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Al-Quds University



**Removal of Chromium (VI) from water using a
modified natural fiber as an adsorbent**

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modified natural fiber as an adsorbent**

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Deanship of Graduate Studies

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Thesis Approval

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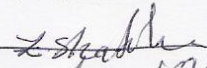
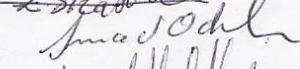
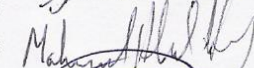

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Dedication

This thesis is dedicated to my parents who sacrificed a lot for me to be what I am now.

A special dedication also goes out to my sisters and my brothers.

Also, to my mother in law, my sisters in law and my brothers in law.

Also, I would like to dedicate my thesis to my husband, Musab, for his love, motivation
and inspiration.

Declaration

I certify that this thesis submitted for the degree of master is the result of my own research, except where otherwise acknowledged, and that this thesis (or any part of the same) has not be submitted for a higher degree to any other university or institution.

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Abstract:

In this work, natural fiber was chemically modified by an oxidation reaction to produce a dialdehyde functionality which was then aminated with tris (2-aminoethyl) amine. The produced fiber was used as an adsorbent to remove Cr (VI) from water. Changes in the Aldehyde content of the fiber was evidenced by FT-IR spectroscopy and the aminated derivative was also characterized by FT-IR spectroscopy. The modified fiber was then evaluated for its capacity to remove Cr(VI). The influence of pH, contact time, adsorbent dosage and initial Cr(VI) concentration on the adsorption process was investigated. FT-IR analysis was performed on the adsorbent before and after Cr(VI) binding. Maximum adsorption of Cr(VI) was achieved in acidic medium and after contact time of 10 minutes with 5g/L adsorbent dosage. The percentage of Cr(VI) removal decreased from 100% to 72.8% when the initial concentration was increased from 10 to 1000 ppm at pH=2 and 25°C as determined by UV-Vis spectroscopy. Also, a non modified natural fiber was evaluated for its capacity to remove Cr(VI) in order to compare it with the capacity of modified natural fiber. The adsorption of Cr(VI) on both modified and non modified natural fiber was evaluated using Langmuir and Freundlich isotherm models, the experimental data fit both Langmuir and Freundlich isotherm models with maximum adsorption capacity of 40 mg/g & 4.5mg/g and relative adsorption capacity of 3.5mg/g & 0.35mg/g for modified and non modified natural fiber, respectively. Total Chromium was determined using ICP-MS. FT-IR Spectra indicated the complexation of Cr(VI) with the adsorbent and the reduction of Cr(VI) to Cr(III) by the adsorbent after complexation. Desorption test indicated 83.4% removal of Cr(VI) from the adsorbent.

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Chapter One

Introduction

1. Introduction

Heavy metals play an important role in water pollution. The heavy metals are continuously released into the aquatic ecosystem from industrial processes like mining, ore processing, metal polishing, cleaning, paint manufacturing and battery manufacturing industries. These industries are producing large amounts of effluents, which are leading to detrimental effects on human life and environment, when it is discharged into water bodies. Moreover the heavy metals are not metabolized and they are bio accumulated into our body through the biological chain.[1]

The major pollutants in effluents are Mercury, Chromium, Arsenic, Lead, Zinc, Copper and Cadmium. Among them Chromium is one of the most toxic metals which causes serious health hazards to the environment. Chromium is the second most common heavy metal in organic contaminant in the ground water. Chromium has broad industrial applications, such as alloy industries, paper and pulp, basic steel works foundries petroleum refining industries, mining, dyes and pigment, textiles, leather, tanning and electroplating. [2]

Generally Chromium exists in two oxidation states they are Cr(VI) and Cr(III). Trivalent Chromium is an essential element in humans and is much less toxic than hexavalent chromium, it is required in trace amounts for sugar and lipid metabolism. Chromium (VI) is one such metal ion, which is a potent carcinogenic and mutagenic.[3]

Exposure to Cr(VI) can cause asthma, bronchitis, ulceration and perforation, liver and kidney damages.[4]

Cr(VI) is becoming the more toxic form of the metal due to its association with oxygen as chromate ions. It is a strong oxidizing agent and in the presence of organic matter, it is reduced to Cr(III) more rapidly in an acidic environment.

However, at high concentration, Cr(VI) may overcome the reducing capacity of the environment and thus, persists as pollutant, its concentration in industrial waste water ranges from 0.5ppm to 270 ppm.. [5]

It is necessary to remove such a toxic metal from our environment. There are various conventional methods available for the removal of toxic metals such as reverse osmosis, precipitation, chemical reduction etc. But these methods require high experimental set-up, and they are expensive and have low efficiency.

Recently, bio sorption is the most promising method for the removal of toxic metals which is of low cost, produces less secondary sludge, it is also more effective and eco friendly.

Bio sorption is important from two aspects : The elimination of poisonous metals and the recovery of precious elements.

Bio sorption is considered to be a fast physico-chemical method. [6]

Hundreds of works have been published in international journals devoted to Cr(VI) bio sorption.

V .Vinodhini et.al. investigated bio waste materials (Neem sawdust, Mango sawdust, Wheat shell, Sugar cane bagasse and Orange peel) to remove Cr(VI) from aqueous solutions. Neem sawdust was the most efficient one in removing Cr(VI). The influence of pH, contact time adsorbent dosage and initial concentration were investigated. The optimum pH in the adsorption process was 2 for all the bio sorbents. The adsorption capacity increased as the time and adsorbent dosage increased. The adsorption data fitted well with the Langmuir isotherm.[7]

J.A.S Ting et.al. enhanced the removal of Cr(VI) by using vacuum drying and plasma pre-treatments of sawdust. The influence of initial concentration and contact time were determined at fixed pH and adsorbent dosage. Results show that both pre-treatments increase the adsorption efficiency of the sawdust. Also, the data fitted well with Langmuir and Freundlich isotherm models. For an adsorbent dose of 2000 g/L adsorbate concentration of 5mg/L, contact time of 240 min and at pH =2, the percentage Cr(VI) removal for the plasma treatments (Oxygen, Hydrogen and Argon) and for the vacuum drying treatment are 81.2%, 73.5%, 66.4% and 58.7%, respectively. These results are higher compared to 33.9% for the untreated dust. It was found that oxygen plasma pre-treatment of saw dust is the most efficient treatment for the removal of Cr(VI).[8]

L.Gurgel et.al. studied the removal of Cr(VI) from aqueous solutions using succinylated mercerized cellulose. succinylated mercerized cellulose (cell 1) was used to synthesize an anion exchange resin. (cell 1) Containing carboxylic acid groups was reacted with triethylenetetraamine to introduce the amine functionality to this material to obtain (cell 2), (cell 2) was reacted with methyl iodide to quaternize the amine groups from this material to obtain (cell 3). (Cell 3) was used for the adsorption of Cr(VI). The optimum pH for the adsorption of Cr(VI) was 3.1 and the adsorption equilibrium time was 200 min. Also, the adsorption data fitted well with Langmuir isotherm model and kinetics studies showed that the rate of adsorption of Cr(VI) on (cell 3) obeyed a pseudo 2nd order kinetic model. [9]

P.Thamilarasu et.al. studied the removal of Cr(VI) by activated carbon prepared from cajanus cajan (L) Milsp seed shell. it was prepared by treating it with concentrated H₂SO₄ followed by heating for 5 hours at 500C. Batch adsorption experiments were carried out as a function of pH, contact time, initial concentration, adsorbent dosage and temperature. The data fitted well with the Freundlich isotherm. ΔH , ΔS and ΔG were calculated. The adsorption was spontaneous and endothermic [10].

P. Pandhram et.al. investigated Neem leaves as low cost adsorbent to remove Cr(VI) from industrial waste water. Effect of pH, contact time, adsorbent dosage and initial concentration on the adsorption process were studied. The maximum adsorption occurred at pH=4.1, after 100 min of agitation for a solution of initial concentration of 300ppm when using an adsorbent dose of 8g\100ml. Also, column adsorption system was studied. The data fitted well with Langmuir adsorption isotherm. It is revealed that the max removal efficiency is observed up to 85% for bio sorbent prepared from Neem leaves.[11]

M. Khamis et.al. investigated low cost abundant adsorbents(Wool, Olive cake, Sawdust, Pine needles, Almond shells, Cactus leaves and Charcoal) to remove chromium (VI) from waste water. The influence of pH, contact time, metal concentration, adsorbent nature and concentration on adsorption process was investigated. The adsorption process was found to follow first order rate mechanism. The data fitted well with both Langmuir and Freundlich isotherm models. The thermodynamic equilibrium constant and the Gibbs free energy were calculated for each system. ΔG for the adsorption by wool = -2.26 kJ \mol supported the findings that wool was the best among the selected adsorbents for the selective removal of Cr(VI) at pH =2 and an adsorbent concentration of 16g\L at 30C. for which the removal was 81% out of 100 ppm after 2hrs of stirring. [12]

H. Krishna et.al. investigated powder of Papaya seeds for the removal of hexavalent Cr from the aqueous solutions. The influence of pH, contact time, initial concentration, adsorbent dosage and the particle size of adsorbent was investigated. The optimum results were determined at an initial concentration of 10ppm, pH=2, agitation time =60min, an adsorbent dose of 150mg/50ml and the particle size (0.6mm). The data fitted well with both Langmuir and Freundlich isotherm models and the data were fitted to pseudo first order model. [13]

M. Nameni et.al. studied the removal of Cr (VI) from aqueous solutions using Wheat bran. The influence of pH, contact time, adsorbent dose and Cr(VI) initial concentration was investigated. The results showed that adsorption of Cr reached equilibrium after 60min, higher adsorption was observed at lower pHs, and the max removal (87.8 %) obtained at pH=2. The adsorption decreased at the higher initial concentration and lower adsorbent doses. The data fitted well with Langmuir isotherm model and the kinetics of the adsorption process follows the pseudo 2nd order kinetics model. [14]

P. Dave et.al. studied the removal of Cr (VI) from aqueous solutions using tea waste and Coconut husk. The effect of contact time, adsorbent dosage, pH and initial metal ions concentration has been investigated. The percentage removal of Cr(VI) increased with the increase of contact time and adsorbent dosage. Adsorption of Cr(VI) showed maximum adsorption capacity of 34.25mg/g and 21.59mg/g with tea waste and coconut husk, respectively at pH =2. The removal of Cr(VI) increases with the increase of adsorbent dosage, the optimum dosage was found 8mg/L. The data fitted well with Langmuir and Freundlich isotherm models. [15]

A.Y Talokar et.al. investigated the removal of Cr(VI) from waste water using low cost adsorbents (Fly ash powder, Bagasse, W.straw, SD and Coconut coir) and compare with PAC. The efficiency of each one was investigated and it was found that the order of removal efficiency was (PAC > Bagasse > FA > SD > WSD > coconut coir). The effect of Cr(VI) solution pH, contact time, adsorbent dosage, initial concentration and adsorbent mesh size on adsorption were studied. The data fitted well with Langmuir and Freundlich isotherm models and the maximum adsorption capacity for each adsorbent was estimated.[16]

In this work, Natural fiber was chemically modified to be used as an adsorbent to remove Cr(VI).

Natural fiber (luffa sponge) is a ligno cellulose material composed mainly of cellulose, hemicelluloses and lignin. The fiber are composed of 60% cellulose, 30% hemicellulose and 10% lignin [17]. It has large surface area for adsorption. Cellulose structure has a large amount of reactive hydroxyl groups that can be modified.

Many studies have been published in international journals devoted to biosorption using natural fiber.

P. Soueprasearsit et.al. investigated the adsorption ability of luffa fiber and modified luffa fiber for adsorption of lead. The influence of pH, contact time, temperature, adsorbent size, adsorbent dose... etc. has been studied. The adsorption isotherm and desorption ability were examined. The results indicated that the suitable condition for adsorption of lead was pH=4, contact time 30min, temperature 40C, adsorbent size 250-600mm, agitation speed 250 rpm, adsorbent dose 10 g/L and initial concentration of 25ppm. The adsorbent data fitted well by Langmuir isotherm. [18]

H. Demir et.al. used luffa fibers as adsorbent to remove methylene blue dye from aqueous solutions. Thermodynamics and kinetics of adsorption were investigated. The data fitted well with the Langmuir isotherm model. Thermodynamic parameters of methylene blue adsorption indicated that the adsorption is exothermic and spontaneous.[19]

A. Altinisik et.al. investigated luffa for the removal of malachite green from aqueous solutions. The effect of contact time, pH and temperature was investigated. By the time pH was increased from 3-5, the amount of sorbed malachite green increased. The data fitted well with Langmuir isotherm model. Mono layer sorption capacity increased with temperature. It was found that the sorption follows pseudo second order kinetic model. The sorption process is endothermic and spontaneous.[20]

In our work modified natural fiber was synthesized from natural fiber that was oxidized using sodium metaperiodate then the oxidized product was reacting with tris (2-amino ethyl) amine as shown in (figure 1.1).

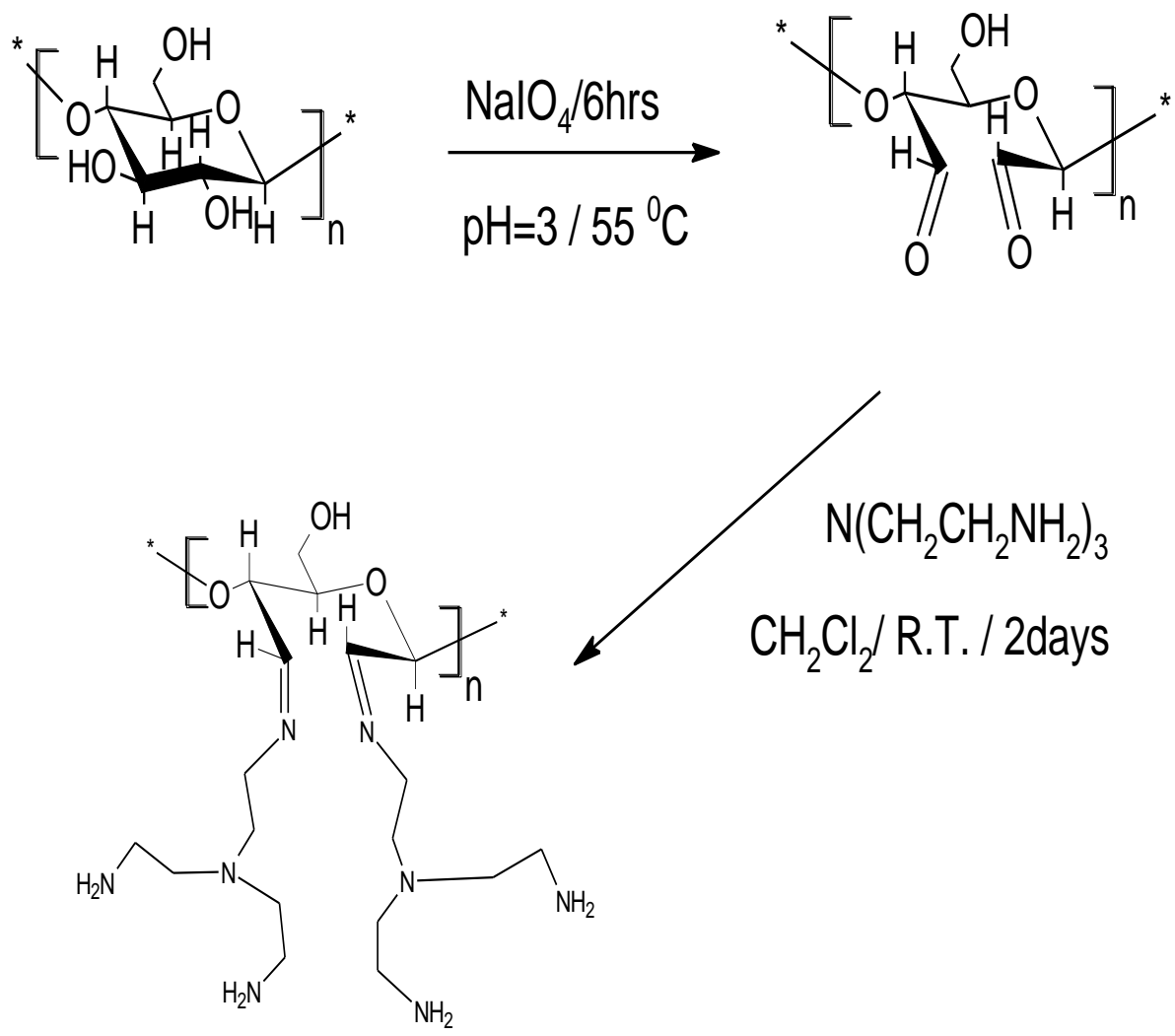


Figure 1.1: Synthesis of the modified natural fiber.

Chapter Two

Proposed work

2. Proposed work.

A modified natural fiber was synthesized from natural fiber using a two step reaction sequence. First bond cleavage to produce dialdehyde. Then, Condensation with tris(2-aminoethyl) amine.

The resulting fiber was characterized by FT-IR and then used to remove Cr(VI) from aqueous solutions.

The effect of pH, contact time, adsorbent dosage and initial Cr(VI) concentration was evaluated.

A comparison between the adsorption capacity of modified fiber and that of non modified fiber for the removal of Cr(VI) was performed.

The mechanism of removal was demonstrated.

FTIR analysis was carried out on the adsorbent metal complex to study the adsorbent's surface before and after metal binding.

Regeneration of the adsorbent was achieved.

Chapter Three

Experimental

3. Experimental

3.1 Reagents

Natural fiber was obtained from a local market. Hydrochloric Acid, Sodium meta periodate, methylene Chloride, tris(2-aminoethyl)amine, 1,5-diphenyl carbazide, Potassium dichromate, Super pure nitric acid, Phosphoric acid, Sodium Hydroxide and Potassium chloride were of analytical grade and were purchased from Sigma-Aldrich. All solutions were prepared in deionized distilled water.

3.2 Instrumentation

The concentration of Cr(VI) was determined colorimetrically by using a Perkin – Elmer Lambda 5 UV- Visible Spectrophotometer, the concentration of Total Chromium was determined using Inductively Coupled Plasma mass Spectrometer ICP-MS (Agilent Technologies 7500 series), IR-Spectra were obtained by a Fourier Transform Infrared Spectrophotometer (Testscan Shimadzu FT-IR 8000 series), microscopic images were obtained by a dissecting microscope (Leica, Germany) and the pH measurements were recorded on a Jenway pH meter (3310) with a combination glass electrode and a tolerance of ± 0.1 pH units).

3.3 Procedure

3.3.1 Synthesis of the modified natural fiber

A sample of natural fiber (20 g) was first washed with 800ml of 0.1 M Hydrochloric acid then washed with distilled water several times and allowed to dry for 48 hours at room temperature.

Sodium meta periodate solution of 0.2M was prepared by dissolving each 2.56g of it in 60 ml of distilled water. One gram of fiber was mixed with 60 ml of 0.2 M of sodium metaperiodate solution according to the ratio 2:1 for Sodium metaperiodate and fiber, respectively. The reaction mixture was then stirred and heated to 55°C and the pH was adjusted to 3. The reaction was kept at 55°C for 6 hours, then the oxidized fiber was washed with distilled water several times and left to dry [21].

One gram of oxidized fiber was immersed in 0.3 ml of tris(2-aminoethyl) amine and 10 ml of methylene chloride, the reaction mixture was stirred for 2 days at room temperature. Then the modified fiber was washed with distilled water several times and left to dry [22].

3.3.2 Preparation of Cr(VI) solutions

Stock solution of 1000 ppm Cr(VI) was prepared by dissolving the appropriate amount of $K_2Cr_2O_7$ in de ionized distilled water. Solutions with different concentrations (5 - 900ppm) were prepared by dilute of appropriate volume from stock solution in de ionized distilled water.

3.3.3 Determination of Cr(VI)

Each of 0.1, 0.3, 0.5, 0.7, 0.9 and 1 ppm Cr(VI) solutions were prepared from 5 ppm Cr (VI) by the transfer of 1, 3, 5, 7, 9 and 10 ml respectively, to a 50 ml volumetric flask, 2 ml of Ligand (1,5-diphenyl carbazide) and 5ml of Phosphoric acid were added to each flask and the volume was made up to 50 ml using distilled water. Absorbance was read at 540 nm for each solution using UV-Visible Spectrophotometer and a Calibration curve was constructed.

3.3.4 Determination of Total Chromium

Multi-element standard solution Fluka (51844) was used to prepare 1, 5, 10, 20 and 40 ppb standard solutions. Standards were analyzed by ICP-MS and calibration curve was constructed.

3.3.5 Testing the adsorbent response to Cr (VI)

A 5 ml of 25 ppm Cr(VI) solution was used to determine the concentration of Cr(VI) ions in solution colorimetrically. Then 20 ml of 25 ppm Chromium were added to 0.3 g of adsorbent and stirred for 1 day. The pH was adjusted to 2 by using 0.1 M Hydrochloric acid. After 1 day the solution was filtered using Millipore filter and the concentration of Cr(VI) ions left in solution was determined colorimetrically.

3.3.6 Sample preparation for ICP-MS analysis

Each sample of 200 μ l was transferred to a 25 ml volumetric flask and 75 μ l of 10% Nitric acid were added, the volume was made up to 25 ml using milli Q water.

3.4 Adsorption Isotherms

3.4.1 Effect of pH

The adsorbent (0.5 g) was transferred to three Erlenmeyer flasks and 20 ml of 25 ppm Cr(VI) solution were added to each flask and the pH was adjusted to 2, 4 and 6, respectively. The solutions were stirred for two hours at 25°C, and then filtered. The concentration of Cr(VI) ions and Total Chromium was determined in the supernatant.

3.4.2 Effect of contact time

The adsorbent (0.5 g) was transferred to a 50 ml Erlenmeyer Flask and 20 ml of 25 ppm of Cr(VI) solution were added. The solution was allowed to stir at pH=2 and 25 °C. samples were taken at time intervals 10, 20 , 30, 60, 90 and 120 minutes. Each sample was filtered and the concentration of Cr(VI) ions and Total Chromium was determined.

3.4.3 Effect of adsorbent dosage

Five different samples (0.1, 0.3, 0.5, 1.0 , 1.5 g) of adsorbent were transferred to 50 ml Erlenmeyer Flasks and 20 ml of 25 ppm Cr(VI) solution were added to each flask. Solutions were left to stir for 2 hours at 25 C and the pH was adjusted to 2. Then the solutions were filtered and the concentration of Cr(VI) ions and Total Chromium was determined.

3.4.4 Effect of initial concentration

Different concentrations (10, 30, 60, 80, 100, 200, 300, 500, 700, 900, 1000 ppm) of Cr(VI) solutions were prepared. 20 ml of each solution was transferred to 50 ml Erlenmeyer Flasks and 0.5 g of adsorbent was added. The solutions were allowed to stir for 2 hours at 25 °C and pH=2. Then the solutions were filtered and the concentration of Cr(VI) ions and Total Chromium was determined.

3.4.5 Comparison between modified and non modified fiber

3.4.5.a Effect of initial Cr(VI) concentration using non modified natural fiber

Different concentrations (1, 10, 50, 100 ppm) of Cr(VI) solutions were prepared. 20 ml of each solution were transferred to 50 ml Erlenmeyer Flasks and 0.35 g of non modified natural fiber was added. The solutions were allowed to stir for 3 hours at 25 °C and pH=2. Then the solutions were filtered and the concentration of Cr(VI) ions and Total Chromium was determined.

3.4.5.b Effect of initial Cr(VI) concentration using modified natural fiber

Different concentrations (1, 10, 50, 100 ppm) of Cr(VI) solutions were prepared. 20 ml of each solution were transferred to 50 ml Erlenmeyer Flasks and 0.35 g of modified natural fiber was added. The solutions were allowed to stir for 3 hours at 25 °C and pH=2. Then the solutions were filtered and the concentration of Cr(VI) ions and Total Chromium was determined.

3.5 Regeneration of the adsorbent

A sample of modified natural fiber (1.5 g) was agitated with 20 ml of 25 ppm Cr(VI) solution for 2 hours at 25C, then the solution was filtered and the solid phase fiber-metal complex was left to dry for 48 hours. Then 1.5 g of fiber metal complex was agitated with 20 ml of 1M KCl for 2 hours at 25C. a sample was taken from the solution filtered and tested for the presence of Cr(VI) using the colorimetric method and ICP-MS [22].

Chapter four

Results and Discussion

4 Results and Discussion

4.4 Proposed mechanism of adsorption

Initially Cr(VI) was adsorbed on the modified natural fiber. Then a reduction of Cr(VI) to Cr(III) occurred by the adsorbent which was oxidized to adsorbent N-oxide. The Cr(III) was either released to the aqueous phase or adsorbed onto the adsorbent N-oxide depending on the availability of free sites. Upon addition of KCl to the adsorbent, desorption of Cr(III) took place and was determined by ICP-MS.

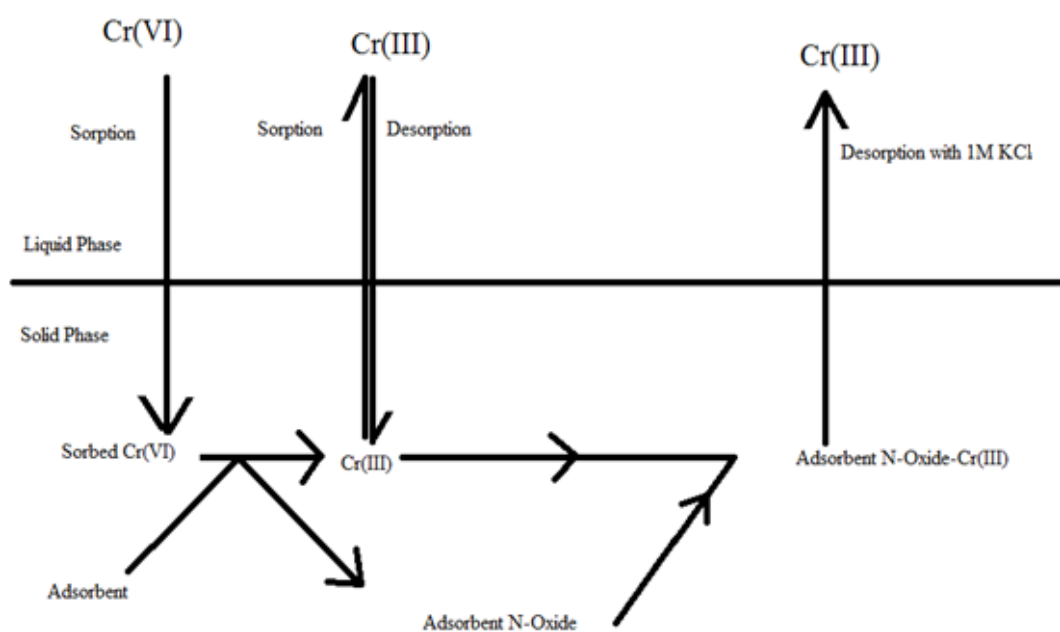


Figure 4.1: Proposed mechanism of adsorption of Cr(VI) by a modified natural fiber.

4.5 Study the changes in the structure of fiber during modification using FT-IR Spectroscopy.

The modified structure of natural fiber was prepared from natural fiber, sodium metaperiodate and tris(2-aminoethyl)amine. The modified natural fiber was analyzed by FT-IR Spectroscopy. Natural fiber showed characteristic band for the free carbonyl group at 1730 cm^{-1} [fig 4.2]. In the oxidized form of the fiber, it was observed that the intensity of this band increased [fig4.3]. After adding tris Amine it was observed that the peak of carbonyl group at 1730 cm^{-1} disappeared and a sharp peak at 1648 cm^{-1} appeared which was assigned to N-H [fig 4.4].

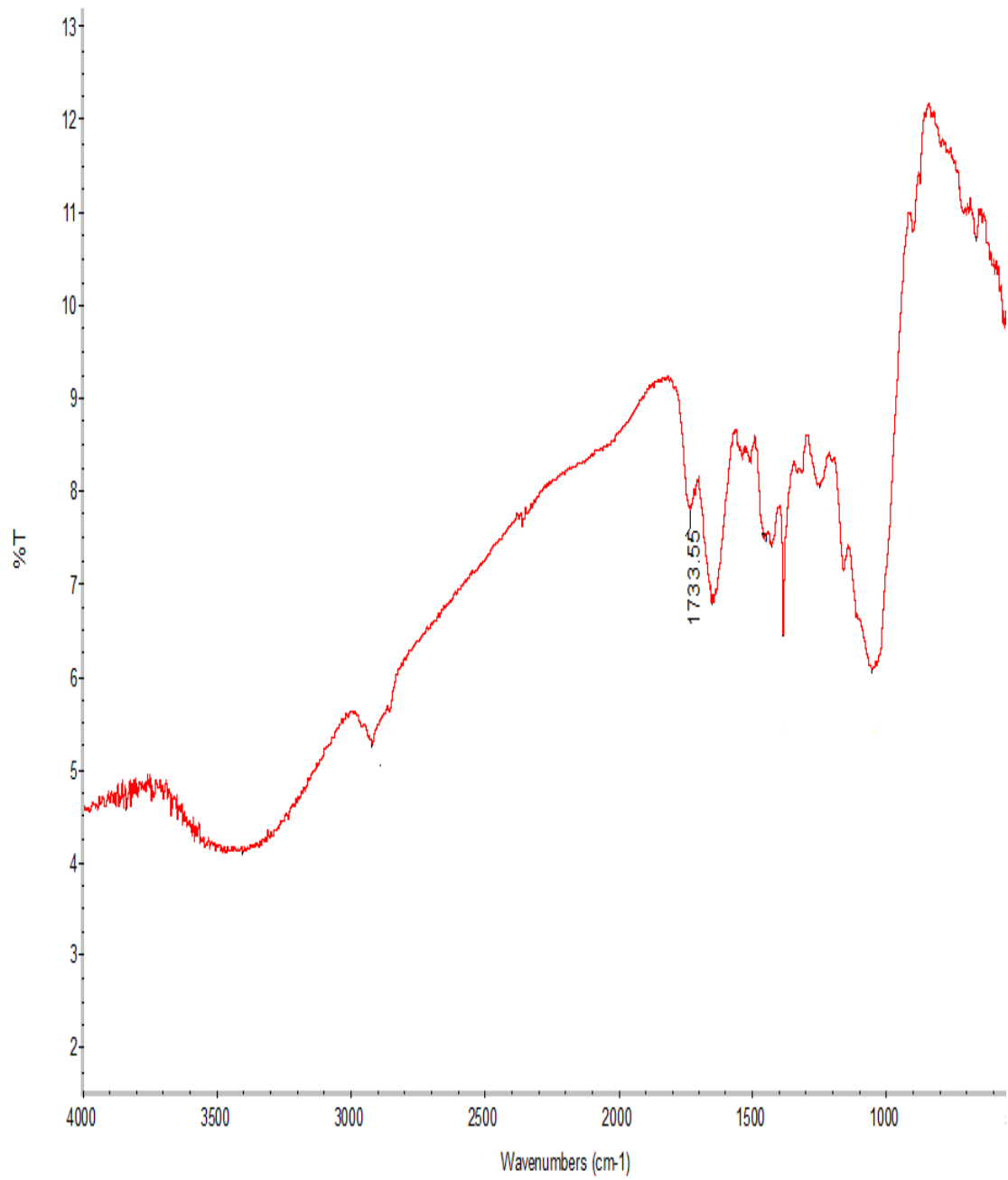


figure 4.2: FT-IR Spectrum of natural fiber.

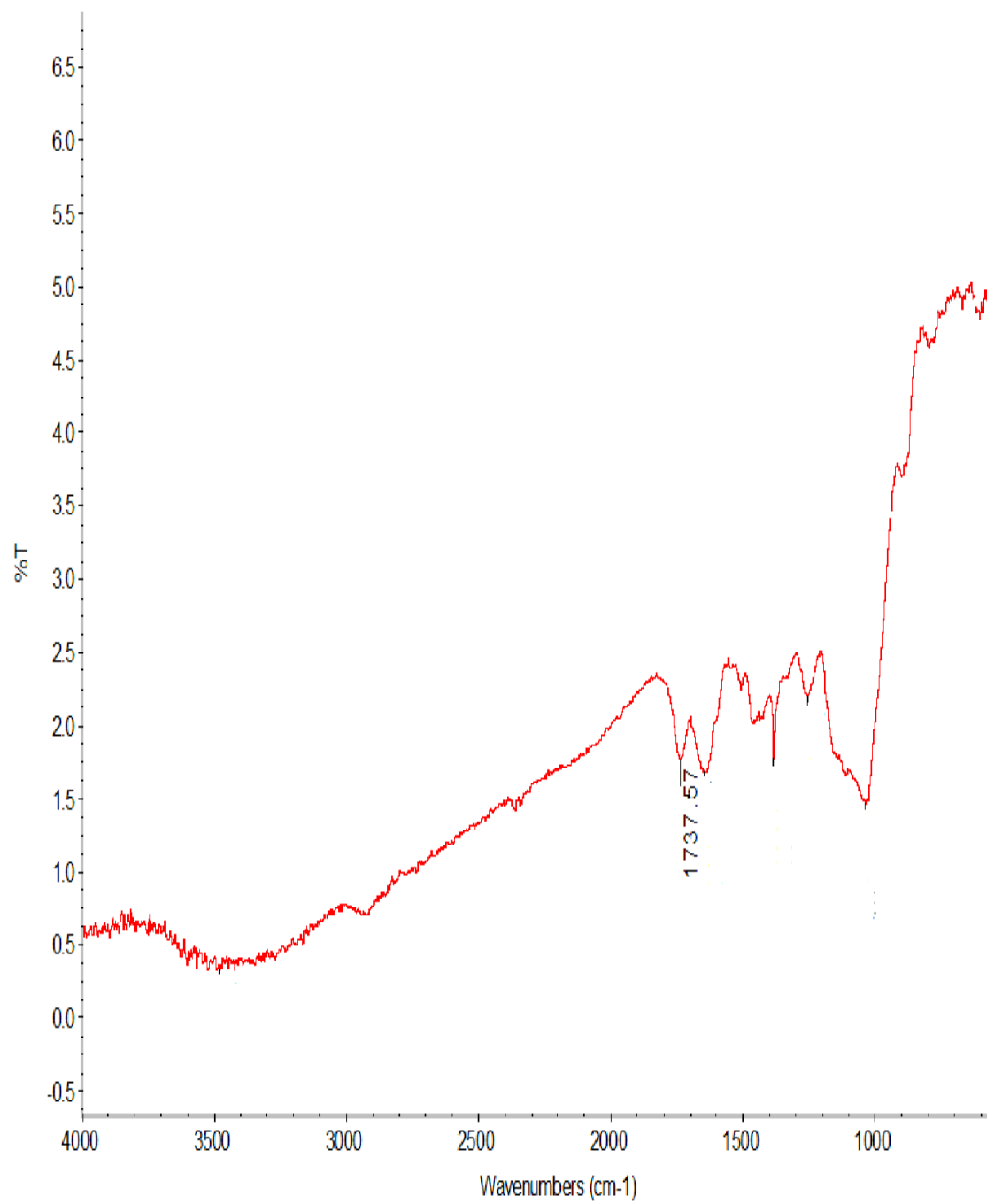


figure 4.3 : FT-IR Spectrum of oxidized natural fiber.

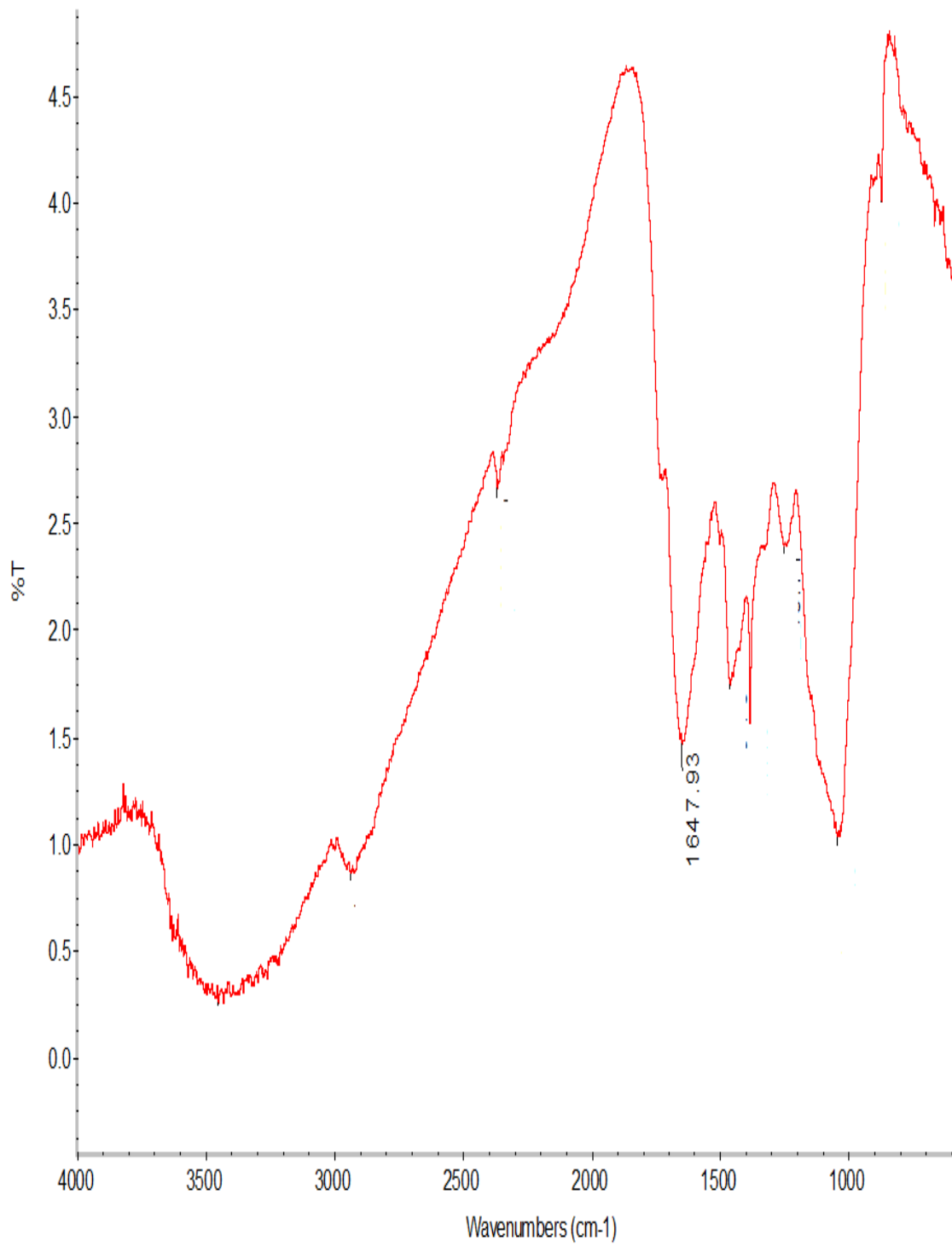


figure 4.4: FT-IR Spectrum of a modified natural fiber after adding a Tris Amine.

4.3.a Determination of Cr(VI)

Absorbance was measured for Cr(VI) solutions of different concentrations after adding the ligand (1,5-diphenyl carbazide) to each solution. The obtained values of absorbance were plotted against concentration of Cr(VI) (ppm) to construct a calibration curve [fig4.4 (a)]. The curve was linear and the correlation coefficient ($R^2 = 0.998$) which indicated a strong positive linear relationship between the parameters, the absorbance increased with the increase in Cr(VI) concentration. Concentrations of Cr(VI) were calculated by using the linear equation of the curve and the absorbance obtained by UV-Vis Spectrophotometer at $\lambda = 540\text{nm}$.

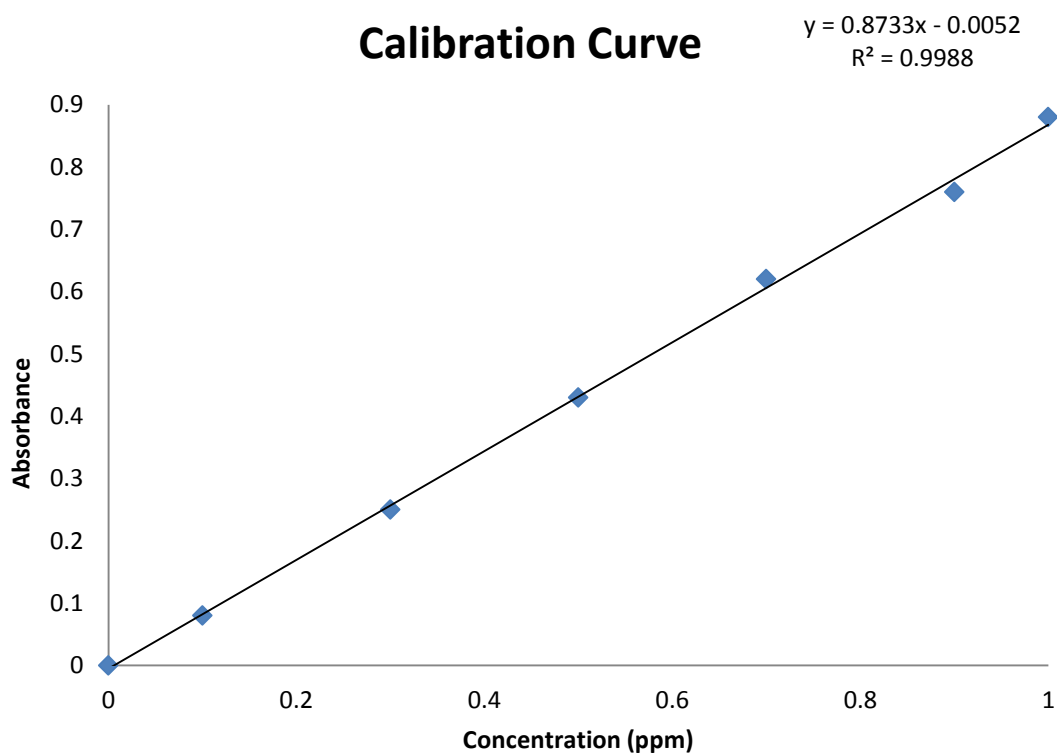


Figure 4.5: (a) Calibration curve for the determination of Cr(VI) at $\lambda = 540\text{nm}$.

4.3.b Determination of Total Chromium

Standard solutions were prepared from a multi-element standard solution obtained from Fluka and were analyzed by ICP-MS. A calibration curve was constructed [fig 4.4(b)] which was linear and with a correlation coefficient ($R^2 = 0.999$) which indicating a strong positive linear relationship between the parameters.

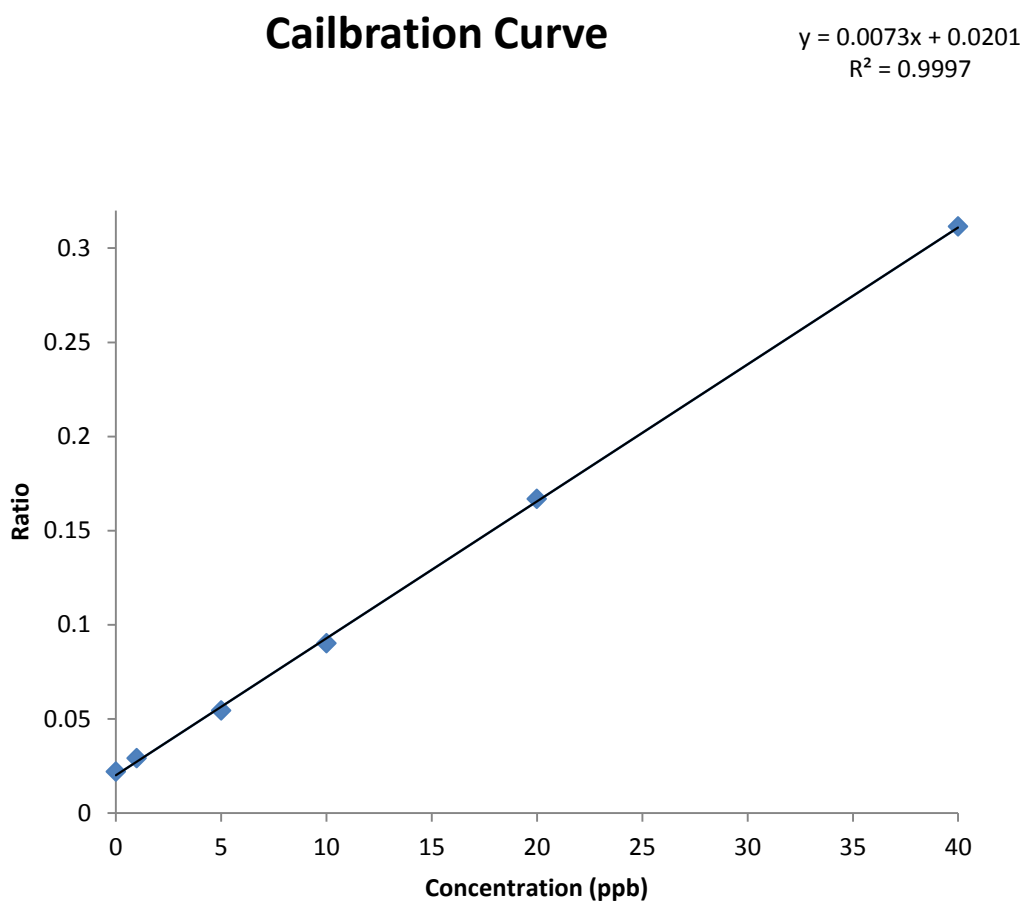


Figure 4.5: (b) Calibration curve obtained by ICP-MS.

4.4 Effect of pH

The adsorption process was performed at different values of pH in the range 2 – 6. The adsorbent achieved maximum retention capacity for Cr(VI) at the three selected pHs (2,4 and 6) where the percentage removal of Cr(VI) was 100% as determined by UV-Vis Spectroscopy [fig4.6].

Although the concentration of Cr(VI) remaining in solution after adsorption was zero as measured by UV-Vis Spectroscopy, but it was larger using ICP-MS [fig4.7]. This was due to the presence of Cr(III) which resulted from the reduction of Cr(VI) by the adsorbent. The concentration of Cr(III) was determined by the difference between the Total Cr obtained by ICP-MS and Cr(VI) obtained by UV-Vis Spectroscopy thus the concentration of Cr(III) is equal to total Chromium because the concentration of Cr(VI) is zero.

At pH=2 the concentration of Cr(III) present in solution was high ~ 14.5 ppm, then it decreased when the pH was raised. The large amount of available protons at pH=2 induced the reduction of Cr(VI) to Cr(III).

As the pH increased the amount of available protons decreased and so the reduction of Cr(VI) to Cr(III) decreased.

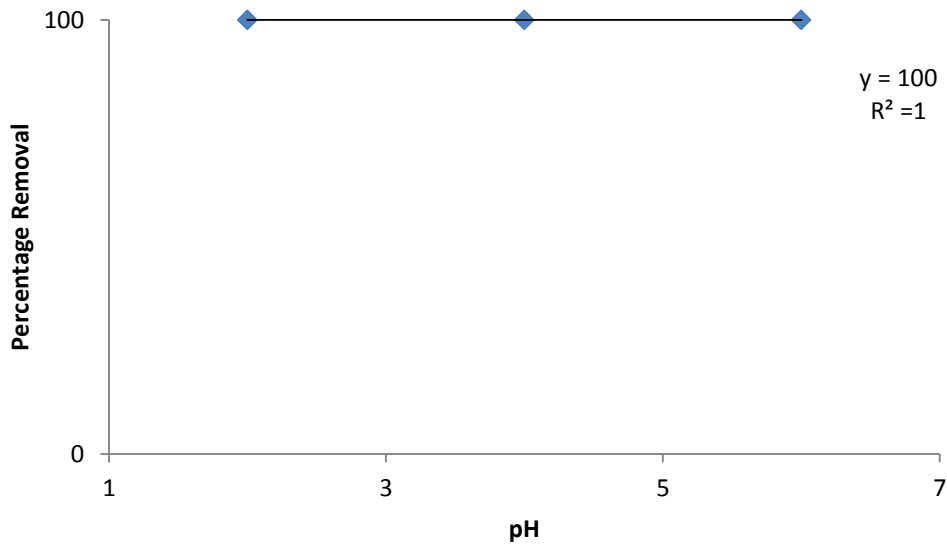


Figure 4.6: Percentage removal of Cr(VI) by adsorption on a modified natural fiber as a function of pH by UV-Vis Spectroscopy (T=25°C, contact time =2 hours, initial concentration =25 ppm and adsorbent dosage =25 g/ L).

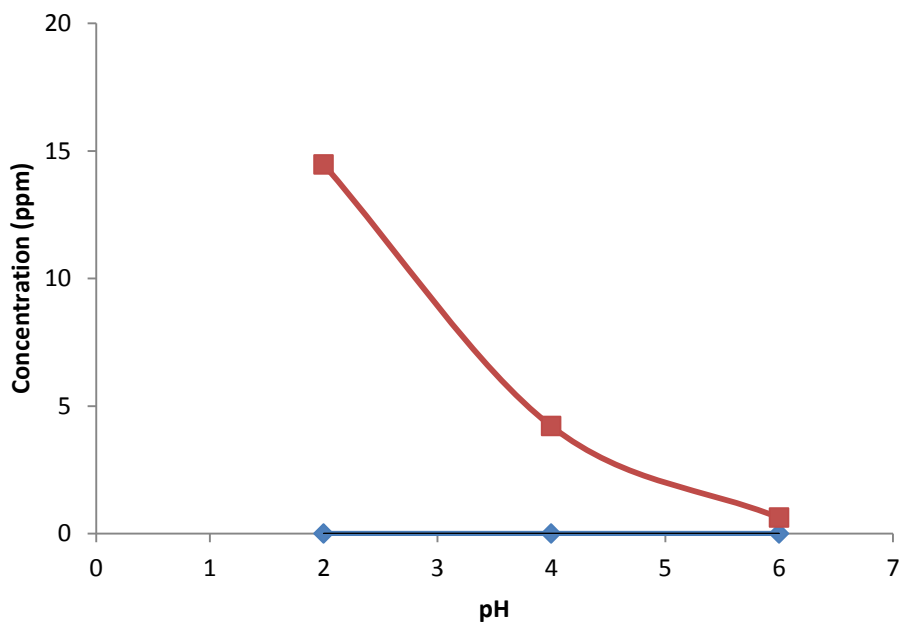


Figure 4.7: Concentration of Chromium remaining in the solution after adsorption on a modified natural fiber as a function of pH (T=25°C, contact time =2 hours and adsorbent dosage =25 g/ L). (blue points for Cr(VI) and red points for Total Chromium).

Two mechanisms appear to be involved in the removal of Cr(VI) by a modified natural fiber, removal by adsorption and removal by reduction. The removal by adsorption can be performed at any desired pH (2, 4 or 6) and this achieves 100% removal [Fig 4.6].

The removal by reduction must be done at pH=2 because at this pH the reduction is the highest [Fig 4.8].

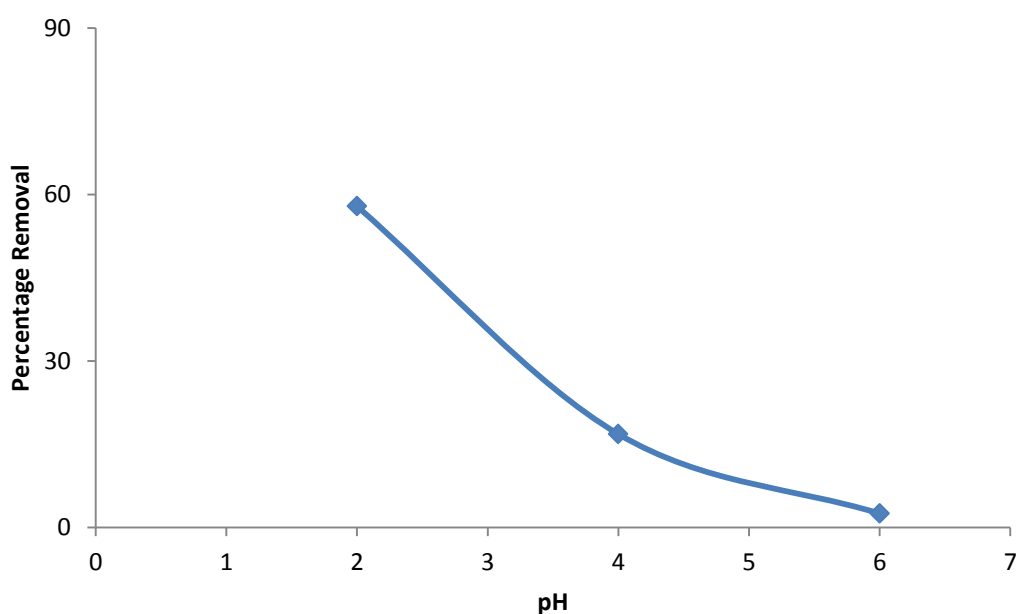


Figure 4.8: Percentage removal of Cr(VI) by reduction on a modified natural fiber as a function of pH by ICP-MS Spectroscopy (T=25°C, contact time =2 hours, initial concentration =25 ppm and adsorbent dosage =25 g/ L).

The basic medium was not found to be suitable as Cr(VI) is in an oxy-anionic form and gets repelled from the OH⁻ ions. These OH⁻ ions have more affinity towards the adsorbent thereby preventing oxy-anion Cr(VI) to get adsorbed onto it. Although reports say that Cr₂O₃ formation takes place at higher pH, finally allowing Cr(VI) to settle down, but the rate of formation is less than the desorption rate at basic medium [23].

4.5 Effect of contact time

The removal of Cr(VI) on a modified natural fiber with 25 g/L adsorbent dosage at different time intervals was studied.

Figures 4.9 & 4.10 show the removal of Cr(VI) by both adsorption and reduction as a function of contact time.

Results obtained from UV-Vis Spectroscopy showed that Cr(VI) was completely adsorbed and the percentage removal was equal 100% [fig 4.9].

The percentage removal increase sharply from $t=0$ to $t=10$ min, then reached a maximum value of 100%.

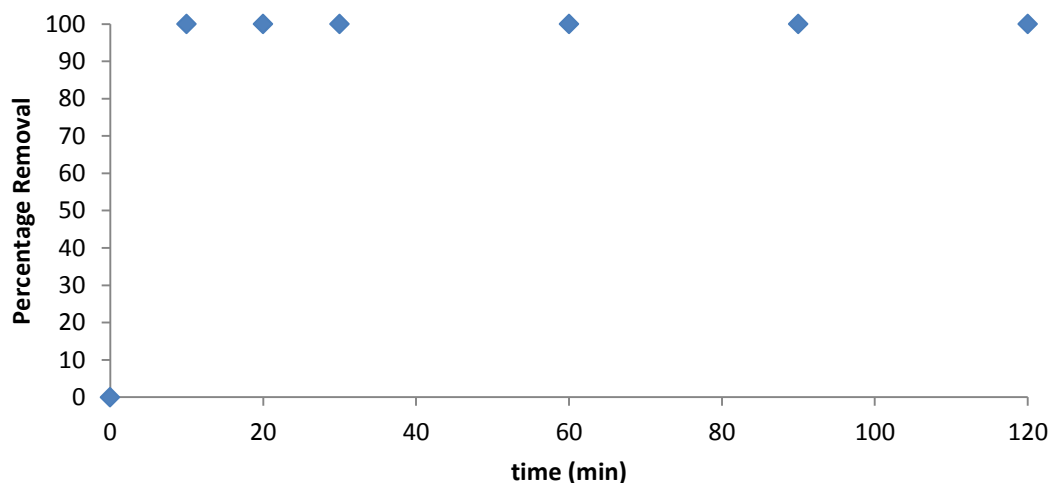


Figure 4.9: Percentage removal of Cr(VI) by adsorption on a modified natural fiber as a function of contact time by UV-Vis Spectroscopy ($T=25^{\circ}\text{C}$, initial concentration =25 ppm, adsorbent dosage =25 g/ L and $\text{pH}=2$).

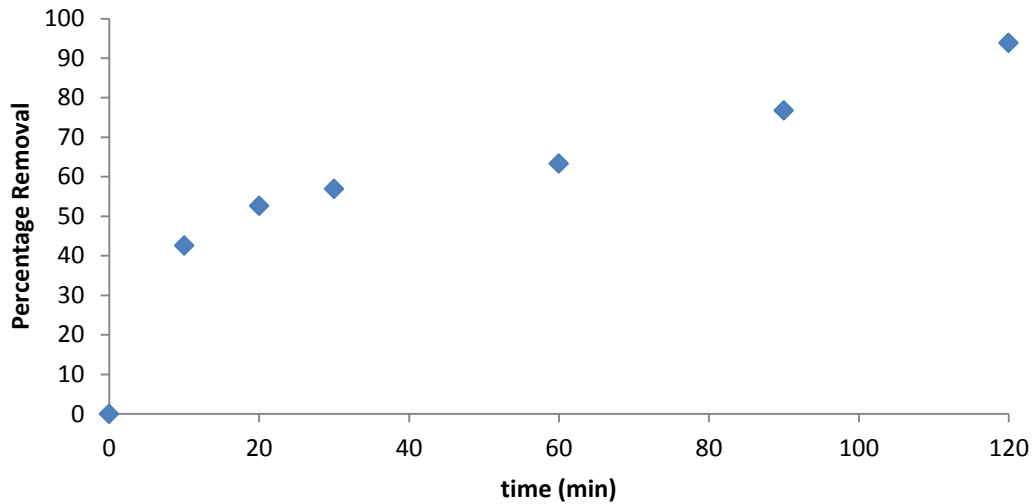


Figure 4.10: Percentage removal of Cr(VI) by reduction on a modified natural fiber as a function of contact time by ICP-MS Spectroscopy (T=25°C, initial concentration =25 ppm, adsorbent dosage =25 g/ L and pH=2).

The percentage removal of Cr(VI) by reduction increased with the increase of contact time and reached the maximum value of 94% after a contact time of 120 minutes.

The adsorbent reduced the bond Cr(VI) to Cr(III) and released it to the solution and with time the concentration of Cr(III) in the solution increase because the reduction process continued [fig 4.11]. The reduction is highest at 120 minutes.

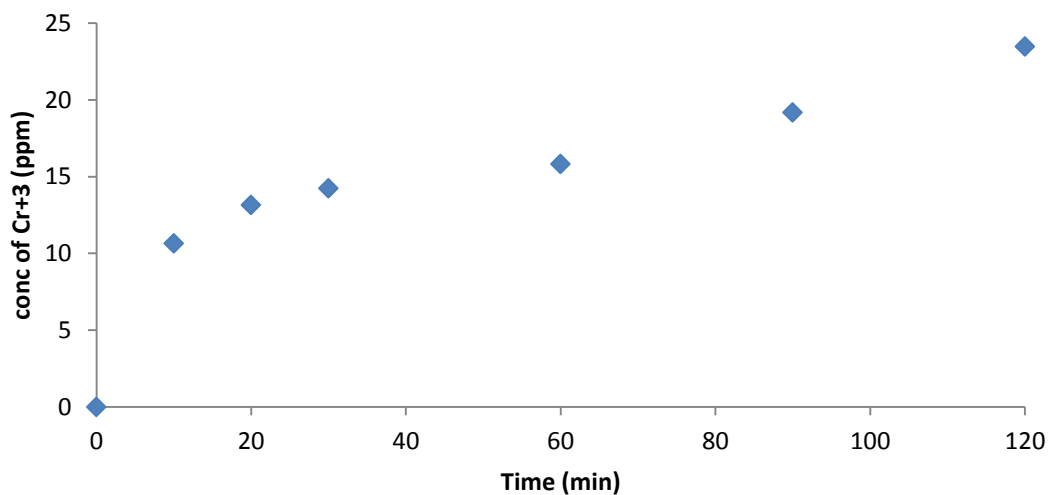


Figure 4.11: Concentration of Cr(III) found in the solution as a function of contact time with modified natural fiber by ICP-MS Spectroscopy (T=25°C, initial concentration =25 ppm, adsorbent dosage =25 g/ L and pH=2).

4.6 Effect of adsorbent dosage

The effect of adsorbent dosage on the removal of Cr(VI) is shown in fig 4.12, 4.13 and 4.14.

The amount of adsorbent ranged from 5 to 75 g/L and equilibrated for 120 minutes at an initial concentration of 25 ppm [fig4.12].

The percent removal of Cr(VI) by adsorption reached the maximum value of 100% at 5 g/L adsorbent dosage as determined by UV-Vis Spectroscopy.

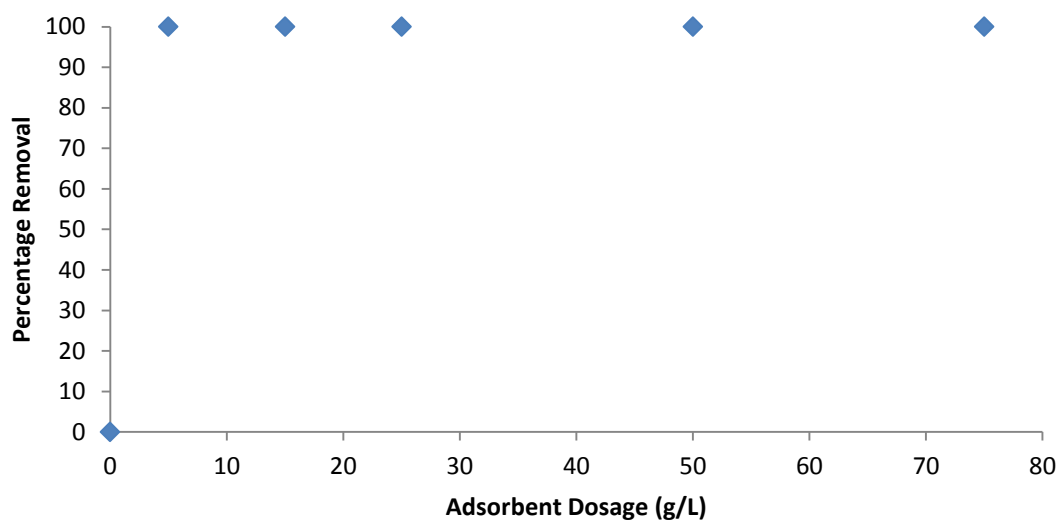


Figure 4.12: Percentage removal of Cr(VI) by adsorption on a modified natural fiber as a function of adsorbent dosage by UV-Vis Spectroscopy (T=25°C, initial concentration =25 ppm, contact time=2 hours and pH=2).

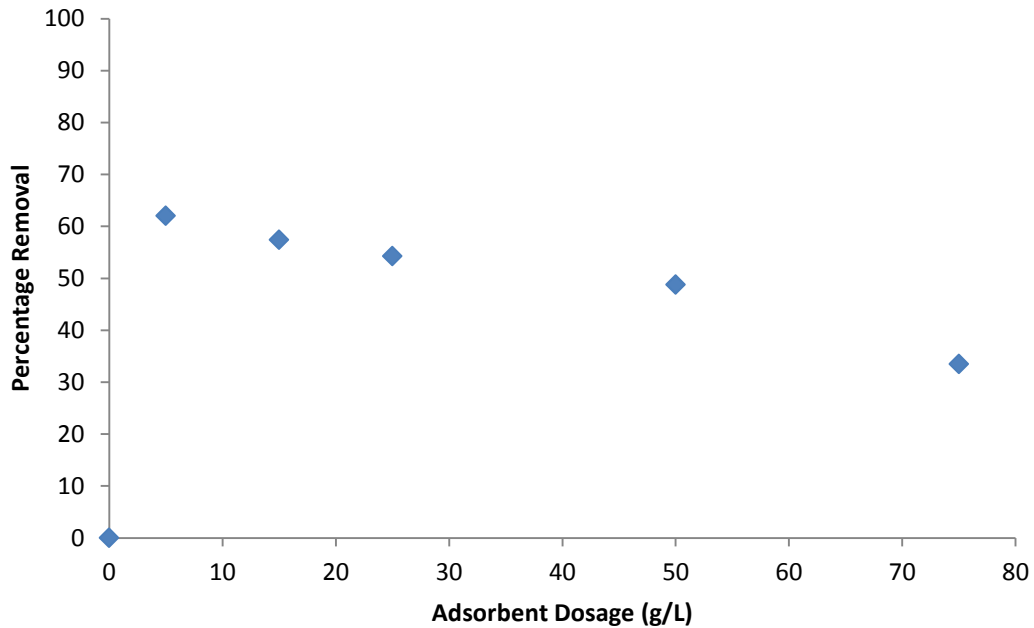


Figure 4.13: Percentage removal of Cr(VI) by reduction on a modified natural fiber as a function of adsorbent dosage by ICP-MS Spectroscopy (T=25°C, initial concentration =25 ppm, contact time= 2hours and pH=2).

The percent removal of Cr(VI) by reduction as determined by ICP-MS is shown in figure 4.13. It is obvious that at 5 g/L adsorbent dosage the percentage removal reached the maximum value of 62%.

The percent removal of total Chromium increased with the increase of adsorbent dosage as determined by ICP-MS [fig4.14]. This increase in removal is due to the availability of more adsorbent and so effectively a large surface area for adsorption.

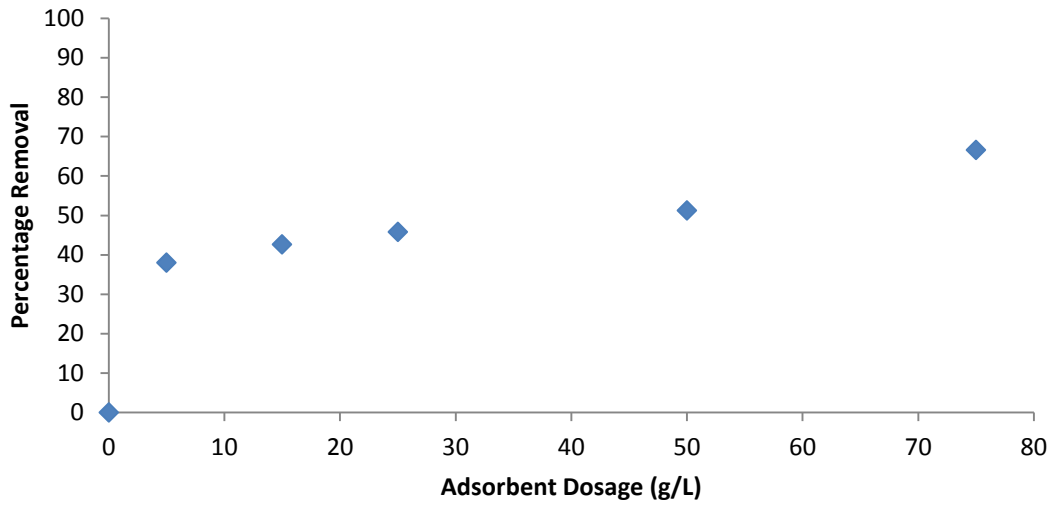


Figure 4.14: Percentage removal of Total Chromium on a modified natural fiber as a function of adsorbent dosage by ICP-MS Spectroscopy (T=25°C, initial concentration =25 ppm, contact time= 2hours and pH=2).

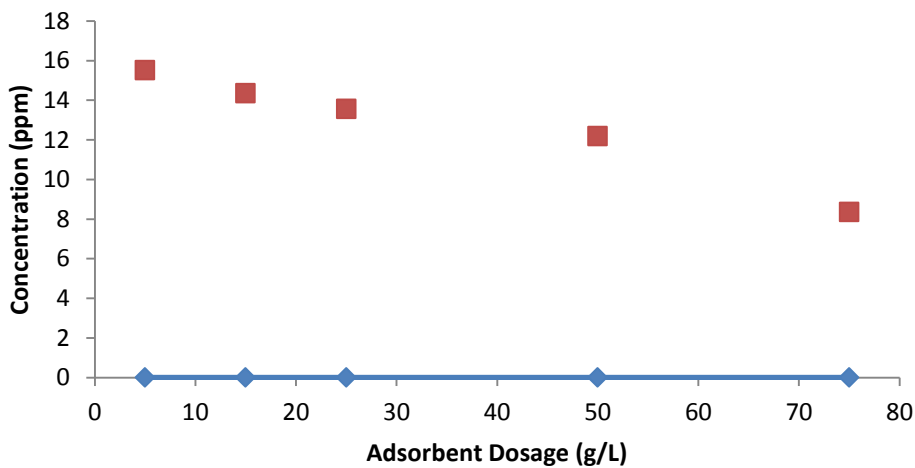


Figure 4.15: Concentration of Chromium remaining in the solution after adsorption on a modified natural fiber as a function of adsorbent dosage (T=25°C, contact time =2 hours and pH=2). (blue points for Cr(VI) and red points for Total Chromium).

The concentration of Chromium that remained in the solution after adsorption on the modified natural fiber as a function of adsorbent dosage at $T=25^{\circ}\text{C}$ and $\text{pH}=2$ with an initial concentration of 25 ppm is shown in figure 4.15.

The adsorbent reduced Cr(VI) to Cr(III) and released it to the solution.

Although the reduction of Cr(VI) increased with the increase of adsorbent dosage, the amount of Cr(III) found in the solution decreased due to the adsorption of Cr(III) on the adsorbent.

The optimum adsorbent dosage was 5 g/L.

4.7 Effect of initial Cr(VI) concentration

The initial concentration of Cr(VI) was varied from 10 to 1000 ppm and equilibrated for 2 hours at adsorbent dosage of 25 g/L [fig 4.16].

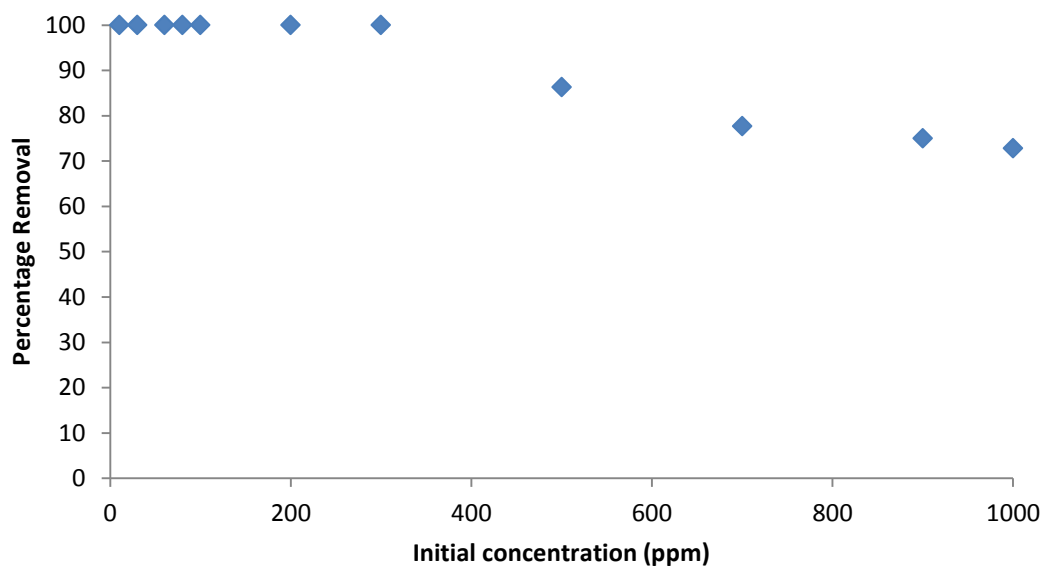


Figure 4.16: Percentage removal of Cr(VI) by adsorption on a modified natural fiber as a function of initial concentration by UV-Vis Spectroscopy ($T=25^{\circ}\text{C}$, adsorbent dosage of 25g/L, contact time=2 hours and $\text{pH}=2$).

The results indicated that the percent removal of Cr(VI) by adsorption decreased with the increase of initial concentration of Cr(VI).

The percentage removal was the highest and equalled 100% at an initial concentration range of [10-300] ppm. At this concentration range the ratio of Cr(VI) ions to the available surface area is small so the adsorption process is concentration independent but at concentrations above 300 ppm the percentage removal depends on the initial concentration since there are fewer sites for adsorption.

The initial concentration was varied from 10 to 80 ppm and equilibrated for 2 hours at adsorbent dosage of 25 g/L [fig 4.17].

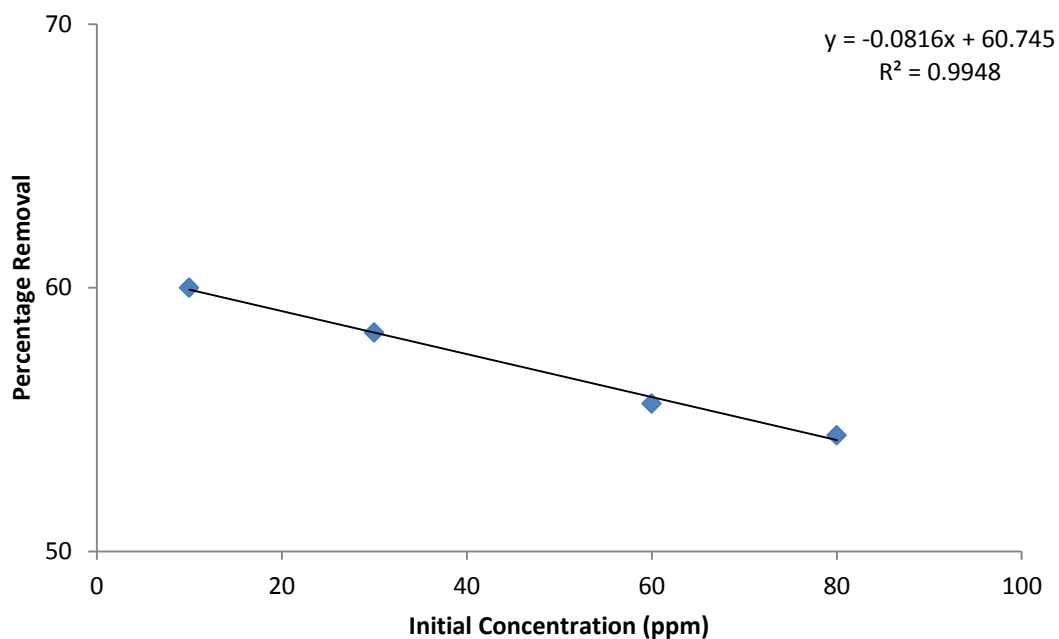


Figure 4.17: Percentage removal of Total Chromium on a modified natural fiber as a function of initial concentration by ICP-MS Spectroscopy (T=25°C, adsorbent dosage =25 g/l, contact time= 2hours and pH=2).

The results indicated that the percentage removal of Total Chromium decreased with the increase of initial concentration of Cr(VI).

Results obtained from ICP-MS indicated the availability of Cr(III) at all concentrations. The reduction appeared to play a bigger role in the removal process of Cr(VI) [fig 4.18].

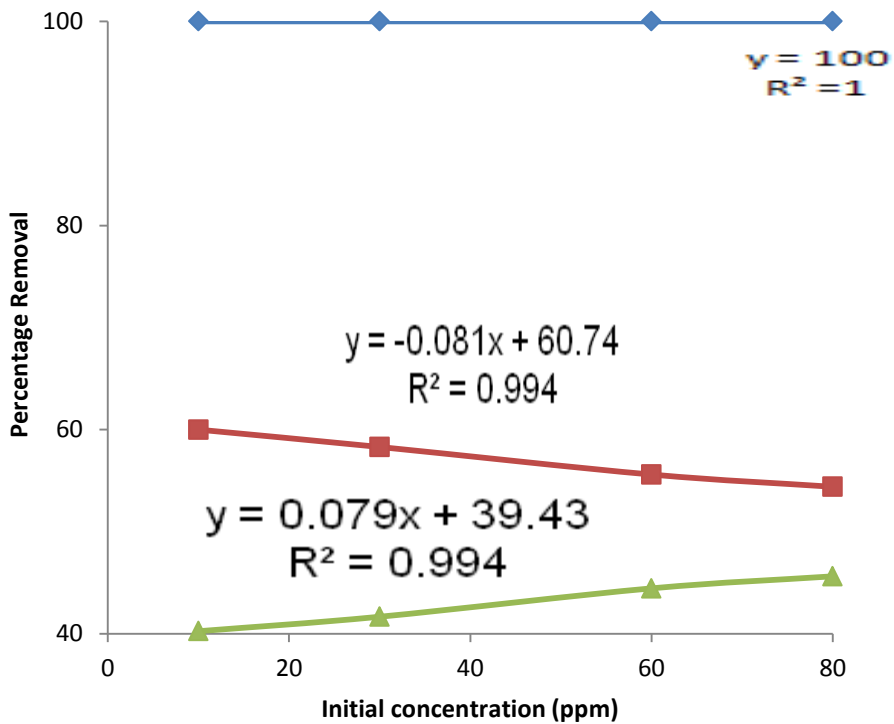


Figure 4.18: Percentage removal of Cr(VI) [by reduction and by adsorption] and Total Chromium on a modified natural fiber as a function of initial concentration (T=25°C, adsorbent dosage =25 g/l, contact time= 2hours and pH=2). (blue points % removal by adsorption, green points % removal by reduction and red points % removal of Total Chromium).

It was observed that the percentage removal of total Chromium decreased as the initial concentration increased, but the percentage removal of Cr(VI) equalled 100% at all concentrations in the figure above. This is the reason for using high concentrations in [fig 4.16] to see at which concentration the percentage removal will be decreased.

4.8 Comparison between modified and non modified natural fiber with respect to initial concentration of Cr(VI).

The initial concentrations were (1, 10, 50, 100 ppm) and equilibrated for three hours at adsorbent dosage of 17 g/L. First, the percent removal was determined using UV-Visible Spectroscopy and was then plotted against initial analyte concentration as shown in [fig 4.19].

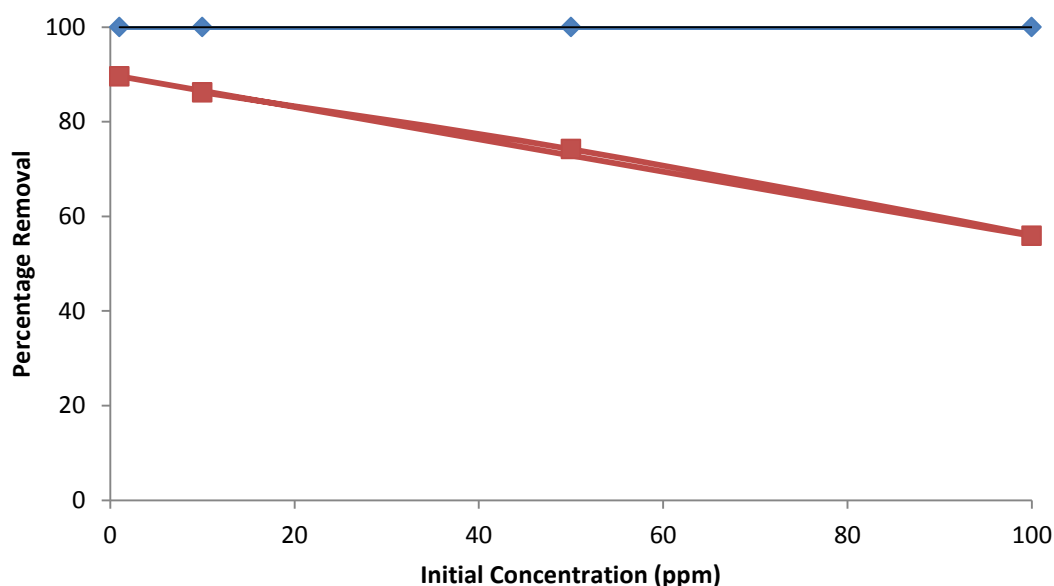


Figure 4.19: Percentage removal of Cr(VI) by adsorption on both modified and non modified natural fiber as a function of initial concentration by UV-Vis Spectroscopy (T=25°C, adsorbent dosage of 17g/L, contact time=3 hours and pH=2). (blue points for modified fiber and red points for non modified)

According to this figure, the percent removal of Cr(VI) using the modified fiber was 100% at all four initial concentrations of analyte. On the other hand the non modified fiber showed a 90% removal at an initial concentration of 1 ppm but then decreased with increasing initial concentration.

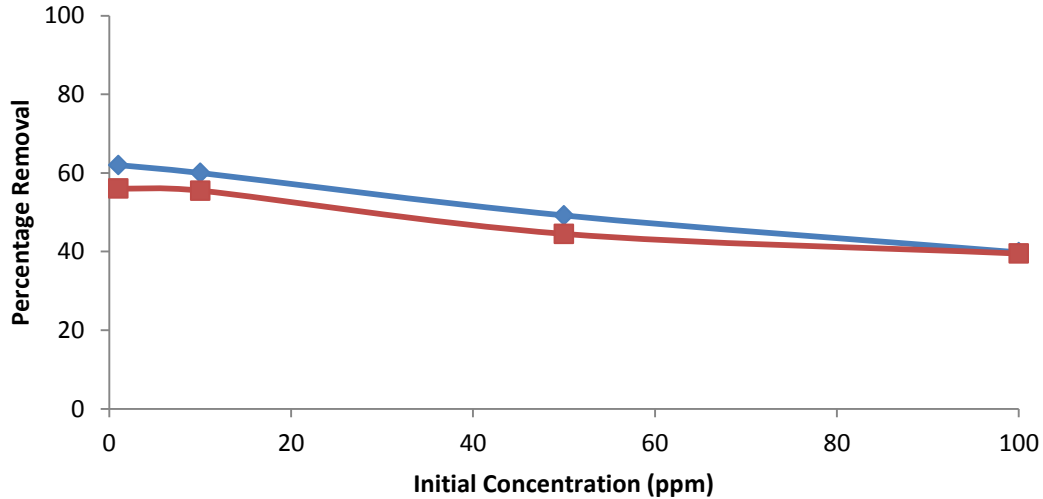


Figure 4.20: Percentage removal of Total Chromium on both modified and non modified natural fiber as a function of initial concentration by ICP-MS Spectroscopy (T=25°C, adsorbent dosage of 17g/L, contact time=3 hours and pH=2). (blue points for modified fiber and red points for non modified)

Secondly, the percent removal was determined using ICP-MS Spectroscopy. The results were plotted as shown in figure 4.20.

According to this figure, the percent removal of total Chromium using the modified fiber was higher than the percent removal when using non modified fiber at all four initial concentrations of analyte. The percent removal of total Chromium using both the modified fiber and the non modified fiber decreased with increasing the initial concentration.

It was observed that the modified natural fiber is better as an adsorbent than a non modified fiber, since a complete adsorption of Cr(VI) occurred on the modified fiber at high initial concentrations of Cr(VI) as shown in figure 4.16, but when using a non modified one there was no complete adsorption of Cr(VI) at very low concentrations of Cr(VI) as shown in figure 4.19.

4.9 Regeneration of the adsorbent

The adsorbent – Cr(VI) complex was stirred with 1M KCl for two hours. The concentration of Cr(VI) desorbed into KCl solution was determined using the colorimetric method. The concentration of Cr(VI) in the KCl solution was found to be zero. The total Chromium concentration determined by ICP-MS was 13.875 ppm. This was the concentration of Cr(III) in the KCl solution Since no Cr(VI) was detected by UV-Visible. Apparently, the adsorbent reduced all Cr(VI) to Cr(III) and when the KCl solution was added, the desorbed form was only Cr(III).

The percentage desorption was calculated using the initial concentration of Cr(VI) on the adsorbent and the final concentration of Cr(III) and Cr(VI) found in KCl solution.

The percentage desorption was 83.4%

4.10 Testing the Removal of Cr(VI) by the regenerated adsorbent

The regenerated adsorbent (0.5g) was agitated with a solution of 25 ppm Cr(VI) for 2 hours at pH=2 and the percent removal was calculated by determining the initial and the final concentration of Cr(VI) in the solution using the colorimetric method.

The percentage removal of Cr(VI) was 100%. The regenerated adsorbent had the same binding ability for Cr(VI) as the original adsorbent which was 100%.

This is a very promising results since we can use the adsorbent multi analysis and thus increasing its efficiency.

4.11 Adsorption Isotherms

Equilibrium relationships between adsorbent and adsorbate are described by adsorption isotherms. The most common models for adsorption process are Langmuir and Freundlich adsorption isotherms.

4.11.1 Langmuir Isotherm

Langmuir isotherm is the most widely used for modeling equilibrium data and determination of the adsorption capacity [12].

Its linear form is represented by equation (1):

$$C_e / Q_e = 1 / (K Q_{max}) + C_e / Q_{max} \dots\dots (1)$$

Where:

C_e : equilibrium concentration of solute in bulk solution (mg/L).

Q_e : equilibrium mass of adsorbed solute per gram of adsorbent (mg/g).

K : Langmuir constant.

Q_{max} : maximum mass of adsorbate removed per gram of adsorbent (mg/g).

A plot of C_e/Q_e versus C_e was linear and the constants Q_{max} and K were determined from the slope and intercept of the plot, respectively.

The correlation coefficient obtained with Langmuir equation was high ($R^2 = 0.966$) with modified natural fiber by UV-Vis Spectroscopy, which indicated a good fit between the parameters [fig 4.21].

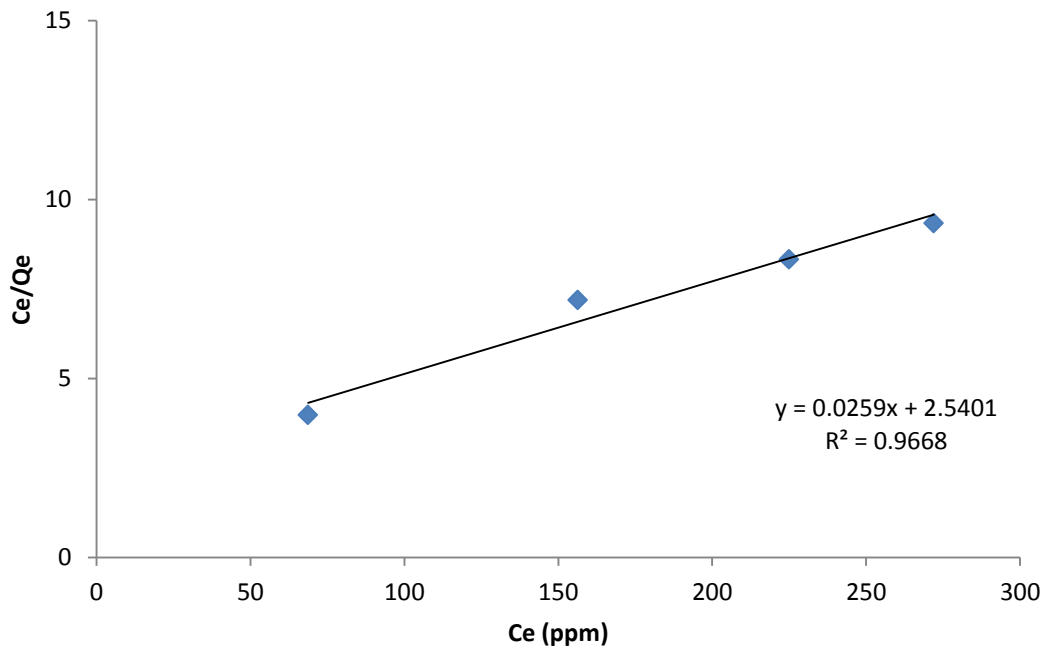


Figure 4.21: Langmuir isotherm for the adsorption of Cr(VI) on a modified natural fiber using UV-VIS Spectroscopy ($T = 25^\circ\text{C}$, $\text{pH} = 2$, contact time = 2 hours and adsorbent dosage = 25 g/L).

$Q_{max} = 40 \text{ mg/g}$ and $K = 0.01$ at 25°C and $\text{pH} = 2$.

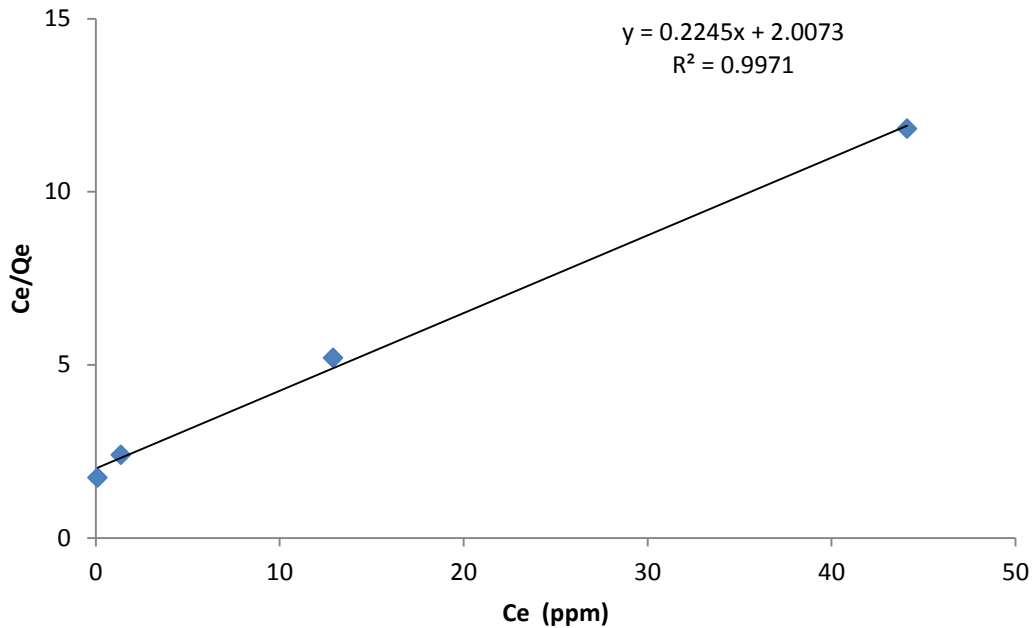


Figure 4.22: Langmuir isotherm for the adsorption of Cr(VI) on a non modified natural fiber using UV-VIS Spectroscopy (T= 25 °C, pH=2, contact time= 3 hours and adsorbent dosage =17 g/L).

In addition, a plot of C_e/Q_e versus C_e for the non modified fiber was linear and the correlation coefficient obtained with Langmuir equation was high ($R^2 = 0.966$) by UV-Vis Spectroscopy, which indicated also a good fit between the parameters.

$Q_{max} = 4.5$ mg/g and $K = 0.1$ at 25°C and pH=2.

Comparison between the modified and the non modified natural fiber, showed that the adsorption capacity of the former is 10 fold larger from the non modified one, this is due to the presence of amine groups in the modified fiber that can be protonated in an acidic medium easier than the hydroxyl groups in the non modified fiber, so a strong electrostatic attraction occurred between the fiber and Chromate ions which cause the adsorption of Chromium from water.

While Compared with other adsorbents, the modified fiber showed the highest adsorption capacity [Table4.1].

4.11.2 Freundlich Isotherm

The Freundlich isotherm is expressed by equation (2):

$$\text{Log } X/m = \text{Log } K_f + 1/n (\text{Log } C_e) \dots\dots\dots(2)$$

Where :

X/m: the amount of solute adsorbed per unit weight of adsorbent (mg/g)

C_e: equilibrium concentration of solute in bulk solution (mg/L).

K_f: Constant indicative of the relative adsorption capacity of the adsorbent (mg/g)

1/n: indicates the intensity of the adsorption

A plot of $\text{Log } X/m$ versus $\text{Log } C_e$ was linear and the constants $1/n$ and K_f were determined from the slope and intercept, respectively.

The correlation coefficient obtained with Freundlich equation was high ($R^2 = 0.976$) with the modified natural fiber by UV-Vis Spectroscopy, which indicated a good fit between the parameters [fig 4.23].

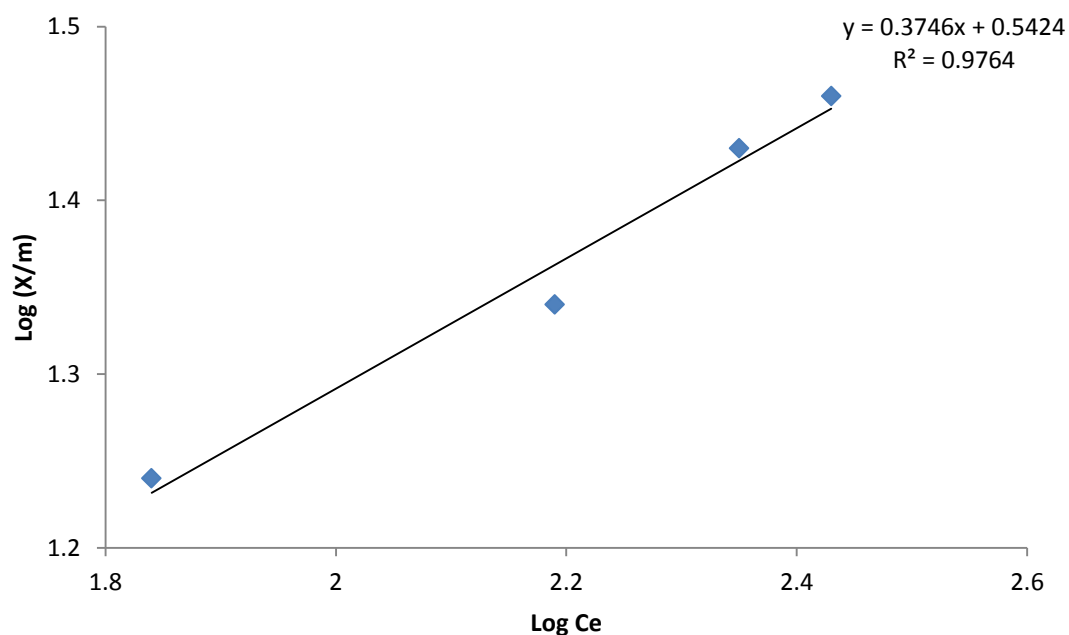


Figure 4.23: Freundlich isotherm for the adsorption of Cr(VI) on a modified natural fiber using UV-VIS Spectroscopy ($T = 25\text{ }^\circ\text{C}$, $\text{pH} = 2$, contact time = 2 hours and adsorbent dosage = 25 g/L).

$1/n = 0.374$ and $K_f = 3.5\text{ mg/g}$ at $T = 25\text{ }^\circ\text{C}$ and $\text{pH} = 2$.

The Freundlich isotherm model agreed well with the adsorption process. So monolayer coverage occurred on the different classes of sites on the modified natural fiber, not only on the available active sites.

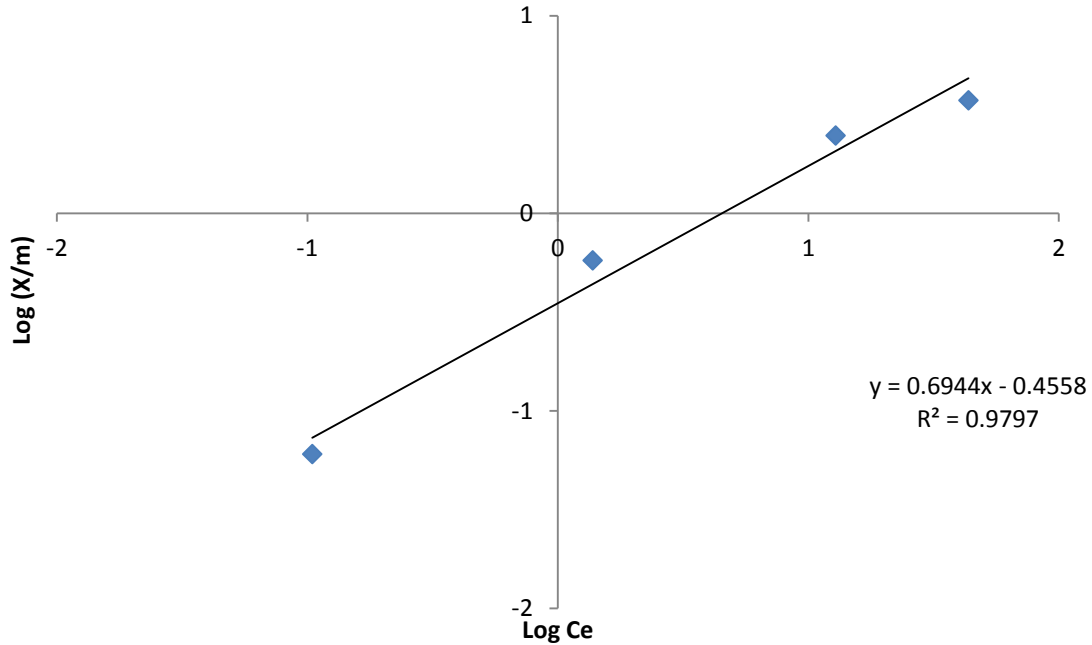


Figure 4.24: Freundlich isotherm for the adsorption of Cr(VI) on a non modified natural fiber using UV-VIS Spectroscopy (T= 25 °C, pH=2, contact time=3 hours and adsorbent dosage =17 g/L).

$1/n = 0.694$ and $K_f = 0.35$ mg/g at T=25°C and pH=2.

On the other hand, a plot of $\text{Log } X/m$ versus $\text{Log } C_e$ for the non modified fiber was linear and the correlation coefficient obtained with Freundlich equation was high ($R^2 = 0.979$) by UV-Vis Spectroscopy, which indicated a good fit between the parameters [fig 4.24].

Also, The Freundlich isotherm model agreed well with the adsorption process. So monolayer coverage occurred on the different classes of sites on the non modified natural fiber, not only on the available active sites.

Comparison of the modified natural fiber with the non modified natural fiber, the former showed a relative adsorption capacity 10 fold that of the non modified.

4.12 Study the adsorbent's surface before and after metal binding using FT-IR Spectroscopy

The mechanism of adsorption was confirmed by the FT-IR Spectroscopy. Variations in the IR Spectrum of the adsorbent complexed with Cr particularly in the $[600-400]\text{cm}^{-1}$ region were observed. A multitude of bands appeared in this region (597, 572, 560, 547, 524, 512, 503, 490, 470, 465, 435, 420 and 405 cm^{-1}). These bands which are not present in the original adsorbent are due to the Cr(III)-O vibrations according to previously reported results [24]. Also observed was a small band around 950 cm^{-1} which is attributed to the vibrations of the N-O bond, apparently as Cr(VI) is reduced to Cr(III) the fiber gets oxidized in the adsorption process.

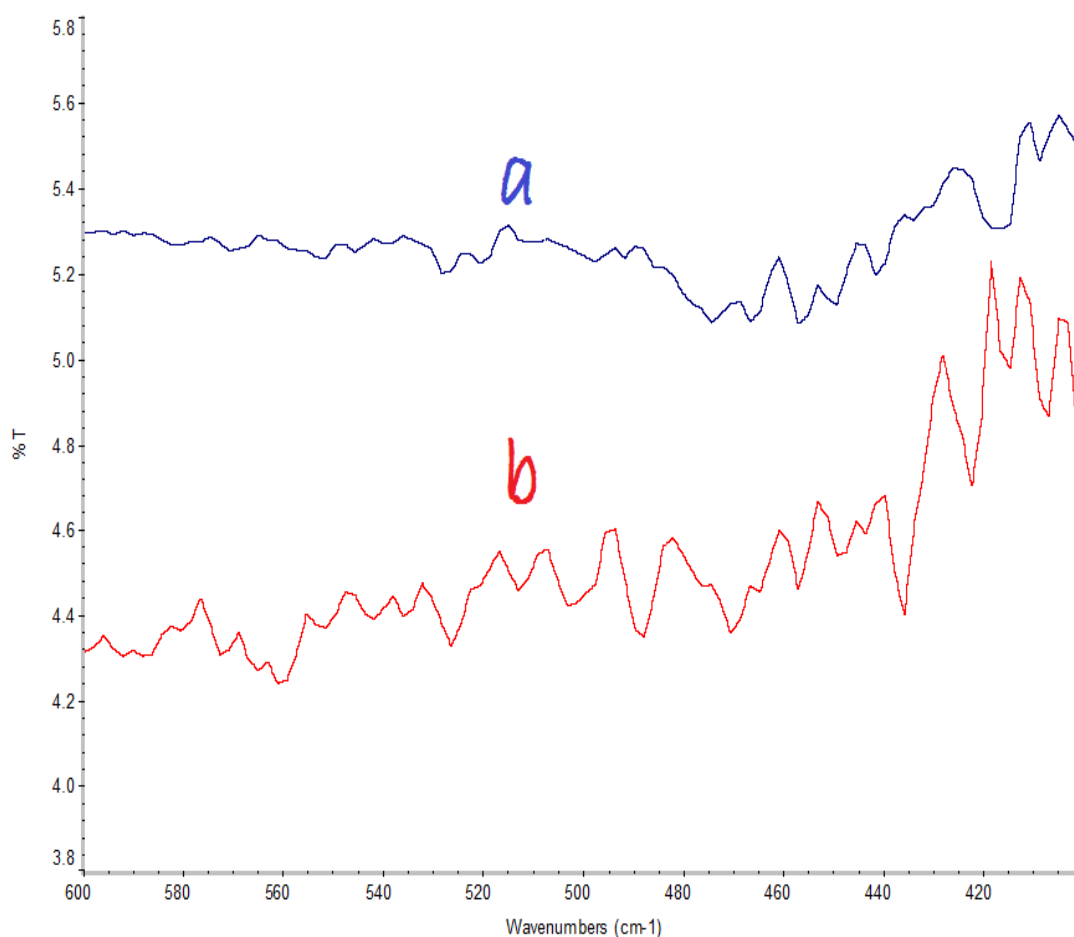


Figure 4.25: FT-IR Spectrum ($600-400\text{ cm}^{-1}$) of (a) modified natural fiber alone (b) modified natural fiber after complexing with Cr(VI).

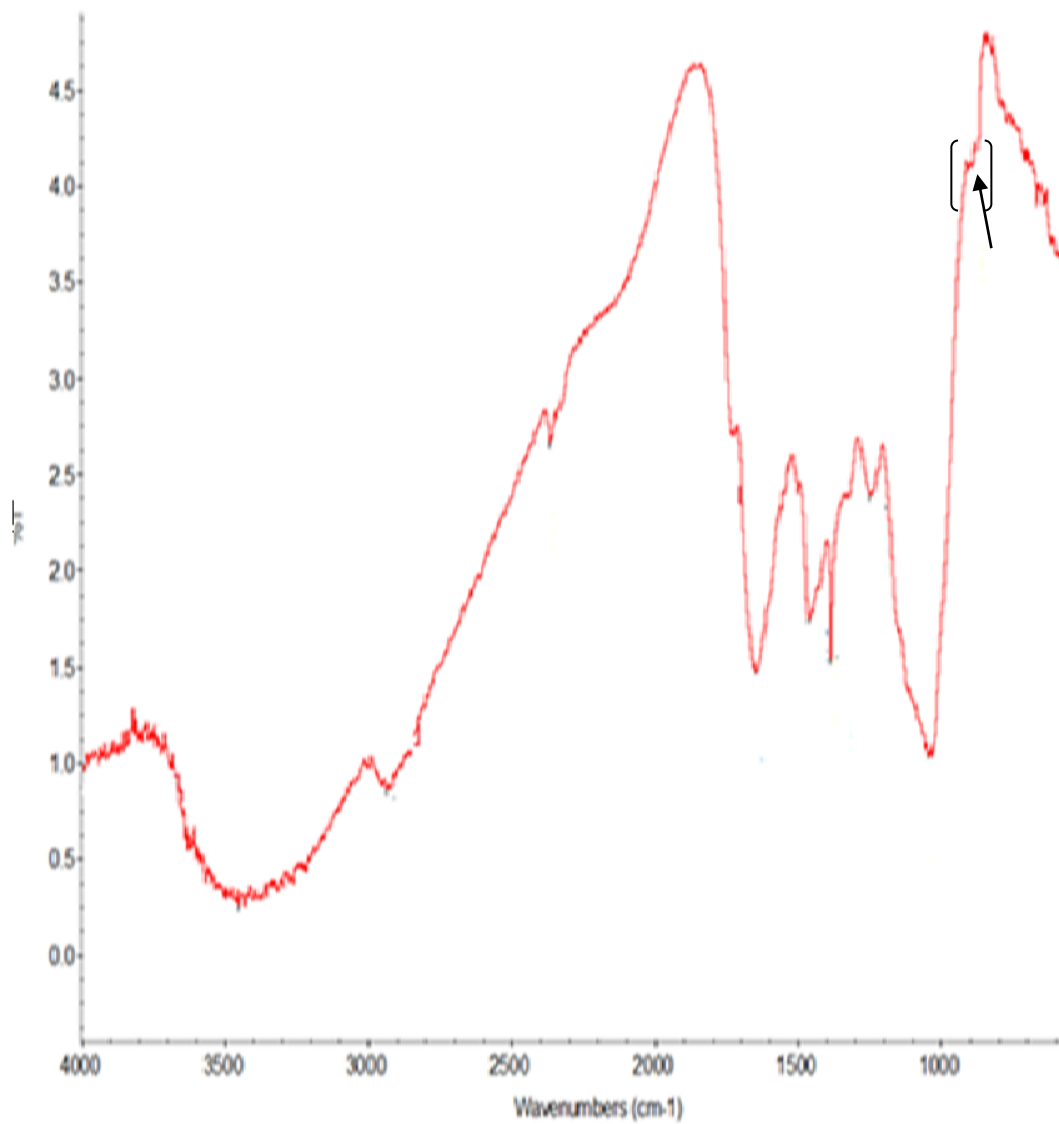


Figure 4.26: FT-IR Spectrum ($4000\text{-}500\text{ cm}^{-1}$) of modified natural fiber.

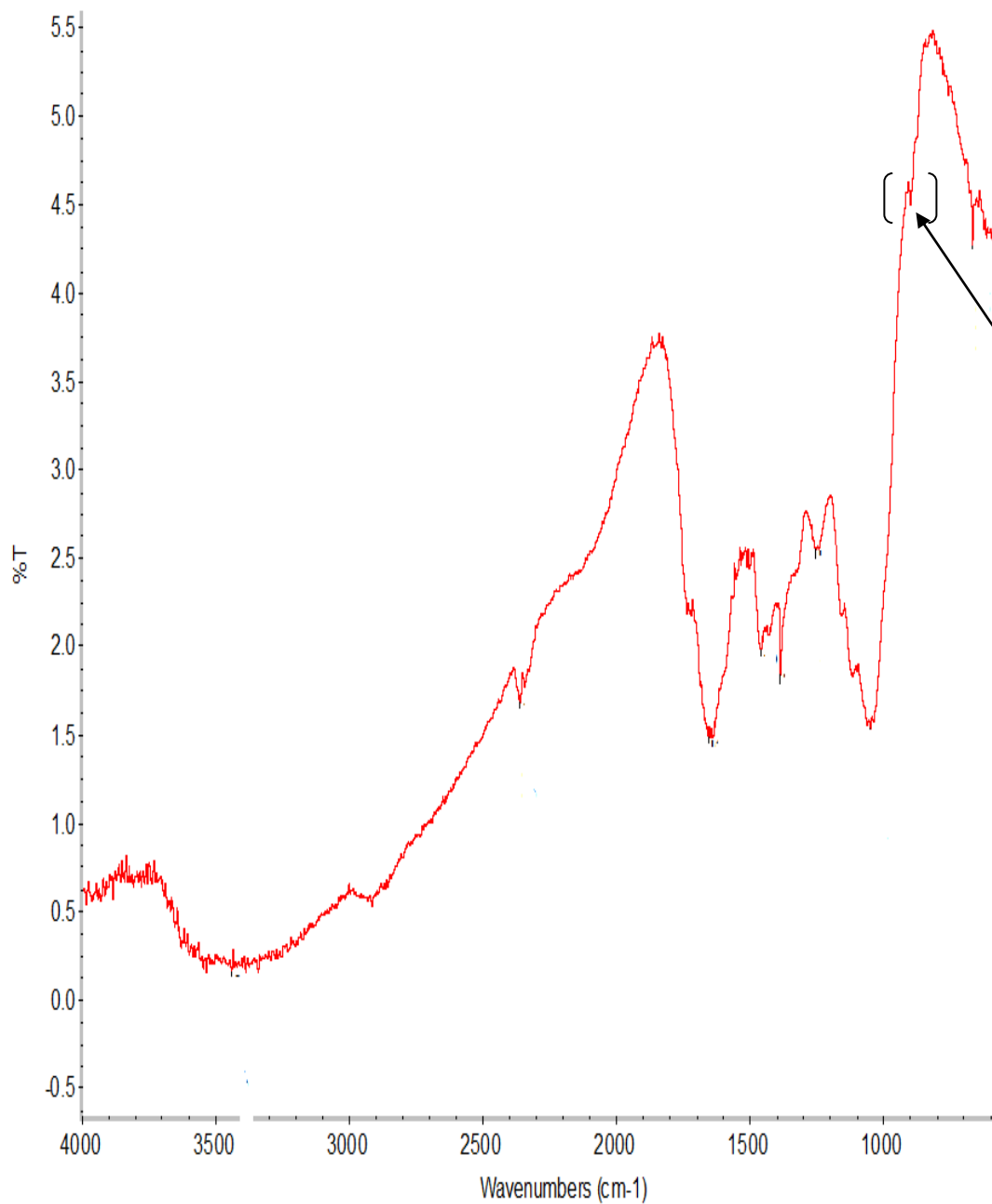


Figure 4.27: FT-IR Spectrum (4000-500 cm^{-1}) of modified natural fiber after complexing with Cr(VI).

4.13 Adsorption capacity of various adsorbents

The adsorption capacity of the modified natural fiber at pH=2 at 25°C was found to be 40 mg/g of adsorbent. This constitutes 10 fold increase from some adsorbents reported earlier such as coconut coir and the straw dust and also more efficient than mango sawdust.

Also, the adsorption capacity of the modified natural fiber is 10 fold times larger than that of the natural fiber without modification [Table 4.1].

The low cost and the high efficiency of this adsorbent make it a good candidate to be used as an adsorbent for the removal of Cr(VI) from water.

Natural fiber was used in previous studies as an adsorbent to remove Lead from water so it is selective toward other heavy metals.

Table 4.1: Adsorption capacities of various adsorbents.

Adsorbent	Adsorption capacity (mg Cr(VI)/ g adsorbent)	References
Tea waste	34.25	15
Coconut husk	21.59	15
Papaya seeds	8.86	13
Mango sawdust	37.73	7
Wheat hunk	28.08	7
Sugar cane bagasse	23.8	7
Orange peel	19.8	7
Powder activated carbon	4.97	16
Bagasse	4.91	16
Fly ash	4.90	16
Straw dust	4.89	16
Coconut coir	4.56	16
Natural fiber	4.5	This work
Modified natural fiber	40	This work

4.14 Reproducibility

Reproducibility of the experiments can check the repetition of the experiments under the same conditions.

Each experiment was repeated three times.

Conclusion

Conclusion

Natural fiber was successfully grafted with tris amine through a combination of periodate oxidation and amination reactions.

The changes in the structure of the natural fiber during modification confirmed by FT-IR Spectra.

The modified natural fiber was a good adsorbent for the removal of Cr(VI) from aqueous solutions.

The percentage removal of Cr(VI) was dependent on pH, contact time, adsorbent dosage and initial Cr(VI) concentration.

During the adsorption process the reduction of Cr(VI) to Cr(III) occurred, possibly by the electrons on the nitrogen's of the adsorbent.

FT-IR analysis showed that the adsorbent gets oxidized in the adsorption process as Cr(VI) was reduced to Cr(III).

Langmuir and Freundlich isotherm models agreed well with the data of the modified fiber and the maximum adsorption capacity was 40 mg/g which is considered to be very high compared to other adsorbents. Also, Langmuir and Freundlich isotherm models agreed well with the data of the non modified fiber and the maximum adsorption capacity was 4.5mg/g.

The maximum adsorption capacity of the modified fiber is about 10 times more than that of the non modified. The modified fiber is a better adsorbent to remove Cr(VI) than the non modified one.

The modified natural fiber can be employed as a low cost alternative to other adsorbents since it is readily available from nature.

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References

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Appendices

Appendix:

A1: Calibration curve (UV-Visible)

Concentration (ppm)	Absorbance
0	0
0.1	0.08
0.3	0.25
0.5	0.43
0.7	0.62
0.9	0.76
1	0.88

A2: Calibration curve (ICP-MS)

Concentration (ppb)	Ratio
0	0.0218
1.0	0.0291
5.0	0.0543
10.0	0.0900
20.0	0.1667
40.0	0.3114

A3: Effect of pH

pH	Final concentration of Cr(VI) (ppm)	%Removal of Cr(VI) by adsorption (UV-VIS)
2	0	100
4	0	100
6	0	100

pH	Final concentration of Cr(VI) (ppm)	Concentration of Total Cr (ppm)
2	0	14.47
4	0	4.21
6	0	0.63

pH	Concentration of Cr (III) (ppm)	%Removal of Cr(VI) by reduction (ICP-MS)
2	14.47	57.88
4	4.21	16.84
6	0.63	2.52

A4: Effect of contact time

Contact time(min)	Final concentration of Cr(VI) (ppm)	%removal of Cr(VI) by adsorption (UV-VIS)
10	0	100
20	0	100
30	0	100
60	0	100
90	0	100
120	0	100

Contact time(min)	Concentration of Cr(III) (ppm)	% removal of Cr(VI) by reduction (ICP-MS)
10	10.64	42.56
20	13.15	52.56
30	14.23	56.92
60	15.82	63.28
90	19.19	76.76
120	23.47	93.88

A5: Effect of adsorbent dosage

Amount of adsorbent (g/L)	Final concentration of Cr(VI) (ppm)	%removal of Cr(VI) by adsorption (UV-VIS)
5	0	100
15	0	100
25	0	100
50	0	100
75	0	100

Amount of adsorbent (g/L)	Concentration of Total Cr (ppm)	% removal of Total Cr (ICP-MS)
5	15.51	37.96
15	14.35	42.60
25	13.56	45.76
50	12.19	51.24
75	8.37	66.54

Cont...

Amount of adsorbent (g/L)	Concentration of Cr(III) (ppm)	% removal of Cr(VI) by reduction (ICP-MS)
5	15.51	62.04
15	14.35	57.40
25	13.56	54.24
50	12.19	48.76
75	8.365	33.46

A6: Effect of initial concentration

Initial concentration (ppm)	Final concentration of Cr(VI) (ppm)	%removal of Cr(VI) by adsorption (UV-VIS)
10	0	100
30	0	100
60	0	100
80	0	100
100	0	100
200	0	100
300	0	100
500	68.71	86.30
700	156.3	77.70
900	225.00	75.00
1000	272.00	72.80

Initial concentration (ppm)	Concentration of Total Cr (ppm)	% removal of Total Cr (ICP-MS)
10	4.02	60.00
30	12.50	58.30
60	26.67	55.60
80	36.50	54.40

A7: Effect of initial concentration when using modified and non modified natural fiber.

Initial conc. (ppm)	Final conc. of Cr(VI) (ppm) (non modified)	Final conc. of Cr(VI) (ppm) (modified)	%removal of Cr(VI) (non modified) (UV-VIS)	%removal of Cr(VI) (modified) (UV-VIS)
1	0.104	0	89.6	100
10	1.38	0	86.2	100
50	12.9	0	74.2	100
100	44.1	0	55.9	100

Initial conc. (ppm)	conc. of Total Cr (ppm) (non modified)	conc. of Total Cr (ppm) (modified)	%removal of Total Cr (non modified) (ICP-MS)	%removal of Total Cr (modified) (ICP-MS)
1	0.44	0.38	56.00	62.00
10	4.45	4.00	55.50	60.00
50	27.75	25.40	44.50	49.2
100	60.50	60.20	39.50	39.8

A8: Langmuir isotherm

Modified fiber:

Ce (ppm)	Ce/Qe
68.71	3.98
156.30	7.19
225.00	8.33
272.00	9.34

Non modified fiber:

Ce (ppm)	Ce/Qe
0.104	1.74
1.38	2.40
12.9	5.20
44.1	11.82

A9: Freundlich isotherm

Modified fiber:

Log Ce	Log X/m
1.84	1.24
2.19	1.34
2.35	1.43
2.43	1.46

Non modified:

Log Ce	Log X/m
-0.98	-1.22
0.14	-0.24
1.11	0.393
1.64	0.57

ازالة الكروم السداسي من المياه باستعمال الليف الطبيعي المعدل كمادة ممتصة

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الملخص:

في هذا العمل، تم تعديل الليف الطبيعي كيميائياً عبر تفاعل الأكسدة لإنتاج المجموعة الوظيفية الالدهايد الذي بعد ذلك تم تفاعله مع ترس(2-امينو ايثل)أمين. تم استخدام الليف الناتج كمادة ممتصة لإزالة الكروم السداسي من المياه. تمت رؤية المتغيرات في محتوى الالدهايد لليف باستعمال جهاز مطيافية الأشعة تحت الحمراء. والمشتقة الامينية أيضاً تم تشخيصها بواسطة جهاز مطيافية الأشعة تحت الحمراء. ولقد تم تقييم قدرة الليف المعدل في إزالة ايونات الكروم السداسي. تمت دراسة اثر الحموضة، وقت الاتصال، كمية المادة الرابطة والتركيز الأولي للكروم على عملية الامتزاز السطحي. تم إجراء تحليل بجهاز مطياف الأشعة تحت الحمراء على المادة الرابطة قبل وبعد ربط الكروم السداسي. عملية الامتصاص السطحي الأقصى حصلت في وسط حمضي وبعد وقت اتصال يساوي 10 دقائق بكمية مادة رابطة تساوي 5 غم لتر⁻¹. نسبة الكروم المزالة انخفضت من 100% إلى 72.8% عندما تم رفع تركيز محلول الكروم السداسي من 10 إلى 1000 مغم/ لتر على درجة حموضة تساوي 2 ودرجة حرارة 25 مئوية وذلك كما حُدد عن طريق جهاز الأشعة فوق البنفسجية - الأشعة المرئية. أيضاً قدرة الليف غير المعدل في إزالة ايونات الكروم السداسي تم تقييمها لمقارنتها مع قدرة الليف المعدل. تم تقييم عملية ربط الكروم السداسي على كل من الليف المعدل وغير المعدل باستخدام نموذج لانغماير الايسوثيرمي و نموذج فريندلش الايسوثيرمي، كانت النتائج تتناسب مع كل من نموذج لانغماير الايسوثيرمي و نموذج فريندلش الايسوثيرمي وكانت قدرة الامتصاص السطحي الأقصى 40 مغم/ غم و 4.5مغم /غم وكانت قدرة الامتصاص السطحي النسبي 3.5 مغم/ غم و 0.35 مغم /غم لليف المعدل وغير المعدل، بالترتيب. تم تحديد الكروم الكلي باستخدام جهاز الامتصاص بواسطة البلازما. أشار جهاز مطيافية الأشعة تحت الحمراء إلى ارتباط الكروم السداسي مع المادة الرابطة تلاها حصول عملية الاختزال للكروم السداسي إلى الكروم الثلاثي. أشار اختبار إعادة إزالة الكروم السداسي عن المادة الرابطة إلى نسبة إزالة تساوي 83.4%.