

Equilibrium, Kinetic and Thermodynamic Study on Chromium (VI) Removal from Aqueous Solution Using Strychnos Nux-Vomica L

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ABSTRACT

The effective and economic removal of heavy metals from industrial effluents is one of the important issues globally. Batch adsorption experiments were carried to fix the adsorption dosage and also to find the optimum pH. A thermodynamic study was made on the adsorption of Cr (VI) ions in aqueous solution distinctly by the adsorbents such as activated Strychnos Nux-Vomica L Nano Carbon. The adsorption of Chromium (VI) ions by activated Strychnos Nux-Vomica L Nano Carbon increased when temperature was raised up to 60 °C. The thermodynamic study and kinetic models showed that the adsorption of Chromium (VI) ions by the above adsorbents were physical and Endothermic.

Keywords: Chromium; activated Strychnos Nux-Vomica L Nano Carbon (ASNVL); adsorption models; equilibrium.

I. Introduction

With the world population set to break seven billion sometime next year, the management and use of natural resources is pushing to the forefront of world concern. With more people entering the worldwide market, an increase in products to meet their needs is inevitable. Individuals, businesses, and industries are seeing not only the long term monetary benefit of using resources wisely, but also the aesthetic and health benefits that come from environmental stewardship. This is seen from the changing of light bulbs at home to the tightening of national government and world standards for environmental quality[1]. With potable water essential to life, no where else are these standards more important than the area of water quality. Not only is water essential for life, it has become the primary workhorse of industries around the world as a working fluid, transport medium, heat transfer fluid, cleaning agent, etc. Unfortunately this has often led to the degradation of water quality as harmful effluents are returned to the environment with various contaminants from these processes [2]. One of the most startling groups of water contaminants are those of heavy metals due to their accumulation in biological systems and their toxicity even at relatively low concentrations [3]. Sources of heavy metal water contamination are varied and can be seen in every step of production from mining, purification and processing, to metal finishing and electroplating, and even end use [4]. Electroplating, the process by which metal is deposited on a surface via an electric current, has been a major contributor to water contamination by a wide variety of heavy metal ions. 10 Industry currently treats electroplating wastewater via a lime-soda

precipitation technique that, although effective, essentially shifts the problem to large volumes of sludge containing heavy metals [5]. Not only does this method not solve the problem of heavy metal pollution, electroplating industries also must deal with the loss of the useable metal which is becoming increasingly expensive due to a decrease in the quality of metal ores [6]. What is needed is an economical method, not only for the removal of heavy metals from waste water, but also the recovery of these metals.

In the present investigation the adsorption of Chromium ion on activated carbon prepared from Strychnos nux-vomica L. by carbonization with sulphuric acid has been achieved. The kinetic and equilibrium adsorption data obtained were utilized to characterize the sample prepared [7]. The amounts and rates of adsorption of Chromium using above activated carbon from water were then measured. Three simplified kinetic models including pseudo first order, Pseudo second order equations and Elovich equations were used to describe the adsorption process.

II. Materials and methods:

All the reagents used for the current investigation were of GR grade from Scientific Equipment Company, Trichy, India. Stock solution (1000 mg/L) of Cr(VI) was prepared by dissolving 5.6578g of $K_2Cr_2O_7$ in double distilled water. The solution was further diluted to the required concentrations before use. Before mixing the adsorbent, the pH of each Cr (VI) solution was adjusted to the required value by 0.1 M NaOH or 0.1 M HCl solution.

2.1 Preparation of Adsorbent:

Strychnos nux-vomica L was collected from local area of Pudukkottai district, Tamilnadu, India. It was dried, charred with excess quantity of concentrated sulphuric acid keeping at 120°C for 10 hours. Then the resultant carbon was washed with excess quantity of distilled water and dried at 110°C for 1 hour and the material obtained was soaked in 5% sodium bicarbonate solution and allowed to stand overnight to remove any residual acid. The material was thoroughly washed with hot distilled water until washings were nearly of neutral effect. To eliminate surface groups by thermal activation, the carbonized material was treated at 1000 °C for 6 hrs in a furnace. The resulting carbons were ground in a mill, washed with pure water and finally dried at 120 °C. The dried powders were sieved in the size range from 180-250 μm.



Strychnos nux-vomica L.

2.2 Adsorbent characterization

Adsorbent characterization was performed by means of spectroscopic and quantitative analysis. The surface area of the adsorbent was determined by Quanta chrome surface area analyzer. The pH of aqueous slurry was determined by soaking 1g of biomass in 50 mL distilled water, stirred for 24 h and filtered and the final pH was measured⁸. The physico-chemical characteristics of the adsorbent were determined using standard procedures⁹. The concentrations of sodium and potassium were determined by Flame Photometer (Model No. Systronics126). The equilibrium Cr(VI) concentration was determined by using 1,5-diphenylcarbazide as the complexing agent and a UV-VIS Spectrophotometer (Systronics, Vis double beam Spectro 1203) at a λ_{max} of 540 nm. For stirring purpose magnetic stirrer was used. The pH of zero-point charge or pH_{ZPC} was determined based on the previous method [8]. The Fourier transform infrared (FTIR) spectra of the adsorbent was recorded with Fourier transform infrared spectrophotometer in the range of 400-4000 cm⁻¹.

Table: 1 physicochemical characteristics of adsorbent

Analysis	Value
pH _{slurry}	6.5
pH _{ZPC}	5.07
Specific gravity	0.253
Moisture content, %	0.115
Bulk density, g cm ⁻³	0.217
Particle density, g cm ⁻³	0.385
Conductivity, μS/cm	43.63
Surface area, m ² /g	27.95
Na ⁺ , mg L ⁻¹	108
K ⁺ , mg L ⁻¹	570

2.3 Batch Adsorption experiments

The Batch adsorption experiments were conducted in 250 mL Erlenmeyer flask with 50mL of standard metal solution and were agitated in a thermo state – controlled shaker at 120 rpm. All experiment were conducted at 30-60 °C, unless otherwise was stated.

The effect of initial pH on the adsorption of the metal ions onto the activated carbon was studied across a pH range of 2.0 – 9.0 with a fixed adsorbent concentration (25 mg/50ml of 50mgL⁻¹ of metal solution). The pit value of the initial metal solution (50mgL⁻¹) was adjusted using a 0.1M HCl or NaOH solution. Activated carbon (0.0250g) was then added to the solution and agitated for enough time to achieve equilibrium. The effect of the agitation period was also studied at a constant concentration of 50 mg L⁻¹ metal solution and a fixed adsorbent concentration of 25mg/50mL at the optimum pH. After agitation the sample solution was withdrawn at different time intervals (10-60min) and centrifuged at 3600 rpm for 10 min. Subsequently an aliquot of the supernatant was used for determination of the remaining Metal concentration, and the remainder was poured back into the original solution. The determination of the effect of the initial concentration of the uptake of the metal was conducted by varying the metal concentration from 25 to 125 mg L⁻¹ at a constant activated carbon dosage of 25 mg at optimum pH and agitation period. The effect of temperature on the adsorption characteristics was studied by determining the adsorption isotherms from 303 – 333K at a metal concentration of 25-125mg/L.

The percentage removal of the metals and the amount of metal taken up by the adsorbent was calculated by applying following equations.

$$\% \text{ Removal} = \frac{C_i - C_t}{C_i} \times 100 \quad (1)$$

$$Q = \frac{(C_i - C_t)}{m} V \quad (2)$$

Where C_i and C_t are the initial and liquid phase concentrations of Cr(VI) at time ‘t’ (mg L⁻¹) Q is the amount of metal adsorbed on the adsorb of at any time (mg g⁻¹), m(g) the mass of the adsorbent

sample used and V the volume of the metal solution (L).

III. Results and Discussion

3.1 Effect of contact time:

The Fig. 1 shows that the adsorption of Chromium metal ion from an aqueous solution reached equilibrium with in 40 min. The contact time significantly affected the metal uptake. The adsorption of metal by all studied adsorbents sharply increased in the first 30 min. The rapid adsorption at the initial stage was probably due to the great concentration gradient between the metal in solution and the metal in the adsorbent because there must be a number of vacant sites available in the beginning. The progressive increase in adsorption and, consequently, the attainment of equilibrium adsorption is initially due to the limited mass transfer of the metal ions from the bulk solution to the external surface of the adsorbent, and is subsequently due to the slower internal mass transfer within the adsorbent particles.

3.2 Effect of initial metal concentration:

The experimental results of adsorption of Chromium (VI) ions on ASNVL at various initial concentration (25, 50, 75, 100 and 125 mg/L) for chromium ions in terms of equilibrium data are given in table.2. The initial concentration provides an important driving force to overcome the mass transfer resistance of all of the molecules between the aqueous and solid phase, the Fig.1 plots the percentage of metal removal versus the initial metal concentration of the adsorbents. While increasing the initial metal concentration from 25.0 to 125.0 mgL⁻¹, the percentage of metal ion removal by the ASNVL decreased from 87.96% to 62.99%, 91.30% - 64.91% and 89.72% - 79.25% respectively, the percentage removal of the metal decreased slowly in the concentration range of 25-125 mgL⁻¹, but reduced rapidly from 25 to 75 mgL⁻¹ metal removal is highly concentration dependent at higher concentrations. This can be explained by the fact that the adsorbent has a limited number of active sites that become saturated above a certain concentration. At low metal concentrations, the ratio of surface active sites to the total metal ions in the solution is high and hence all metal ions may interact with the active functional groups on the surface of the carbon and be removed from the solution. However, with increased metal concentrations, the number of active adsorption sites is not enough to accommodate the metal ions. Therefore, the initial metal concentration was fixed at 50.0 mg L⁻¹ in the following experiments.

3.3 Effect of adsorbent dose

In this study, Five different adsorbent dosages were selected ranging from 0.010 to 0.250 g while the Cr(VI) concentration was fixed at 50 mg/L. The results are presented in Fig. 2. It was observed that percentage of Cr(VI) ion removal increased with

increase in adsorbent dose. Such a trend is mostly attributed to an increase in the sorptive surface area and the availability of more active binding sites on the surface of the adsorbent. This may be due to the decrease in total adsorption surface area available to Cr(VI) ion resulting from overlapping or aggregation of adsorption sites. Thus with increasing adsorbent mass, the amount of Cr(VI) ion adsorbed onto unit mass of adsorbent gets reduced, thus causing a decrease in q_e value with increasing adsorbent mass concentration. Furthermore maximum Cr(VI) ion removal (83.46%) was recorded by 0.025 g Activated Nux-Vomica L biomass and further increase in adsorbent dose did not significantly change the adsorption yield. This is due to the non-availability of active sites on the adsorbent and establishment of equilibrium between the Cr(VI) ion on the adsorbent and in the solution.

3.4 Effect of initial solution pH:

The pH of an initial metal solution exerts profound influence on the adsorptive uptake of adsorbate molecules, presumably due to its influence on the surface properties of the adsorbent and ionization/ dissociation of the adsorbate molecule, Therefore investigation of the effect of pH on the adsorption process is helpful to determine the optimized operational parameters for application and to reveal the adsorption mechanism[9], Adsorption of Chromium ion onto Strychnos nux-vomica L was carried out to examine the effect of pH (in a range of 2-9) on the removal of ago disperse metal from aqueous solution, As seen in fig 3. Metal removal by all studied adsorbents decreased significantly with increasing pH, especially between pH 2.0 and 7.0, the maximum removal percentages of Chromium onto ASNVL, were 80 to 83% respectively.

3.5 Effect of other ions:

The effect of other ions like Cl⁻ on the adsorption process studied at different concentrations. The ions added to 50mg/L of metal ion solutions and the contents were agitated for 60 min at 30 °C. The results had shown in the (fig.4) reveals that low concentration of Cl⁻ does not affect the percentage of adsorption of metal ion on activated SNVL, because the interaction of Cl⁻ at available sites of adsorbent through competitive adsorption is not so effective. This is so because ions with smaller hydrated radii decrease the swelling pressure within the sorbent and increase the affinity of the sorbent for such ions [10] (Chien & Clayton, 1980).

3.6 Effect of Temperature:

It is well known that temperature plays an important role in the adsorption process. The removals of metal ions were found to be 87.96% - 88.49%, 83.46% - 88.86%, 77.91% - 84.40%, 69.15% - 76.16% and 62.99% - 68.90% at 30,40,50,60 °C respectively. The metal ions removal increase rapidly

from 303K to 333K, this result suggests that the experimental temperature had a greater effect on the adsorption process implying that the surface coverage increased at higher temperatures. This may be attributed to the increased penetration of metal ions inside micro pores or the creation of new active sites at higher temperatures. This indicates the endothermic nature of the controlled adsorption process. Similar result has been reported in the literature.

3.7 Adsorption Kinetic and isotherm models:

3.7.1 Adsorption Isotherms

Adsorption isotherms describe the interaction of adsorbate with adsorbents. The experimental adsorption data of Cr (VI) ions on the *Strychnos nux-vomica* L were analyzed by Langmuir and Freundlich.

3.7.2 Langmuir Isotherm

The Langmuir adsorption model is based on the assumption that maximum adsorption corresponds to a saturated monolayer of solute molecules on the adsorbent surface, with no lateral interaction between the adsorbed molecules. The Langmuir adsorption isotherm has been successfully used in many monolayer adsorption processes, the values are in table 3. The adsorption isotherm data were analyzed by the Langmuir isotherm model in the linearised form,

$$C_e/q_e = C_e/q_{max} + 1/(b q_{max}) \quad (3)$$

Where q_e is the equilibrium adsorption capacity of the adsorbent (mg/g), C_e is the equilibrium Cr (VI) concentration in solution (mg/l), q_{max} is the maximum amount of Chromium that could be adsorbed on the adsorbent (mg/g) and b is the Langmuir adsorption equilibrium constant (L/mg). In order to find out the feasibility of the isotherm, the essential characteristics of the Langmuir isotherm can be expressed in terms of dimensionless constant separation factor R_L by the equation

$$R_L = (1/(1+bC_0)) \quad (4)$$

Where C_0 (mg/L) is the highest initial concentration of adsorbent and b (L/mg) is Langmuir isotherm constant. The parameter R_L indicates the nature of shape of the isotherm accordingly.

$R_L > 1$	Unfavorable adsorption
$0 < R_L < 1$	Favorable adsorption
$R_L = 0$	Irreversible adsorption
$R_L = 1$	Linear adsorption

The R_L values between 0 to 1 indicate favorable adsorption for all initial concentration (C_0) and temperatures studied. The calculated R_L values are given in table 4. High b values indicate high adsorption affinity the monolayer saturation capacity Q_m were around.

3.7.3 Freundlich Isotherm

The Freundlich model can be applied to multilayer adsorption with non-uniform distribution of adsorption heat and affinities over the heterogeneous

surface [11]. The experimental data were analyzed by Freundlich isotherm model in the linearised form,

$$\log q_e = 1/n \log C_e + \log K_F \quad (5)$$

where K_F is the Freundlich adsorption constant and it is the maximum adsorption capacity of metal ions (mg/g) and n is the constant illustrates the adsorption intensity (dimensionless). The values are presented in table 3 shows the favorability of the adsorption process.

3.7.4 pH optimization

The removal of Cr(VI) at different pH was studied in batch mode. A 50mL of test solution of fixed concentrations was treated with 0.025 g of ASNVL and agitated intermittently for 60 min. The contact time and conditions were selected on the basis of preliminary experiments, which demonstrated that equilibrium was established in 40 min. After this period the solutions then both phases were separated by filtration. The metal content of the filtrate was determined by atomic spectrometry. The metal concentration retained in the sorbent phase (q_e , mg/g) was calculated by using Eq. (1)

$$q_e = \frac{(C_0 - C_e) V}{m} \quad (6)$$

where C_0 and C_e are the initial and final (equilibrium) concentrations of the metal ion in solution (M), V the solution volume (L) and m is the mass of Activated *Strychnos nux-vomica* L (g).

3.8 Adsorption Thermodynamics

The thermodynamic parameters for the adsorption of Cr (VI) ions by Activated *Strychnos nux-vomica* L were determined using the following equations:

$$K_D = q_e/C_e \quad (7)$$

$$\Delta G^\circ = -RT \ln K_D \quad (8)$$

$$\ln K_D = (\Delta S^\circ/R) - (\Delta H^\circ/RT) \quad (9)$$

where K_D is the distribution coefficient for the adsorption in g/L, ΔG° is the Gibbs free energy in J/mol, R is the universal gas constant in J/mol K, T is the absolute temperature in K, ΔS° is the entropy change in J/mol K and ΔH° is the enthalpy change in kJ/mol [12]. The values of Gibbs free energy (ΔG°) for various temperatures were calculated from the experimental data. The values of enthalpy change (ΔH°) and entropy change (ΔS°) were estimated from the slope and intercept of the plot of $\ln K_D$ Vs $1/T$. The estimated thermodynamic parameters were tabulated and shown in table 5, the negative values of Gibbs free energy change (ΔG°) obtained for the adsorption of Cr (VI) ions by Activated *Strychnos nux-vomica* L at various temperatures had shown the spontaneous nature of the adsorption process. The negative values of enthalpy change (ΔH°) obtained for the adsorption of Cr (VI) ions by Activated *Strychnos nux-vomica* L at various temperatures indicated that the adsorption reactions were endothermic. The positive values of entropy change (ΔS°) for the

adsorption of Cr (VI) ions by Activated Strychnos nux-vomica L at various temperatures showed the increased randomness at solid liquid interphase during the sorption processes of Cr (VI) ions on the adsorbent ASNVL. This is a direct consequence of (i) opening up of structure of adsorbent beads (ii) enhancing the mobility and extent of penetration within the adsorbent beads and (iii) overcoming the activation energy barrier and enhancing the rate of intra-particle diffusion [13].

The adsorption of Cr (VI) ions by Activated Strychnos nux-vomica L slightly increased when temperature was raised up to 60 °C. It might be due to the generation of new active sites on the adsorbent surface and also due to the increased rate of pore diffusion. But when the temperature was further raised, adsorption processes had slightly increased. It showed that the adsorption processes of Cr (VI) ions by Activated Strychnos nux-vomica L were endothermic reactions and physical in nature which involved the strong forces of attraction between the sorbate-sorbent molecules.

3.9 Kinetic modeling in a batch system

In order to investigate the mechanism of adsorption kinetic models are generally used to test experimental data. Pseudo-first-order and pseudo-second-order equations can be used assuming that the measured concentrations are equal to surface concentrations [14]. The pseudo-first-order rate Lagergren model is:

$$\frac{dq}{dt} = k_{1,ads}(q_e - q) \quad (10)$$

where q (mg/g) is the amount of adsorbed heavy metals on the adsorbent at time t and $k_{1,ads}$ (min^{-1}) is the rate constant of first-order adsorption. The integrated form of Eq. (10) is:

$$\log(q_e - q) = \log q_e - \frac{k_{1,ads}}{2.303} t \quad (11)$$

q_e the equilibrium sorption uptake, is extrapolated from the experimental data at time $t = \text{infinity}$. A straight line of $\log(q_e - q)$ versus t suggests the applicability of this kinetic model. q_e and $k_{1,ads}$ can be determined from the intercept and slope of the plot, respectively. The pseudo-second order kinetic model is expressed as:

$$\frac{dq}{dt} = k_{2,ads}(q_e - q)^2 \quad (12)$$

where $k_{2,ads}$ (g/mg min) is the rate constant of second-order adsorption. The integrated form of Eq. (12) is:

$$\frac{1}{q_e - q} = \frac{1}{q_e} + k_{2,ads} t \quad (13)$$

Eq. (13) can be rearranged and linearized to obtain:

$$\frac{t}{q} = \frac{1}{k_{2,ads} q_e^2} + \frac{1}{q_e} t \quad (14)$$

The plot t/q versus t should give a straight line if second order kinetic model is applicable and q_e and $k_{2,ads}$ can be determined from the slope and intercept of the plot, respectively. It is important to notice that for the application of this model the experimental estimation of q_e is not necessary.

3.9.1 The Elovich equation

The Elovich model equation is generally expressed as

$$dq_t/dt = \alpha \exp(-\beta q_t) \quad (15)$$

Where; α is the initial adsorption rate ($\text{mg g}^{-1} \text{min}^{-1}$) and β is the desorption constant (g/mg) during any one experiment. To simplify the Elovich equation. Chien and Clayton (1980) assumed $\alpha\beta t \gg t$ and by applying boundary conditions $q_t = 0$ at $t = 0$ and $q_t = q_t$ at $t = t$ Eq.(15) becomes:

$$q_t = 1/\beta \ln(\alpha\beta) + 1/\beta \ln t \quad (16)$$

If Cr (VI) ions adsorption fits with the Elovich model, a plot of q_t vs. $\ln(t)$ should yield a linear relationship with a slope of $(1/\beta)$ and an intercept of $(1/\beta)\ln(\alpha\beta)$. The Elovich model parameters α , β , and correlation coefficient (γ) are summarized in table 6. The experimental data such as the initial adsorption rate (α) adsorption constant (β) and the correlation co-efficient (γ) calculated from this model indicates that the initial adsorption (α) increases with temperature similar to that of initial adsorption rate (h) in pseudo-second-order kinetics models. This may be due to increase the pore or active site on the ASNVL adsorbent.

3.9.2 The Intraparticle diffusion model

The kinetic results were analyzed by the [15] Intraparticle diffusion model to elucidate the diffusion mechanism. The model is expressed as:

$$q_t = K_{id} t^{1/2} + I \quad (17)$$

Where I is the intercept and K_{id} is the intra-particle diffusion rate constant. The intercept of the plot reflects the boundary layer effect. Larger the intercept, greater is the contribution of the surface sorption in the rate controlling step. The calculated diffusion coefficient K_{id} values are listed in Table 6. The K_{id} value was higher at the higher concentrations. Intraparticle diffusion is the sole rate-limiting step if the regression of q_t versus $t^{1/2}$ is linear and passes through the origin. In fact, the linear plots at each concentration did not pass through the origin. This deviation from the origin is due to the difference in the rate of mass transfer in the initial and final stages of the sorption. This indicated the existence of some boundary layer effect and further showed that Intraparticle diffusion was not the only rate-limiting step.

It is clear from the Table 6 that the pseudo-second-order kinetic model showed excellent linearity with high correlation coefficient ($R^2 > 0.99$) at all the studied concentrations in comparison to the other kinetic models. In addition the calculated q_e values also agree with the experimental data in the case of pseudo-second-order kinetic model. It is also evident from Table 6 that the values of the rate constant k_2 decrease with increasing initial Cr (VI) concentrations. This is due to the lower competition for the surface active sites at lower concentration but at higher concentration the competition for the surface active sites will be high and consequently lower sorption rates are obtained.

3.10 Desorption studies

In order to assess the reusability of chromium-loaded Activated Strychnos Nux-Vomica L biomass desorption experiments were carried out. The effect of strength of desorbing solution (NaOH) on the recovery of Cr(VI) is shown in Fig. 5. It is evident from the above figure that when the strength of the desorbing solution increased from 0.5 to 2.0 M, Cr (VI) desorption percentage increased from 28.5% to 79%. Thus a significant amount of chromium is being desorbed, which shows that the ASNVL biomass can be effectively reused after desorption.

IV. Conclusion

This study is revealed that Strychnos nux-vomica L can be used as an alternative adsorbent for heavy metal ions removal in industrial wastewater due to its efficiency of Chromium ions adsorption in aqueous solution. The adsorption of Cr (VI) onto ASNVL was affected by pH, adsorbent dosage, and temperature. The Cr (VI) uptake percentage by ASNVL was found to be 83.46% when 0.025 g of adsorbent was agitated with 50mL of Cr(VI) solution of 50 mg/L for 60 min at pH. The adsorption data was fitted well by pseudo-second order kinetic indicating that chemical reaction is involved in the adsorption process. The adsorption process was found to be controlled by three steps of diffusion mechanisms. The temperature equilibrium data fitted well with Langmuir isotherm model and the monolayer adsorption capacity was found to be 212.70 mg/g at 333 K. An increase of Q_0 value with the increase of temperature implied that chemisorption occurs in the process. Thermodynamic constants were also evaluated using equilibrium constants from Langmuir isotherm. The negative values of ΔG° indicated the spontaneity of Cr(VI) adsorption process and the positive values of ΔH° and ΔS° showed the endothermic nature. This study illustrated that it is possible to remove Chromium ion from aqueous solution with Strychnos nux-vomica L.

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Table: 2. Equilibrium Parameters for the Adsorption of Chromium ion onto ASNVL

M ₀	Ce (Mg / L)				Qe (Mg / L)				Removal %			
	30°C	40°C	50°C	60°C	30°C	40°C	50°C	60°C	30°C	40°C	50°C	60°C
25	3.00	2.17	2.56	2.87	43.98	45.65	44.86	44.24	87.96	91.30	89.72	88.49
50	8.26	7.67	6.84	5.56	83.46	84.64	86.31	88.86	83.46	84.64	86.31	88.86
75	16.5	14.8	13.8	11.3	116.8	120.3	122.2	127.2	77.91	80.22	81.52	84.80
100	30.8	28.9	13.85	23.8	138.3	142.0	172.2	152.3	69.15	71.04	86.14	76.16
125	46.2	43.8	25.9	38.8	157.4	162.2	198.1	172.2	62.99	64.91	79.25	68.90

Table: 3. Langmuir and Freundlich Isotherm Parameter for the Adsorption of Chromium ion onto ASNVL

Temp. (°C)	Langmuir Parameters		Freundlich Parameters	
	Q _m	b	K _f	n
30°C	190.74	0.0950	4.3062	2.1606
40°C	189.59	0.1191	4.6550	2.3488
50°C	330.45	0.0559	4.0107	1.5143
60°C	212.70	0.1112	4.5232	2.0327

Table: 4. Dimensionless Separation factor (R_L) for the Adsorption of Chromium ion onto ASNVL

(C _i)	Temperature °C			
	30°C	40°C	50°C	60°C
25	0.2961	0.2513	0.4167	0.2644
50	0.1738	0.1437	0.2632	0.1523
75	0.1230	0.1006	0.1923	0.1070
100	0.0951	0.0774	0.1515	0.0824
125	0.0776	0.0629	0.1250	0.0670

Table: 5. Thermodynamic Parameter for the Adsorption of Chromium ion onto ASNVL

(C ₀)	ΔG°				ΔH°	ΔS°
	30°C	40°C	50°C	60°C		
25	-5009.8	-6118.24	-5819.7	-5648.12	0.01176	17.802
50	-4078.95	-4441.7	-4944.7	-5751.31	12.5734	54.646
75	-3175.38	-3644.02	-3986.5	-4759.64	12.1930	50.579
100	-2033.69	-2336.2	-4907.0	-3216.4	17.0950	63.581
125	-1340.21	-1601.49	-3599.4	-2202.46	13.0273	47.841

Table: 6. The Kinetic Parameters for the Adsorption of Chromium ion onto ASNVL

C ₀	Temp °C	Pseudo second order				Elovich model			Intraparticle diffusion		
		q _e	K ₂	γ	h	α	β	γ	K _{id}	γ	C
25	30	48.798	0.0188	0.9981	5.8804	60.758	0.1474	0.9959	1.6182	0.9952	0.1759
	40	50.218	0.0238	0.9964	6.0532	63.424	0.1436	0.9968	1.6320	0.9983	0.1751
	50	50.224	0.0223	0.9948	6.2167	44.386	0.1322	0.9982	1.6054	0.9960	0.1931
	60	48.578	0.0189	0.9971	6.5907	68.732	0.1483	0.9948	1.6286	0.9940	0.1739
50	30	91.979	0.0137	0.9932	12.244	111.54	0.0761	0.9961	1.5936	0.9946	0.1801
	40	92.939	0.0143	0.9946	13.476	178.46	0.0812	0.9987	1.6303	0.9988	0.1637
	50	94.567	0.0157	0.9923	14.215	208.36	0.0813	0.9967	1.6467	0.9954	0.1596
	60	97.608	0.0192	0.9951	13.807	174.50	0.0766	0.9989	1.6466	0.9990	0.1657
75	30	128.87	0.0097	0.9976	17.205	207.04	0.0575	0.9984	1.5828	0.9987	0.1683
	40	132.91	0.0112	0.9964	18.160	210.81	0.0553	0.9967	1.5963	0.9967	0.1694
	50	135.19	0.0121	0.9971	19.422	197.64	0.0530	0.9983	1.6001	0.9961	0.1739
	60	139.76	0.0145	0.9941	15.703	264.78	0.0567	0.9943	1.6214	0.9981	0.1576
100	30	156.63	0.0069	0.9964	16.622	95.071	0.0402	0.9982	1.4585	0.9975	0.2094
	40	160.15	0.0075	0.9939	17.824	107.75	0.0398	0.9972	1.4796	0.9969	0.2049
	50	166.23	0.0100	0.9943	19.239	129.68	0.0394	0.9969	1.5105	0.9973	0.1976
	60	168.98	0.0091	0.9937	22.218	201.54	0.0414	0.9981	1.5553	0.9989	0.1804
125	30	182.64	0.0055	0.9981	16.440	69.215	0.0317	0.9948	1.3689	0.9928	0.2369
	40	186.66	0.0060	0.9990	17.445	74.065	0.0311	0.9994	1.3850	0.9941	0.2351
	50	193.33	0.0079	0.9976	17.944	77.134	0.0301	0.9972	1.4010	0.9948	0.2342
	60	196.40	0.0070	0.9981	19.945	99.179	0.0309	0.9963	1.4388	0.9959	0.2201

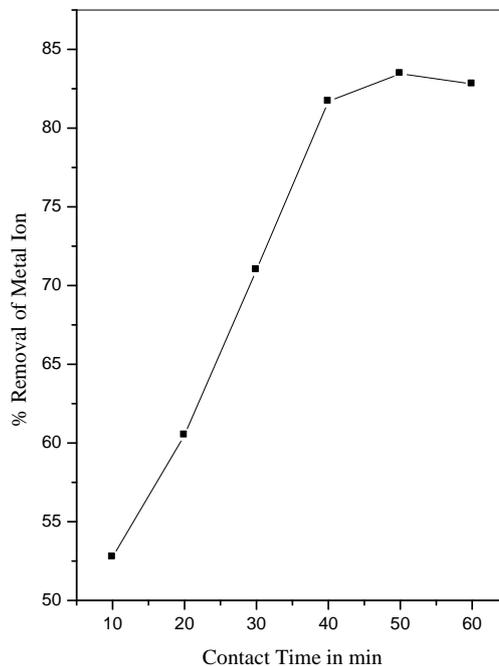


Fig:1-Effect of Contact Time on the Removal of Metal ion
 [M]=50 mg/L; adsorbent dose=25mg/50ml; pH-6.5;Temp 30°C

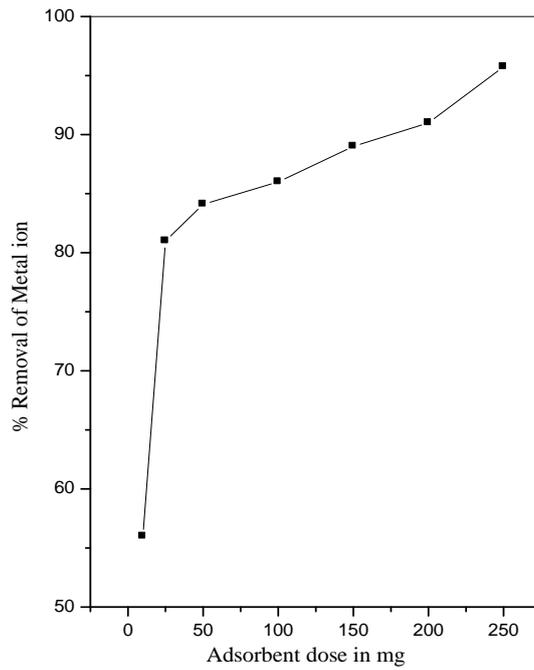


Fig.2-Effect of adsorbent dose on the removal of Metal Ion
[M]=50mg/L: Contact time=60 min: pH=6.5: Temp 30°C

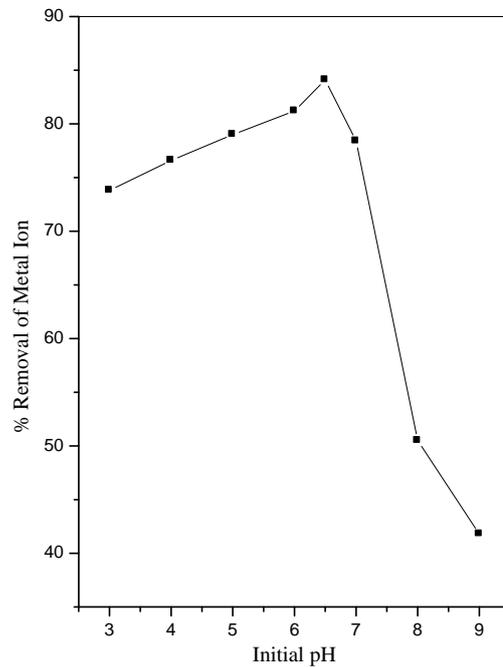


Fig.3-Effect of Initial pH on the removal of Metal Ion
[M]=50mg/L: Contact time=60 min: dose=25mg/50ml

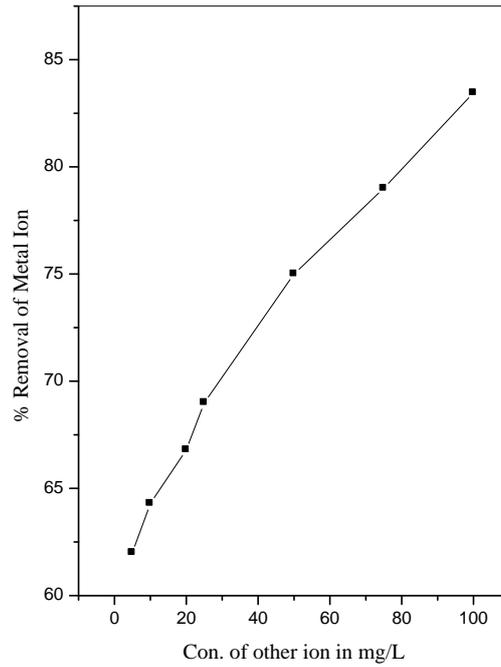


Fig.4-Effect ionic strength on the adsorption of Metal ion
[M]=50 mg/L;Contact time=60 min;Dose=25 mg/50 ml

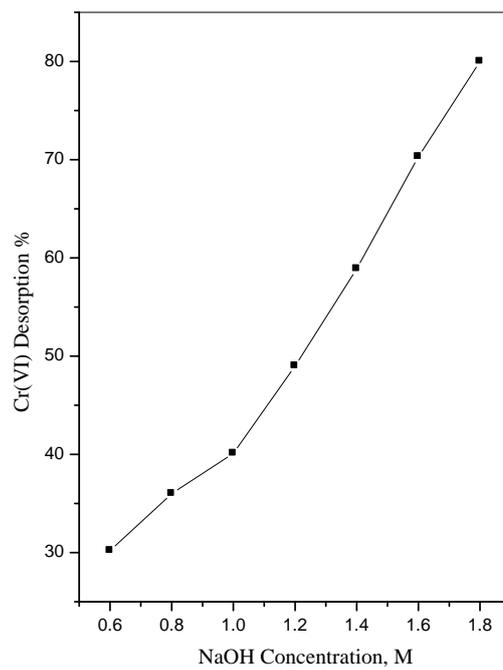


Fig.5- Effect of NaOH Concentration on Cr(VI) desorption