

Comparative study on the removal of copper (II) and nickel (II) from aqueous solution using cellulose extracted from sisal fiber and cellulose grafted acrylonitrile copolymer

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Batch adsorption studies have been carried out to remove Cu (II) and Ni (II) ion from aqueous solution using cellulose extracted from sisal fiber and cellulose-g-acrylonitrile copolymer by steam explosion method. The effect of pH, contact time and amount of adsorbent dose have also been investigated for both cellulose extracted from sisal fiber and cellulose-g-acrylonitrile copolymer. From the observed results, it is evident that the adsorption of metal ions increases with the increase in contact time and adsorbent dosage. The optimum pH is found to be 5.0 for the removal of copper (II) and nickel (II) for both the extracted cellulose and cellulose-g-acrylonitrile copolymer. The adsorption kinetics of cellulose and cellulose-g-acrylonitrile is found to follow pseudo-second-order kinetic model. The experimental data are fitted to Langmuir adsorption isotherms for both cellulose extracted from sisal fiber and cellulose-g-acrylonitrile copolymer. From the results it is concluded that the cellulose graft acrylonitrile copolymer is found to be efficient adsorbent for the removal of heavy metals from aqueous solutions.

Keywords: Sisal fiber, Cellulose, Adsorption, Copper (II), Nickel (II), Cellulose-g-acrylonitrile copolymer

Water is one of the essential items needed for living beings for the survival and growth. It also maintains an ecological balance between various groups of organisms and their environment. The quality of water is of initial concern for mankind since it is directly linked with human welfare¹. Heavy metals are widely used in the industries like textiles, leather, paper, plastics, electroplating, cement, metal processing, wood preservatives, paints, pigments and steel fabricating industries². These industries discharge large quantities of toxic wastes and the untreated effluents from these industries causes water pollution³. Heavy metals are classified into the following three categories: toxic metals (Hg, Cr, Pb, Zn, Cu, Ni, Cd, As, Co, Sn, etc.), precious metals (Pd, Pt, Ag, Au, Ru, etc.) and radionuclides (Ra, Am, etc.)⁴. The presence of heavy metal in environment is of major concern because of their transformation from relatively low toxic species into more toxic ones. Some metal ions such as Hg and Cd are highly toxic even in lower concentration 0.001-0.1 mg/L (Ref. 5). The current physicochemical processes for heavy metal removal like (precipitation, electrochemical treatment, ionexchange, adsorption

on activated carbon)⁶ etc. are expensive and inefficient in treating large quantities. They also cause metal bearing sludges which are difficult to dispose of. More stringent rules by the government and media and public pressure regarding effluent discharges have necessitated the search for newer methods of treatment^{7,8}. The excessive levels of heavy metals have been linked with a wide range of health conditions, including skin disease, birth defects and cancer⁹ and so the World Health Organization has recommended strict controls on the percentages of various heavy metals in effluent waters. Since the cost of these materials is much lower than the cost of commercial adsorbents, such as activated carbon or ion-exchange resins, the prepared biological materials might gain a special attention. These materials including: activated carbon¹⁰⁻¹³, lignite¹⁴, kaolinite and ballclay¹⁵, diatomite¹⁶, coconut fiber¹⁷ sisal fiber and limestone¹⁸.

Cellulose fibres are becoming popular because they are cheap, renewable and low in density, and exhibit better processing flexibility¹⁹. Among many natural fibers, sisal is of particular interest due to its moderate high specific strength and stiffness,

durability, ability to stretch, and resistance to deterioration in saltwater^{20,21}. There are several referenced chemical treatments for cellulose extraction from natural fibers but the most used one is the alkaline treatment, sometimes named mercerisation, in which the fibre is immersed into a concentrated NaOH solution^{22,23}. Another treatment, is the bleaching by hydrogen peroxide or sodium hypochlorite which results in the degradation of lignin and hemicellulose matrix, releasing the cellulose fibres. Afterwards, acidic and mechanical treatment was done on the cellulose fibers to reduce the polymeric chain to the desirable size^{24,25}.

The aim of the present work is to modify the extracted cellulose using grafting phenomenon. The four different stages of fibers were prepared at first from the sisal fiber to extract the cellulose using a combination of chemical and mechanical treatments. Batch technique was performed using cellulose graft acrylonitrile copolymer as an adsorbent to study the sorption of Cu^{2+} and Ni^{2+} . Different parameters, such as temperature, pH of the solution, different concentrations of metal ion and effect of shaking time were manifested.

Experimental Section

Materials

The sisal fiber was purchased from the local farms. The analytical grade reagents such as NaOH, acetic acid, sodium hypochlorite, oxalic acid were obtained from Central Drug House Pvt Ltd. The stock solutions of copper (II) (200 mg/L) and nickel (II) (200 mg/L) were prepared for the metal ion removal studies. These solutions were prepared by dissolving Copper sulphate and nickel chloride (procured from Merck, India) in double distilled water. All the chemicals used above were of analytical reagent grade.

Preparation of steam exploded fibers

About 30 g of sisal fibers were chopped into uniform sizes of approximately 10cm. The 2% NaOH (fiber to liquor ratio 1:10) was added to the above chopped fibers taken in a beaker. This mixture was then placed in an autoclave for a period of 1 h by maintaining at a pressure of 20 lb/in². After a certain period of time, the pressure was released immediately. The fibers were removed from the autoclave which was then washed with water till they were rid of alkali. The washed fibers were allowed to drain off free from water.

Preparation of steam exploded bleached fibers

The bleaching treatment of the steam exploded fibers was carried out using a mixture of NaOH and acetic acid (27 and 78.8 g, respectively) and a mixture of 1:3 sodium hypochlorite solutions. This treatment was then repeated for approximately six times. After this process is over, the fibers were thoroughly washed in distilled water and dried²⁶.

Preparation of steam exploded fibers in acidic medium

The steam exploded bleached fibers taken in an autoclave was treated with different concentrations of oxalic acid such as 5, 7, 9 and 11% until it attained a pressure of 20 lb. After it attains that particular pressure, the pressure was released immediately. The autoclave was again set to reach a pressure of 20 lb/in², and the fibers were kept under that pressure for 15 min. The pressure was released and the process was repeated for approximately 8 times. Then the fibers were taken out and washed well using distilled water^{27,28}.

Mechanical treatment of the processed fibers

The acidically treated fibers was suspended in water and then stirred well using a mechanical stirrer of type RQ – 1.27 A at a speed of 8000 R.P.M. for 4 h. The suspension was then finally kept in an oven at 90°C till it was dry.

Preparation of cellulose graft acrylonitrile copolymer

About 1 g of extracted cellulose was added to 100 mL of water and stirred well to form a homogeneous suspension. Acrylonitrile monomer (1 mL) dissolved in 20 mL of water was then added to that homogenous solution. The initiator ceric ammonium nitrate (0.5 g of CAN in 10 mL of 1N HNO_3) was added in the above mixture to initiate the polymerization process²⁹. After all the addition was over, the above mixture was heated to 70°C. Simultaneously the stirring of that mixture was performed for a period of approximately 30 min using a magnetic stirrer. After a time period of 30 min the above solution was poured into excess sodium hydroxide (2N) solution to precipitate the graft copolymer. Finally, the obtained graft copolymer precipitate was then filtered, dried and weighed.

Experimental process of removal of copper and nickel by cellulose as adsorbent

Batch studies were carried out to investigate the adsorption of the extracted cellulose for both Cu^{2+} and Ni^{2+} using copper sulphate and nickel chloride

solutions (200 mg/L) which was taken separately in a stoppered bottle. The extent of removal of the metals was examined separately by changing the *pH* of solution, adsorbent dosage, and time of shaking of the adsorbent metal solution mixture. The adsorption experiments were carried out in a stoppered bottle containing about 1 g of the cellulose extracted from sisal fiber with 200 mL of Cu (II) solution and Ni (II) solution taken separately at the desired concentration.

The solutions taken in stoppered bottle was then agitated at 30°C using orbital shaker at a fixed rate of 160 rpm. Finally the adsorbent was separated by filtration using whatmann filter paper and the aqueous phase concentration of metal was determined with atomic adsorption technique. A similar procedure was carried out at various time intervals, adsorbent doses and *pH*. Using either the sodium hydroxide or the hydrochloric acid the *pH* of each solution was adjusted to different values.

Experimental process of removal of copper and nickel by cellulose grafted acrylonitrile

The extent of adsorption was investigated with different concentrations of copper sulphate and nickel chloride using the batch studies. Investigation was done to find out the extent of adsorption of Cu (II) and Ni (II) by cellulose graft acrylonitrile. The extent of removal of the metals was examined separately by changing the *pH* of solution, adsorbent dosage, and time of shaking of the adsorbent metal solution mixture. The adsorption experiments were carried out in a stoppered bottle containing about 1 g of the cellulose-g-acrylonitrile with 200 mL of Cu (II) solution and Ni (II) solution taken separately at the desired concentration.

The solutions taken in stoppered bottle were then agitated at 30°C using orbital shaker at a fixed rate of 160 rpm. Finally the adsorbent was separated by filtration using whatmann filter paper and the aqueous phase concentration of metal was determined with atomic adsorption technique. A similar procedure was carried out at various time intervals, adsorbent doses and *pH*. Using either the sodium hydroxide or the hydrochloric acid the *pH* of each solution was adjusted to different values.

Results and Discussion

Effect of *pH*

One of the most important parameter in heavy metal biosorption was the *pH*. Fig. 1(a) and Fig. 1(b) shows the effect of solution *pH* on the adsorption

capacity of extracted cellulose and cellulose grafted acrylonitrile copolymer for Cu²⁺ and Ni²⁺. The results presented in the Fig. 1(a) and Fig. 1(b) revealed that the adsorption increases with an increase in *pH* of the metal ion solution initially but thereafter it declines. It can be seen from Fig. 1(a) and Fig. 1(b), that the amount of Cu²⁺ and Ni²⁺ adsorbed by extracted cellulose and cellulose grafted acrylonitrile slowly increased with increase in *pH* of Cu²⁺ and Ni²⁺ solution from 4 to 6, the optimum adsorption *pH* being located at 5. The increase in the metal ion removal with increasing *pH* was mainly due to the lower electrostatic repulsion. The lower electrostatic repulsion between surface and metal ions arises from the decrease in competition between proton and metal cations for same functional groups and also by the decrease in positive surface charge. Decrease in adsorption at higher *pH* was attributed to the formation of soluble hydroxyl complexes³⁰.

On comparing the *pH* of both extracted cellulose and grafted cellulose with acrylonitrile it was showed that at *pH*-5 maximum adsorption of Cu²⁺ occurs on Cellulose grafted acrylonitrile was 82.1% and adsorption of Ni²⁺ was 72.2% when compared to extracted cellulose in which maximum adsorption of

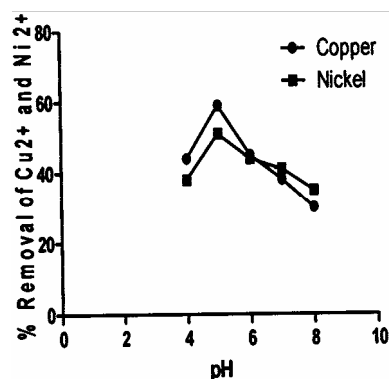


Fig. 1—(a) Effect of *pH* on the extracted cellulose.

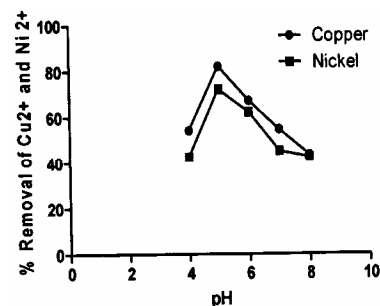


Fig. 1—(b) Effect of *pH* on the cellulose grafted acrylonitrile.

Cu^{2+} occurs on Cellulose was 59% and Ni^{2+} was 51% adsorption. Table 1 lists the comparison between effect of pH on the removal of copper (II) and nickel (II) from aqueous solution using the extracted cellulose and cellulose-g-acrylonitrile copolymer.

Effect of adsorbent dose

The adsorption of Cu (II) and Ni (II) from aqueous solution onto the extracted cellulose and cellulose graft acrylonitrile copolymer was studied by varying the amount of adsorbents from 1 to 6 g, while keeping other parameters (pH, and contact time) as constant. Fig. 2(a) and Fig. 2(b) represents the effect of adsorbent dose on the removal of copper (II) and nickel (II) from the aqueous solution using cellulose extracted from sisal fiber and cellulose grafted acrylonitrile copolymer. From the above Figs. 2(a) and 2(b), it was evident that the adsorption of copper and nickel ions increases rapidly with increase in the amount of adsorbent at first but after it reaches an optimum dosage it remains constant. The rapid uptake revealed a high affinity between the heavy metals and adsorbent, which was directly attributed to the characters of adsorbent. The positive charged adsorbent dispersed in solution evenly after grafting, which was favorable to the rapid contacting between heavy metals and the active sites. But further addition of the adsorbent beyond this (4 g) in both cases did not cause any significant change in the adsorption which may be due to the overcrowding of adsorbent particles³¹. On comparing the adsorbent dose of both extracted cellulose and grafted cellulose with acrylonitrile it was showed that at the dosage of 6 g maximum adsorption of Cu^{2+} occurs on cellulose grafted acrylonitrile was 85% and adsorption of Ni^{2+} was 72% when compared to extracted cellulose in which maximum adsorption of Cu^{2+} occurs on Cellulose was 48% and Ni^{2+} was 44.0% adsorption. Table 2 lists the comparison between effect of adsorbent dose on the removal of copper (II) and

nickel (II) from aqueous solution using the extracted cellulose and cellulose grafted acrylonitrile copolymer.

Effect of contact time

The effect of contact time on the adsorption of Cu^{2+} and Ni^{2+} ions onto the extracted cellulose and cellulose-g-acrylonitrile copolymer was represented in Fig. 3(a) and Fig. 3(b). The adsorption of copper (II) and nickel (II) was measured at five different contact time from 60 to 360 min. From the results of

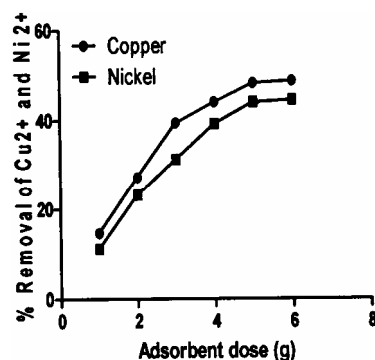


Fig. 2—(a) Effect of adsorbent dose on the extracted cellulose.

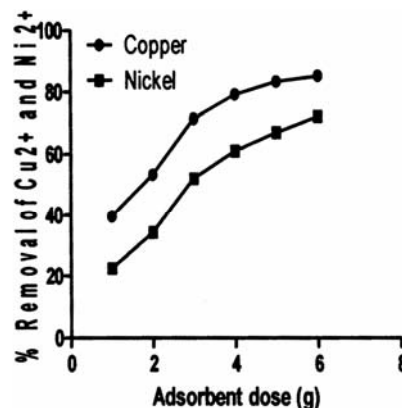


Fig. 2—(b) Effect of adsorbent dose on the cellulose grafted acrylonitrile.

Table 1—Effect of pH on cellulose and cellulose grafted acrylonitrile

pH	Cellulose		Cellulose-g-acrylonitrile	
	% Cu^{2+} Removed	% Ni^{2+} Removed	% Cu^{2+} Removed	% Ni^{2+} Removed
4	44	38	54.2	42.5
5	59	51	82.1	72.2
6	45	44	67.2	62.1
7	38	41	54.7	45.2
8	30	35	43.5	42.5

Table 2—Effect of adsorbent dose on cellulose and cellulose grafted acrylonitrile.

Adsorbent dose (g)	Cellulose		Cellulose-g-acrylonitrile	
	% Cu^{2+} Removed	% Ni^{2+} Removed	% Cu^{2+} Removed	% Ni^{2+} Removed
1	14.7	11.2	39.7	22.5
2	27.2	23.2	53.4	34.4
3	39.4	31.3	71.5	52.1
4	44.1	39.2	79.4	61.1
5	48.3	44.1	83.5	67.1
6	48.8	44.6	85.4	72.3

various figures it was evident that the metal ion removal increased with increase in the contact time and reached a maximum at 240 min for both copper (II) and nickel (II). The higher rate of adsorption initially was probably due to the larger surface area being available at beginning for the adsorption of copper and nickel ions³². Due to a quick exhaustion of the adsorption sites after a certain time of contact, further increase in contact time did not bring about any improvement^{33,34}. On comparing the contact time of both extracted cellulose and grafted cellulose with acrylonitrile it was showed that at 360 min maximum adsorption of Cu^{2+} occurs on cellulose grafted acrylonitrile was 84% and adsorption of Ni^{2+} was 76% when compared to extracted cellulose in which maximum adsorption of Cu^{2+} occurs on cellulose was 42% and Ni^{2+} was 41.0% adsorption. Table 3 lists the comparison between effect of time on the removal of copper (II) and nickel (II) from aqueous solution using the extracted cellulose and cellulose-g-acrylonitrile copolymer.

Kinetic studies of adsorption

The examination of the controlling mechanism of the adsorption process such as mass transfer and

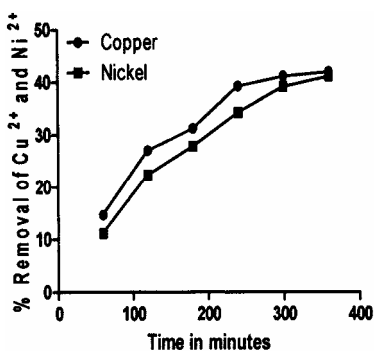


Fig. 3—(a) Effect of contact time on the extracted cellulose.

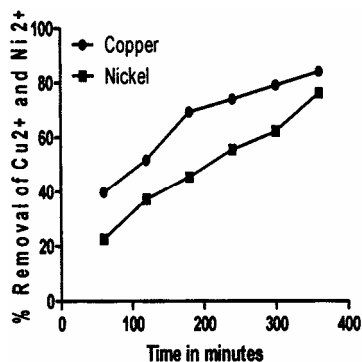


Fig. 3— (b) Effect of contact time on the cellulose grafted acrylonitrile

chemical reaction was done by the Pseudo first order and pseudo second order kinetic models. These pseudo first order and second order kinetic models were used to test the experimental data³⁵. The pseudo first order equation was given as follows:

$$\log (q_e - q_t) = \log q_e - (k_1/2.303)t$$

where q_e and q_t are the amount of Cu(II) and Ni(II) adsorbed on adsorbent (mg/g) at equilibrium and at time t , respectively, k_1 is the rate constant of first order adsorption with min^{-1} as the unit. The straight line plots of $\log (q_e - q_t)$ against t was used to determine the rate constant k_1 , and correlation coefficient R^2 values of Cu(II) and Ni(II) under different concentration range. These values were calculated from the plots which was shown in the Figs. 4(a) and Fig. 4(b).

The plots of $\log (q_e - q_t)$ versus t were straight lines. The slopes and intercepts of plots of $\log (q_e - q_t)$ versus t were used to determine the first-order rate constant k_1 and equilibrium adsorption density q_e . The second order equation may be expressed as^{36,37}:

$$t/q_t = 1/h + 1/q_e$$

where $h = k_2 q_e^2$ ($\text{mg g}^{-1}\text{min}^{-1}$) which can be regarded as the initial adsorption rate as t tends to

Table 3—Effect of contact time on cellulose and cellulose grafted acrylonitrile.

Time (min)	Cellulose		Cellulose-g-acrylonitrile	
	% Cu ²⁺ Removed	% Ni ²⁺ Removed	% Cu ²⁺ Removed	% Ni ²⁺ Removed
60	14.7	11.2	39.7	22.5
120	27.1	22.4	51.7	37.2
180	31.3	27.9	69.4	45.5
240	39.3	34.3	74.1	55.6
300	41.2	39.2	79.2	62.4
360	42	41.2	84.2	76.3

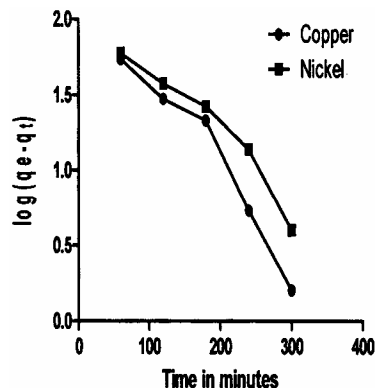


Fig. 4— (a) Pseudo first order kinetic for Cu(II) and Ni(II) for extracted cellulose.

0 and k_2 is the rate constant of second order adsorption ($\text{g mg}^{-1} \text{min}^{-1}$). The straight line plots of t/q_t against t have been tested to obtain rate parameters and it suggests the applicability of this kinetic model to fit the experimental data [Fig. 5(a) and Fig. 5(b)].

The results of the kinetic parameters for Cu(II) and Ni(II) adsorption are given in Table 4 for both extracted cellulose and cellulose-grafted-acrylonitrile.

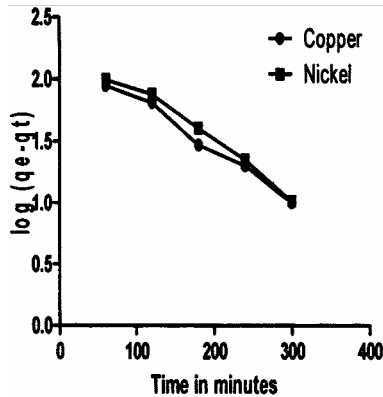


Fig. 4— (b) Pseudo first order kinetic for Cu(II) and Ni(II) for cellulose grafted acrylonitrile

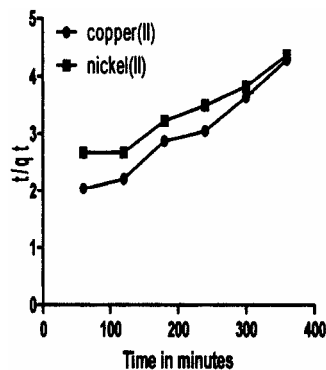


Fig. 5— (a) Pseudo second order kinetic for Cu(II) and Ni(II) for extracted cellulose.

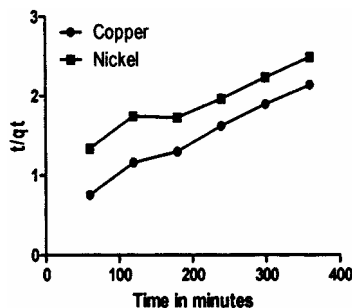


Fig. 5— (b) Pseudo second order kinetic for Cu(II) and Ni(II) for cellulose grafted acrylonitrile

Based on the calculated correlation coefficients, it was concluded that the adsorption of Cu(II) and Ni(II) follows the second order kinetics for both extracted cellulose and cellulose grafted with acrylonitrile. In most of the cases, the first order equation does not fit well to the whole range of contact time and is generally applicable over the initial stage of adsorption process³⁶. The second order equation correlates well to the adsorption behavior in many cases which may involve valency forces through sharing of electrons between metal cations and adsorbent.

Adsorption isotherm

The distribution of the adsorbate species among liquid and solid phases was described by adsorption isotherm (mathematical models). Adsorption isotherm mainly describes the interaction between the solute and the adsorbent and so is critical in optimizing the use of adsorbent. The Langmuir equation has been frequently used to give the sorption equilibrium³⁸. The Langmuir model assumes that the uptake of metal ions occurs on a homogenous surface by monolayer adsorption without any interaction between adsorbed ions. The linearized Langmuir isotherm allows the calculation of adsorption capacities and Langmuir constant by the following equation:

The linearized Langmuir isotherm

$$C_{ads} = (K_L C_{eq}) / (1 + b C_{eq})$$

Linearised form of the Langmuir isotherm

$$C_{eq} / C_{ads} = b C_{eq} / K_L + 1 / K_L \quad \dots(1)$$

$$C_{max} = K_L / b \quad \dots (2)$$

where

C_{ads} = amount of metal ion adsorbed ($\text{mg} \cdot \text{g}^{-1}$)

C_{eq} = equilibrium concentration of metal ion in solution ($\text{mg} \cdot \text{dm}^{-3}$)

K_L = Langmuir constant ($\text{dm}^3 \cdot \text{g}^{-1}$)

b = Langmuir constant ($\text{dm}^3 \cdot \text{mg}^{-1}$)

C_{max} = maximum metal ion adsorbed

The constants “ b ” and “ K_L ” can be obtained from linearized form of Langmuir equation (1). With the help of the slope and intercept of linear plot of C_{eq} / C_{ads} against C_{eq} , the Langmuir constants K_L and b can be calculated. Positive sorption results in the removal of solute from the bulk solution and the concentration at the surface of the solid in a solid liquid system. At equilibrium there is a defined distribution of the solute between the liquid and the solid phases, which can generally be expressed by

Table 4—Comparative results of pseudo-first order and pseudo-second order kinetic model for extracted cellulose and cellulose grafted acrylonitrile.

	Metal ion	Pseudo-first-order kinetic model			Experimental value	Pseudo-second-order kinetic model		
		qe (mg/g)	k ₁ (min ⁻¹)	R ²		qe (mg/g)	qe (mg/g)	k ₂ (g mg ⁻¹ min ⁻¹)
Extracted	Cu(II)	352.60	0.006347	0.9436	160	194.16	0.007468	0.9712
Cellulose	Ni(II)	460.61	0.004646	0.9332	144	373.32	0.005794	0.9618
Cellulose-g-	Cu(II)	555.97	0.004011	0.9843	168	118.88	0.004492	0.9903
acrylonitrile	Ni(II)	558.150	0.004153	0.9783	140	326.79	0.003568	0.9869

one or more isotherms³⁹. The isotherm of the sorption of copper and nickel ions by extracted cellulose and cellulose graft acrylonitrile copolymer was represented in the Fig.6(a), Fig.6(b), and Fig.7(a), Fig.7(b). The isotherm is characterized by the initial region, which is represented as being concave to the concentration axis. The isotherm is beginning to reach a plateau, which can typically be described by the Langmuir isotherm⁴⁰.

The data derived from the adsorption of Cu (II) and Ni (II) ions by cellulose and cellulose graft acrylonitrile copolymer adsorbent over the entire concentration range studies was described by Langmuir equation. A plot of C_{eq}/C_{ads} vs. C_{eq} yielded a straight line [see Fig. 6(a), Fig. 6(b) and Fig. 7(a), Fig. 7(b)] confirming the applicability of the Langmuir adsorption isotherm. The calculated results of the Langmuir isotherm constants and C_{max} are given in Table 5.

From the above results it was obtained that the adsorption of Cu (II) and Ni (II) onto extracted cellulose and cellulose g acrylonitrile copolymer correlates with the Langmuir equation. The essential features of the above equation can be expressed in terms of the dimensionless parameter R_L . A dimensionless constant separation factor or equilibrium parameter, R_L is used to predict whether the adsorption system is "favourable" or "unfavourable"⁴¹. The separation factor, R_L is defined by:

$$R_L = 1 / (1 + bC_f) \quad \dots (3)$$

where C_f is the final Cu (II) and Ni (II) concentration (mg/dm³) and b is the Langmuir adsorption equilibrium constant (dm³/mg). When the observed R_L values are in the range of $0 < R_L < 1$, then the extracted cellulose and cellulose grafted g acrylonitrile copolymer was found to be the favourable adsorbent. The values of R_L were calculated for different initial Cu (II) and Ni (II) concentrations. Since the calculated R_L values are obtained in the range of $0 < R_L < 1$, it was concluded that the adsorption of Cu (II) and Ni(II) onto extracted

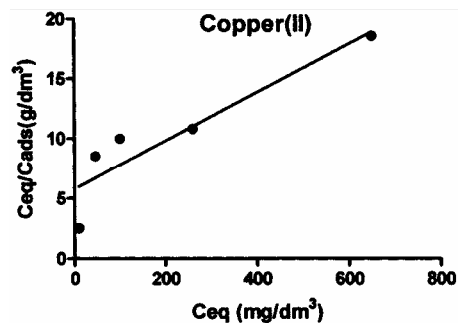


Fig. 6— (a) Langmuir isotherm plot of Cu(II) for extracted cellulose.

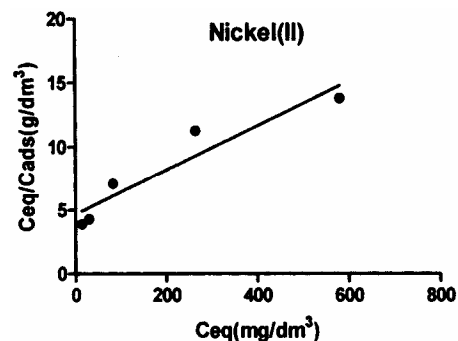


Fig. 6— (b) Shows Langmuir isotherm plot of Ni(II) for extracted cellulose

cellulose and cellulose grafted acrylonitrile copolymer is favourable.

One of the most frequently used isotherm for the determination of adsorption parameters was the Freundlich isotherm which was presented by Herbert Freundlich in the year 1906⁴². The widely used empirical Freundlich equation based on a heterogeneous surface was given by

$$\log q_e = \log K_F + 1/n \log C_e$$

where K_F and n are constants incorporating all factors affecting the adsorption process such as adsorption capacity and intensity of adsorption. A plot of $\log q_e$ versus $\log C_e$ gives a straight line of slope $(1/n)$ and an intercept of $\log K_F$. With the help of slope and intercept the Freundlich constants K_F and n

are calculated. The linear regression plot of Freundlich isotherm for Cu(II) and Ni(II) uptake by extracted cellulose and cellulose graft acrylonitrile copolymer was shown in the Fig. 8(a), Fig. 8(b) and Fig. 9(a), Fig. 9(b). The calculated results of the Freundlich adsorption isotherm constants are represented in Table 5.

From the comparison of the obtained R^2 values it was concluded that the Freundlich model better describes the adsorption process very effectively when compared to the Langmuir model for both extracted cellulose and cellulose-grafted acrylonitrile which was shown in Table 5.

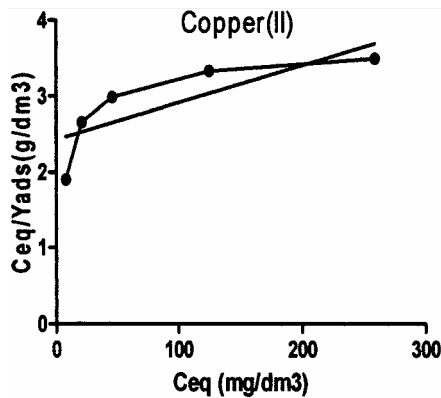


Fig. 7— (a) Langmuir isotherm plot of Cu(II) for cellulose grafted acrylonitrile

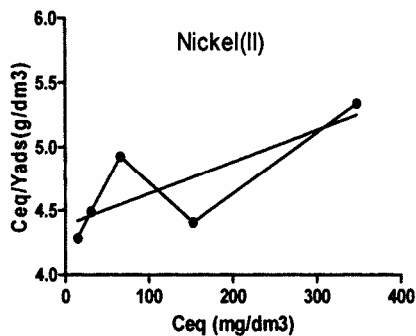


Fig. 7— (b) Langmuir isotherm plot of Ni(II) for cellulose grafted acrylonitrile

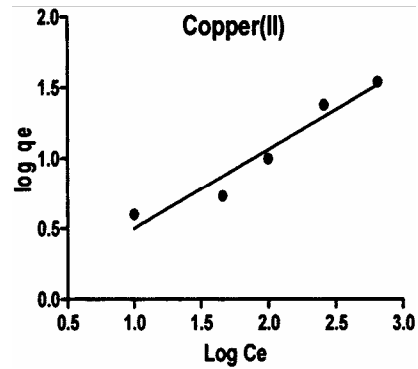


Fig. 8— (a) Freundlich isotherm plot of Cu(II) for extracted cellulose.

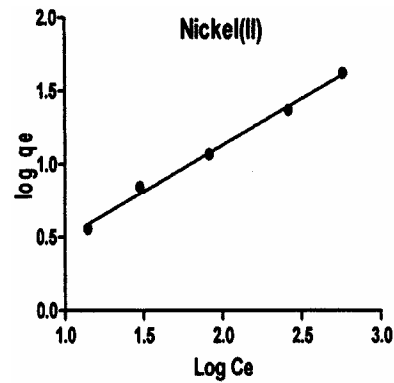


Fig. 8— (b) Freundlich isotherm plot of Ni (II) for extracted cellulose.

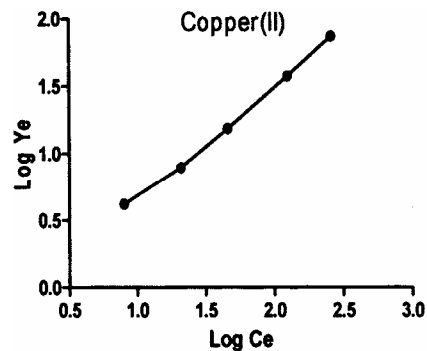


Fig. 9— (a) Freundlich isotherm plot of Cu(II) for cellulose grafted acrylonitrile.

Table 5—Comparison of Langmuir and Freundlich isotherm parameters for extracted cellulose and cellulose-grafted-acrylonitrile

	Metal ion	Langmuir constants				Freundlich constants		
		K_L (dm^3/g)	B (dm^3/mg)	C_{max} (mg/g)	R^2	K_F (dm^3/g)	n (dm^3/mg)	R^2
Extracted cellulose	Cu(II)	5.779	0.02020	286.09	0.8462	0.8687	1.7775	0.9365
	Ni(II)	4.690	0.01739	269.69	0.8984	0.7251	1.5790	0.9942
Cellulose-g-acrylonitrile	Cu(II)	2.428	0.004873	498.26	0.6426	0.6758	1.1992	0.9956
	Ni(II)	4.386	0.002478	1769.98	0.6088	0.2679	1.0560	0.9973

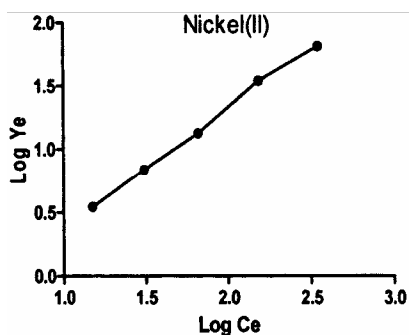


Fig. 9— (b) Freundlich isotherm plot of Ni(II) for Cellulose grafted acrylonitrile

Conclusion

The cellulose is extracted from the sisal fiber using steam explosion technique and the extracted cellulose is grafted with the acrylonitrile monomer using ceric ammonium nitrate as an initiator. Comparative adsorption study has been carried out for both extracted cellulose and Cellulose grafted acrylonitrile. The results of the adsorption studies show that the adsorbent dose, contact time, and pH had a marked effect on the removal of Cu (II) ions and nickel (II) ions from metal solution using cellulose and cellulose grafted with acrylonitrile. The results of kinetic studies reveal that the adsorption of Cu^{2+} and Ni^{2+} is very rapid in the initial stage and decreases while approaching equilibrium. Experimental results are in good agreement with Freundlich adsorption isotherm models, which have shown a good fitting to the experimental data for both extracted cellulose and cellulose grafted acrylonitrile. Adsorption of Cu^{2+} and Ni^{2+} obeys pseudo-second order equation with good correlation for both extracted cellulose and cellulose grafted acrylonitrile. From the observed results it is concluded that the cellulose-g-acrylonitrile copolymer is found to be an effective adsorbent for the removal of copper (II) and nickel (II) from aqueous solutions than the cellulose extracted from the sisal fiber itself. Hence the cellulose grafted acrylonitrile copolymer can be used for waste water treatment at industrial level.

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