate constants could be measured experimentally by plotting t/Q_t against t as shown in Fig. 6. All the second-order kinetic parameters for metal adsorption are also shown in Table 1. It can be inferred that the experimental Q_e and the Q_e value calculated from second-order kinetic model accordingly matches with each other. Therefore, the pseudo-second-order equation can be used to interpret Cu(II), Pb(II) and Cr(VI) adsorption on the amidoxime-non woven PE film. Pseudo-second-order model fits with the experimental kinetic data indicates that intra-particle diffusion process was the rate-limiting step of the adsorption [42] and it also proves that the chelating interaction plays the key role in the adsorption process [43].

The effect of adsorbent dose on adsorption of Cu(II), Pb(II) and Cr(VI) was studied using different adsorbent dosages in the range of 1–3 g/L for 100 mg/L of initial metal ion concentration. It was observed that on increasing adsorbent dose above 1 g/L the adsorption of metal ions remained unchanged.

This was due to the fact that the concentration of metal ions reached at equilibrium state between solid and solution phase.

The pH of the medium has a massive effect on the adsorption capacity of grafted adsorbent, because at various pH values, due to the protonation and deprotonation behaviors of acidic and basic groups, the surface arrangement of the adsorbent could be dominated and the metal ions would exist in dissimilar forms. The experimental results of pH influencing the adsorption of metal ions are presented in Fig. 7. As observed, the adsorption capacity was highly dependent on the pH with maximum adsorption at pH = 5.2 for Cu(II), pH = 5.4 for Pb(II) and pH = 1.5 for Cr(VI). At low pH adsorption of Cu(II) and Pb(II) was low, because at low pH value the NH_2 groups on the surface of the amidoxime-PE film are protonated to form NH_3^+ (positively charged) which electrostatically repel the positively charged Cu^{2+} and Pb^{2+} . With the increase of pH, the NH_2 groups of the amidoxime-PE are deprotonated to form $\text{NH}_2\cdots\text{OH}^-$ which attracts the positively charged Cu^{2+} and Pb^{2+} . At higher pH (pH more than 5.4) hydroxides of Cu(II) and Pb(II) are produced and thus adsorption capacity is reduced. On the contrary, the amount of Cr(VI) removal decreased with increasing pH of Cr(VI) solution. At low pH value, the NH_2 groups on the surface of the

Table 1 The pseudo-first-order and pseudo-second-order rate constants for Cu(II), Pb(II) and Cr(VI) adsorption by amidoxime adsorbent

Metal Ion	Q_e (exp.) (mg/g)	Pseudo-first-order rate constant			Pseudo-second-order rate constant		
		Q_e (theor.) (mg/g)	K_1 (h^{-1})	R^2	Q_e (theor.) (mg/g)	k_2 ($\text{g h}^{-1} \text{mg}^{-1}$)	R^2
Cu(II)	67	44.3	0.0430	0.9855	65.35	0.0037	0.9963
Pb(II)	107	90.2	0.0370	0.9762	109.89	0.0009	0.9998
Cr(VI)	100	75	0.0394	0.9699	98	0.0017	0.9993

Fig. 6 Pseudo 2nd order plot
Cu(II), Pb(II), Cr(VI) adsorption

amidoxime-PE film are protonated forming NH_3^+ (positively charged) which easily binds to the negatively charged species (HCrO_4^- , CrO_4^{2-} , and $\text{Cr}_2\text{O}_7^{2-}$) due to the electronic attraction. At high pH value, the NH_2 groups of the amidoxime-PE are de-protonated forming $\text{NH}_2\cdots\text{OH}^-$ which electrostatically repel the negatively charged Cr(VI) species and thus the adsorption is reduced. The pH zpc (zero point charge) value of the adsorbent was determined by pH drift method. The pH zpc was found to be 4.5. At $\text{pH} < \text{pH}_{\text{zpc}}$, the surface charge is positive, at $\text{pH} = \text{pH}_{\text{zpc}}$, the surface charge is neutral, and at $\text{pH} > \text{pH}_{\text{zpc}}$, the surface charge is negative. The pH_{zpc} value is in agreement with the metal adsorption results obtained.

Figure 8 represents the effects of the initial concentration of metal ions on the adsorption capacity. It can be inferred that with the increase of initial metal ion concentration, the

adsorption amount of metal ions also increased, then at some higher concentration the adsorption reached a plateau value. The main reason behind this outcome is that with the increase of concentration the chelating sites of the adsorbent become saturated. For elucidation of the Cu(II), Pb(II) and Cr(VI) adsorption data, the Langmuir isotherm model is applied. The linear form of the Langmuir isotherm model is expressed by the following equation:

$$C_e/Q_e = C_e/Q_o + 1/(Q_o b) \quad (7)$$

Where, C_e is the equilibrium concentration (mg/L), Q_o is the monolayer saturation adsorption capacity of the adsorbent (mg/g), Q_e is the equilibrium adsorption capacity (mg/g) and b is the Langmuir adsorption constant

Fig. 7 Effect of pH on Cu(II),
Pb(II) and Cr(VI) adsorption

Fig. 8 Effect of initial metal ion concentration on the adsorption capacity

(L/mg). The plot of C_e/Q_e versus C_e represented by Fig. 9 was drawn from the experimental data given in Fig. 8. The relationship between C_e/Q_e and C_e is linear which indicates that Langmuir adsorption isotherm is obeyed by the adsorption behavior. From the Langmuir equation, the monolayer saturation adsorption capacity of the adsorbent was found to be 74.62 mg/g for Cu(II), 107 mg/g for Pb(II) and 156.25 for Cr(VI).

The effect of temperature on the adsorption capacity is studied and the results are shown in Fig. 10. The Gibbs free energy change (ΔG°) of the adsorption process can be calculated from classic Van't Hoff [44, 45] equation:

$$\Delta G^\circ = -2.303RT \log K_d \quad (8)$$

$$K_d = Q_e/C_e \quad (9)$$

The Enthalpy change (ΔH°) (i.e. heat of adsorption) and Entropy change (ΔS°) are related with the Gibbs free energy by the equation:

$$\log K_d = \Delta S^\circ / 2.303R - \Delta H^\circ / 2.303RT \quad (10)$$

Where: K_d is equilibrium constant of Van't Hoff equation, Q_e is solid phase concentration of metal ions at equilibrium (mg/g), C_e is concentration of metal ions in solution at equilibrium (mg/L), ΔG° is Gibbs free energy change (KJ/mol), ΔH° is Enthalpy change (KJ/mol) and ΔS° is entropy change (KJ/mol K).

$\log K$ was plotted against $1/T$ to calculate ΔH° and ΔS° from the slope and intercept, respectively (Fig. 11).

Fig. 9 Langmuir isotherm plot for Cu(II), Pb(II) and Cr(VI) adsorption

Fig. 10 Effect of temperature on adsorption capacity

Free energy values (ΔG) are very small and positive, and decreases with an increase of temperature. This indicates that better adsorption is obtained at higher temperature. The value of ΔS° can be used to describe the randomness during adsorption process, the positive value of ΔS° reflected the affinity of the adsorbent for particular heavy metal ions and confirms the increased randomness at the solid–solution interface during adsorption. The positive standard enthalpy change in this study suggests that the adsorption of metal ions by the amidoxime adsorbent is endothermic, which is supported by the increasing adsorption of metal ions with increase in temperature.

The adsorbents were regenerated after adsorption of metal ions on the amidoxime-PE film, by treatment with 2 M HCl solution for Cu(II) and Pb(II) and 2 M sodium

hydroxide solution for Cr(VI). Desorption equilibrium was achieved after 20 h of time interval. The desorption ratio was 99%. The sorption capacities of the film for Cu(II), Pb(II) and Cr(VI) adsorption from aqueous solutions were carried out in five successive cycles. Repeated use of the adsorbent for metal adsorption does not show any significant change in the sorption capacity.

The adsorption capacity of present adsorbent with some other adsorbents is compared in Table 2.

The adsorbent is important due to its high adsorption capacity compared to other adsorbents (Table 2). Other advantage of the adsorbent is that it can adsorb both positively charged metal ions such as Cu(II), Pb(II) and negatively charged species (HCrO_4^- , CrO_4^{2-} and $\text{Cr}_2\text{O}_7^{2-}$). The adsorbents prepared in this study have

Fig. 11 Plot of $\log(Q_e/C_e)$ versus $1/T$

Table 2 Cu(II), Pb(II) and Cr(VI) adsorption capacity of amidoximated AN grafted non-woven PE compared with some other adsorbents

Adsorbent	Adsorption capacity (mg/g)		
	Cu(II)	Pb(II)	Cr(VI)
Amidoximated AN grafted non-woven PE [present study]	74.62	107	156.25
Itaconic acid/acrylamide graft PET fiber [19]	7.73		
Methacrylic acid/acrylamide graft PET fiber [18]	31.25		
Multi-walled carbon nanotubes [46]	12.34		
Sugar beet pulp carbon [47]	14.81		
Rice husk [48]		11.62	
Silica Ceramic [49]		2.7	
Activated carbon from <i>Phoenix dactylifera</i> . L [50]		9.91	
Activated carbon from Eichhornia [51]		16.61	
Palm trunk charcoal [52]			24.7
Activated carbon derived from acrylonitrile-divinylbenzene co-polymer [53]			101.2
Chemically modified banana peels [54]			6.17
Amine functionalized nanofibers [55]			137

high metal removal efficiency and the adsorbents are economic because they can be reused. The adsorbent preparation is still in the research scale; roughly, the cost of 1 g adsorbent production is 10 taka or US\$0.125. One gramme of adsorbent can adsorb 74 mg of Cu(II) or 107 mg of Pb(II) or 156 mg of Cr(VI) from aqueous solution. It is expected that an adsorbent can be reused 10 times. So, 1 g adsorbent can treat 10 L of 74 ppm Cu(II) or 107 ppm Pb(II) or 156 ppm Cr(VI) solution.

Conclusion

AN-g-PE films were successfully constructed using pre-irradiation process. Graft yield 130% was achieved at 70 kGy radiation dose, 60% monomer concentration and 4 h reaction time with the help of H₂SO₄ as an additive. The modification of AN grafted films with hydroxyl amine hydrochloride was done for the preparation of amidoxime adsorbent. The adsorbent was analyzed using FTIR, DMA and SEM. The constructed amidoxime adsorbent showed quality adsorption capacity for Cu(II) and Pb(II) and high affinity towards Cr(VI) adsorption. Kinetics and isotherm of metal adsorption were also investigated. The experimental data for the adsorption of Cu(II), Pb(II) and Cr(VI) on amidoxime adsorbent matched with pseudo-second-order kinetic model and Langmuir isotherm model. From the Langmuir equation, the monolayer saturation adsorption capacity of the adsorbent was found to be 74.62 mg/g for Cu(II), 107 mg/g for Pb(II) and 156.25 for Cr(VI). The investigation of thermodynamics indicates that the metal adsorption by the adsorbent is endothermic and better adsorption is achieved at higher temperature. Desorption and reuse of the adsorbent film also showed successful results.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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