

# Kinetic, Equilibrium and Thermodynamic studies on the removal of Cr(VI) by activated carbon prepared from *Cajanus Cajan(L)* Milsp seed shell.

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This paper presents the feasibility of the removal of hexavalent chromium ions from aqueous solutions by using activated carbon prepared from *Cajanus Cajan(L)* Milsp. It was carbonized and activated by treating it with concentrated sulfuric acid followed by heating for 5 h at 500°C. Batch adsorption experiments were carried out as a function of pH, contact time, initial concentration of the adsorbate, adsorbent dosage and temperature. The experimental data fitted well to the Freundlich isotherm. The thermodynamic parameters such as  $\Delta H^\circ$ ,  $\Delta S^\circ$ , and  $\Delta G^\circ$  were calculated, which indicated that the adsorption was spontaneous and endothermic in nature. The adsorbent used in this study was characterized by FT-IR and SEM before and after the adsorption of metal ions. The results indicate that *Cajanus Cajan(L)* Milsp can be employed as a low cost alternative and commercial adsorbents in the removal of chromium (VI) from water and waste water.

**Keywords:** Adsorption, isotherm, activated carbon, chromium and seed shell.

## INTRODUCTION

Rapid increase in population and industrial growth are responsible for the inclusion of heavy metals in the environment. These heavy metals and their compounds are potential pollutants that could be particularly problematic due to their stability, mobility and toxicity. The pollution due to heavy metals has received wide spread attention in recent years<sup>1</sup>, due to the toxicological problems in the ecosystem, agriculture and human health, which has led to the development of alternative technologies for the effective removal of these pollutants from aquatic ecosystems. Low cost and waste biomaterials used as adsorbents of dissolved metal ions have been shown to provide cost effective solutions to this global problem<sup>2</sup>. In this work, it has been shown that an adsorbent (*Cajanus Cajan(L)* Milsp seed shell) can be used in an effective and eco-friendly way for the removal of Cr(VI) ions from wastewaters.

Chromium is a highly toxic pollutant generated from various industries such as leather, electroplating, dye, paint and paper. Chromium exists in the aquatic environment mainly in two states; trivalent chromium and hexavalent chromium. Hexavalent chromium is primarily present in the form of chromate and dichromate ions<sup>3</sup>. The USEPA has set the maximum contaminate level (MCL) for chromium in drinking water at 0.1mg L<sup>-1</sup>. These standards are based on the total concentration of the trivalent and hexavalent forms of the dissolved chromium. Chromium has the potential to cause the following health effects from long-term exposures at levels above the MCL: damage to liver, kidney, circulatory and nerve tissues and dermatitis. Furthermore, chromium has serious effects on the health of humans<sup>4</sup>.

Some of the conventional methods that are used to remove the dissolved heavy metal ions are: chemical precipitation, chemical oxidation and reduction, ion exchange, filtration, electrochemical treatment and

evaporative recovery. However, these highly technological processes have significant disadvantages, including incomplete metal removal, requirements for expensive equipments and monitoring systems, high reagent or energy requirements or generation of toxic sludge and or other waste products that require addressing of disposal problems<sup>5</sup>.

Adsorption on activated carbon has been found to be an effective process for Cr(VI) removal, although this method is too expensive. Large quantities of natural materials are available and certain waste products from industrial or agricultural operations may have the potential to be used as inexpensive sorbents. Due to their low cost, after these materials have been expended, they can be disposed of without expensive regeneration. Most of the low cost sorbents have the limitation of low sorption capacity and thereby for the same degree of treatment they possess disposal problems. Therefore, there is a need to explore low cost biosorbents having high contaminant sorption capacity<sup>6</sup>. Consequently, numerous low cost alternatives have been studied including beech sawdust<sup>7</sup>, eucalyptus bark<sup>8</sup>, walnut sawdust<sup>9</sup>, seaweeds<sup>10</sup>, coir pitch<sup>11</sup>, peanut husks carbon<sup>12</sup>, Zeolite tuff<sup>13</sup>, activated carbon fabric cloth<sup>14</sup>, bagasse fly ash<sup>15</sup>, activated slag<sup>16</sup> etc. In spite of all these, new economical, easily available and highly effective adsorbents are still needed. Generally, biosorption processes can reduce the capital costs by 20%, operational costs by 36% and the total treatment costs by 28%, compared with other conventional methods<sup>17</sup>.

A detailed literature survey shows that *Cajanus Cajan(L)* Milsp has not been tried for use as adsorbent for the removal of chromium ions. The *Cajanus Cajan(L)* Milsp is an important pulse crop in India known as Pigeonpea or Arhar or Tur. It is mainly cultivated and consumed in developing nations. This crop is widely grown in India making it the largest producer and consumer of

Cajanus Cajan(L) Milsp in the world. It accounted for about 20 percent of the total pulse production of the country during the year 2000–2001. Cajanus Cajan(L) Milsp seed shell activated carbons can be used as a low-cost material adsorbent for the removal of Cr(VI) in wastewater. The objectives of the present study is to adsorb Cr(VI) from aqueous solution by batch mode studies. In batch studies, the dynamic behavior of the adsorption was investigated on the effect of initial metal ion concentration, temperature, adsorbent dosage and pH. These thermodynamic parameters were evaluated from the adsorption measurements. The Langmuir and Freundlich adsorption isotherms, adsorption Kinetics, FT-IR spectroscopy and SEM were also studied.

## EXPERIMENTAL

### Preparation of adsorbent

Activated carbons were prepared from Cajanus Cajan(L) Milsp seed shell (CCC). The raw material was procured from local vendors. The material was washed in hot distilled water to remove earthy matter, cut into small pieces and dried. The activated carbon was prepared from the above material, impregnated with concentrated sulfuric acid. For impregnation, a 1:1 of acid volume to weight ratio was employed. After that, the charred material was washed several times in distilled water until the pH of the washings becomes neutral. The material was then dried and carbonized at 500°C in a muffle furnace. Finally, the activated material was ground and sieved using 180–300  $\mu\text{m}$  standard sieves. Commercially available analytical grade other reagents (Merck, SRL, India and SD-fine, India) were used for this study.

### Adsorbate

A stock solution of the adsorbate was prepared by dissolving the exact calculated quantity of potassium dichromate in doubly distilled water which was used throughout the experiments.

### Batch mode studies

50 mL of a known concentration of Cr(VI) solution was taken in a 100 mL screw-cap conical flask with 50 mg of adsorbent. The mixture was agitated at 120 rpm in a thermostatic shaker water bath at 30°C for a 60 min of contact time and the solution was centrifuged. The remaining concentration of Cr(VI) was measured using a UV-Visible spectrophotometer (Systronics 169) with 1,5-diphenyl carbazide in acid medium. The amount of Cr(VI) adsorbed in mg/g at time  $t$  was computed by the following equation<sup>18</sup>.

$$q_t = (C_0 - C_t) \frac{V}{M} \quad (1)$$

where,  $C_0$  = Initial concentration of Cr(VI),  $C_t$  = Concentration at a given time  $t$ ,  $V$  = volume of the Cr(VI) solution in L and  $M$  = weight of activated carbon in g.

The percentage of removal Cr(VI) ions in solution was calculated using the following equation,

$$R(\%) = \frac{C_0 - C_t}{C_0} \times 100 \quad (2)$$

## RESULT AND DISCUSSION

### Adsorbent Characterization

All the parameters were analyzed using standard testing methods<sup>18</sup>. Activated carbons are widely used as adsorbent due to their high adsorption capacity, high surface area, micro porous structure and high degree of surface adsorption. The chemical nature and pore structure usually determine the sorption activity. Some important physico-chemical characteristics of CCC are given in Table 1. The lower ash content values are attributed to lower inorganic content and higher fixed carbon. The high surface area is considered to be most suitable for adsorption of adsorbates in the aqueous solution. The lower bulk density value indicates the highly branched and porous carbon with more void space. Acid soluble matter content was found higher in the carbon because of the incorporated carbonate groups in the pores. Sodium and potassium content may be due to the presence of mineral sodium and potassium in the CCC seed shell<sup>19</sup>.

**Table 1.** Characteristics of the CCC

Parameter	Value
pH	7.48
pHzpc	5.24
Moisture Content (%)	2.8
Bulk density (g/ml)	0.4757
Solubility in water (%)	0.8052
Solubility in 0.25M HCl (%)	4.9114
Porosity (%)	59.098
Specific gravity	1.0718
Volatile matter (%)	8.15
Ash content	3.86
Fixed Carbon	85.19
Sodium (ppm)	67
Potassium (ppm)	3.3
Phenol adsorption capacity (%)	36.2
Conductivity (mS)	1.85
Surface area (m <sup>2</sup> /g)	532

### Effect of adsorbent dosage

The removal of chromium by Cajanus Cajan(L) Milsp seed shell at different adsorbent doses (50–300 mg) for the chromium concentration of 10 mg/L has been investigated. The results (Fig. 1) show that the percent removal of Cr(VI) increases rapidly with increase in the dose of CCC due to the greater availability of the adsorbent<sup>20</sup>. The increase in adsorbent dosage from 50 to 300 mg resulted in an increase from 77.5 to 80.3% in the adsorption of Cr(VI) ions. However, the uptake of Cr(VI) showed a reverse trend against the removal percentage of adsorptions. With increasing adsorbent dosage from 50 mg to 300 mg, the adsorption of Cr(VI) ion per unit weight of adsorbent decreased from 1.77 to 1.66 mg/g. Therefore, 50 mg was taken as the optimum adsorbent dose.

### Effect of pH

The adsorption of Cr(VI) on the activated carbon was examined at seven different pH levels in the range of 2 to 8 as shown in Fig. 2. It is observed that the percent adsorption of Cr(VI) decreases with increase in pH value from 2 to 8. It is important to see that the maximum adsorption occurs at a concentration of pH value of 2. This behavior can be explained considering

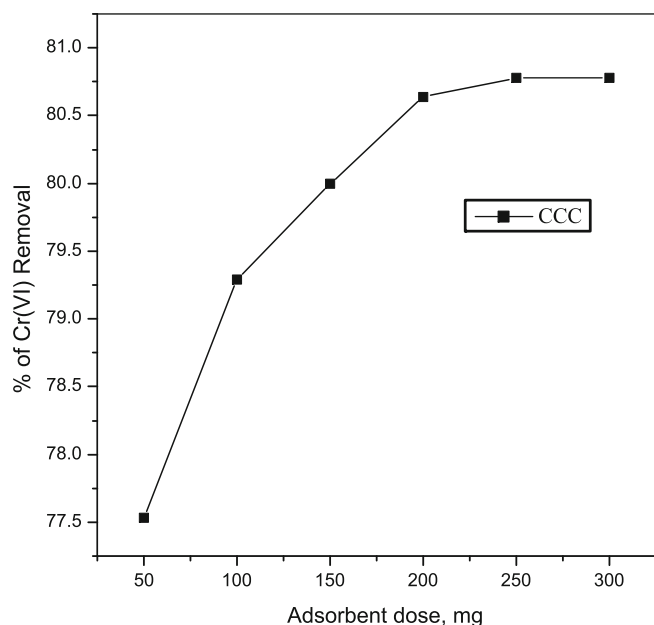


Figure 1. Effect of adsorbent dosage

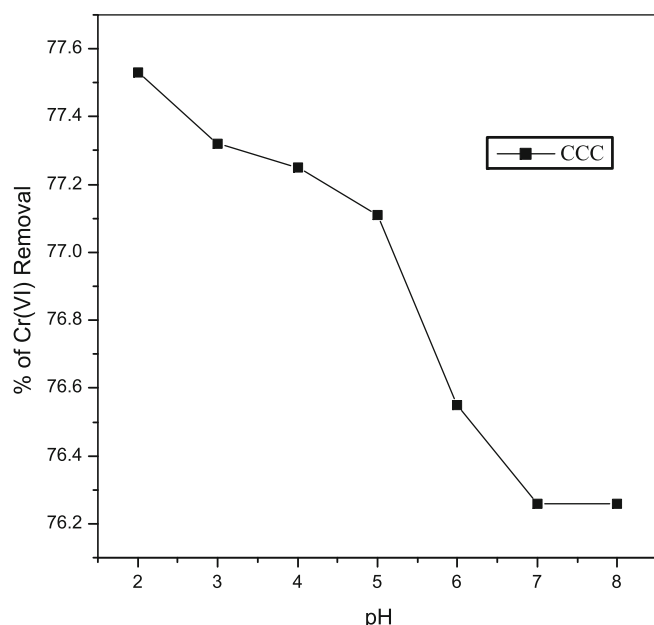


Figure 2. Effect of pH

the nature of metal adsorption at different pH values. The cell wall of activated carbon contains large number of surface functional groups. The pH dependence of metal adsorption can largely be related to the type and ionic state of these functional groups and also on the metal chemistry in solution<sup>21</sup>.

#### Effect of contact time

The effect of contact time on the batch adsorption of Cr (VI) at 30°C, with an initial pH value of 2 and at an initial concentration from 2 to 10 mg/L was done. It is obvious that the increase in contact time from 10

to 60 min. significantly enhanced the percent removal of Cr(VI). The nature of adsorbent and its available adsorption sites affected the time needed to reach equilibrium. All the other experiments were conducted at optimum contact time of 60 min.

#### Effect of initial concentration and temperature

In the present investigation, 50 mg of adsorbents (CCC) were treated with 50 mL of Cr(VI) solutions of different concentration. Sorption experiments were carried out at the most suitable pH value of 2 for each sorbent. As seen from Table 2, at 30°C, as the initial Cr(VI) ion concentration was increased from 2 to 10 mg/L, Cr(VI) the adsorption removal decreased from 79.73 to 77.49% and the uptake capacity of CCC increased from 1.59 to 7.75 mg/g. The increase in the uptake capacity of CCC with the increase in Cr(VI) ion concentration is due to the higher availability of Cr(VI) ions in the solution for the adsorption. Moreover, higher initial Cr(VI) concentration increased the driving force to overcome all mass transfer resistance of metal ions between the aqueous and solid phases resulting in higher probability of collisions between Cr(VI) ions and the adsorbent. This also results in higher metal uptake<sup>22</sup>.

The rise in adsorption capacity with temperature is because of the rise in kinetic energy of the sorbent particles. Thus the collision frequency between adsorbent and adsorbate increases, resulting in the enhanced sorption onto the surface of the adsorbent. Secondly, at higher temperatures due to the rupture of bonds of the functional groups on adsorbent surface, there may be an increase in the number of active sorption sites, leading to enhanced sorption with rise in temperature.

#### Adsorption Isotherms

Isotherms are mathematical relationships used to describe the adsorption behavior of a particular adsorbent- adsorbate combination. They help in modeling the adsorption behavior and in calculating the adsorption capacity of materials. There are three such adsorption isotherms like the Langmuir, Freundlich and Tempkin isotherms.

Linear form of the rearranged Langmuir model<sup>23</sup> is given as

$$\frac{C_e}{q_e} = \frac{1}{Q_0 b_L} + \frac{C_e}{Q_0} \quad (3)$$

The constants  $Q_0$  and  $b_L$  can be calculated from the slope and intercept of the plot of  $C_e/q_e$  versus  $C_e$ . The Linear form of Freundlich equation<sup>24</sup> is

$$\log q_e = \log k_f + \frac{1}{n} \log C_e \quad (4)$$

When  $1/n$  is  $>1.0$ , the change in adsorbed metal ion concentration is greater than the change in the solute concentration.

The Tempkin isotherm assumes that the fall in the heat

Table 2. Effect of the initial Cr (VI) concentration on removal by CCC

C <sub>0</sub> , ppm	Equilibrium concentration (mg/L)			% of Cr(VI) Removal		
	30°C	40°C	50°C	30°C	40°C	50°C
2	0.405	0.366	0.335	79.74	81.67	83.27
4	0.825	0.744	0.673	79.37	81.40	83.16
6	1.291	1.185	1.083	78.49	80.25	81.96
8	1.798	1.633	1.467	77.52	79.59	81.66
10	2.250	2.042	1.844	77.49	79.58	82.55

of adsorption is linear rather than logarithmic as stated in the Freundlich expression. The heat of sorption of all the molecules in the layer would decrease linearly with coverage due to sorbate and sorbent interactions. The Tempkin isotherm is applied in the linear form of Tempkin equation is

$$q_e = \frac{RT}{b_T \ln a_T} + \frac{RT}{b_T \ln C_e} \quad (5)$$

Tempkin constants  $a_T$  and  $b_T$  are calculated from the slopes and intercepts of the plot  $q_e$  vs  $\ln C_e$  and are given in Table 3. Tempkin sorption potential and the Tempkin constant related to the heat of adsorption increases while increasing the temperature up to 50°C. However, the model failed to explain the adsorption isotherm Cr(VI) onto CCC when compared to Freundlich adsorption isotherm due to its poor correlation coefficient ( $r^2 = 0.9675$ ).

**Table 3.** Results of isotherm models for the adsorption of Cr(VI) onto CCC

Isotherms	Parameters	Temperature °C		
		30	40	50
Langmuir isotherm	$Q_o$ (mg/L)	45.454	45.871	52.356
	$b_L$ (L/mg)	0.089	0.101	0.098
	$r^2$	0.973	0.962	0.944
Freundlich isotherm	$N$	1.094	1.097	1.086
	$k_f$	3.694	4.137	4.630
	$r^2$	0.999	0.999	0.999
Tempkin isotherm	$b_T$ (mg/g)	670.502	697.326	721.189
	$a_T$ (L/mg)	3.277	3.682	4.110
	$r^2$	0.974	0.974	0.975

The essential characteristics of the Langmuir equation can be described by the dimensionless equilibrium parameter  $R_L$ ,

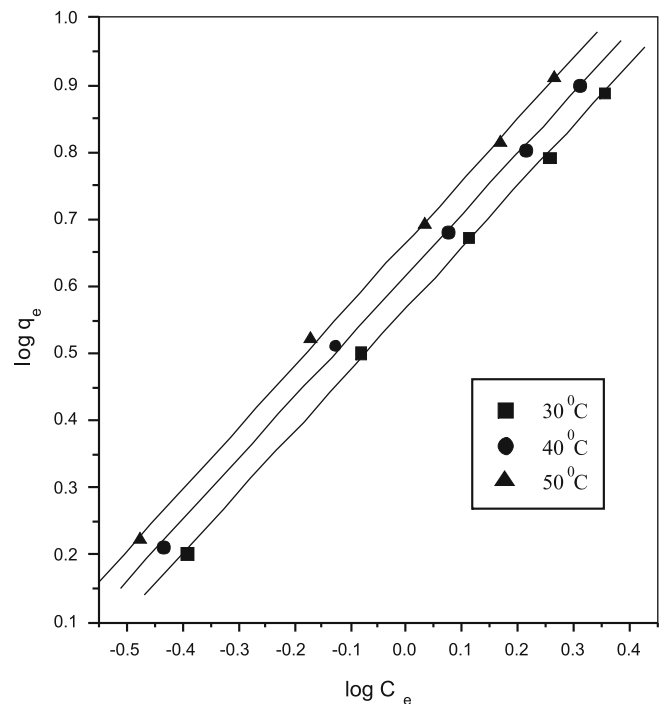
$$R_L = \frac{1}{(1 + b_L \cdot C_o)} \quad (6)$$

Where,  $b_L$  = Langmuir constant,  $C_o$  = initial concentration of Cr(VI) (mg/L). The value of  $R_L$  indicates the shape of the isotherms to be either unfavorable ( $R_L > 1$ ), linear ( $R_L = 1$ ), favorable ( $0 < R_L < 1$ ) or irreversible ( $R_L = 0$ ). Based on  $R_L$  values, adsorption is seen to be a favorable one.

The Langmuir (Figure not shown) and Freundlich isotherms for the removal of Cr (VI) from aqueous solution by activated carbon prepared from Cajanus Cajan(L) Milsp seed shell are shown in Fig. 3. The correlation coefficients and constants of Langmuir and Freundlich isotherms are presented in Table 3. From Table 3, it was observed that correlation coefficients of Freundlich isotherm are higher than the correlation coefficients of Langmuir isotherm and Tempkin isotherms. This indicates that the Freundlich isotherm fits well with the experimental data of the present system. The good agreement of Freundlich isotherm indicates that the surface of the activated carbon prepared from Cajanus Cajan (L) Milsp seed shell is highly heterogeneous<sup>25</sup>.

**Table 4.** Thermodynamic parameters for the removal of Cr (VI) by CCC

$C_o$ , ppm	$K_o$			$\Delta G^\circ$ (KJ/mol)			$\Delta H^\circ$ (KJ/mol)	$\Delta S^\circ$ (J/mol K)
	30°	40°	50°	30°	40°	50°		
2	3.935	4.457	4.976	-3.451	-3.889	-4.309	9.752	43.605
4	3.848	4.377	4.94	-3.395	-3.842	-4.289	10.376	45.402
6	3.649	4.064	4.543	-3.261	-3.649	-4.065	9.104	40.813
8	3.448	3.899	4.453	-3.8527	-3.541	-4.011	10.634	45.369
10	3.444	3.897	4.422	-3.8344	-3.539	-3.992	10.384	44.559



**Figure 3.** Freundlich plot for the removal of Cr(VI) by CCC

#### Thermodynamics studies

The standard free energy, enthalpy and entropy changes along with equilibrium constants were computed<sup>26</sup> and are given in Table 4. The results shown in Table 4 indicate that the standard free energy values are negative which means that the reaction is spontaneous. The values of enthalpy of an adsorption process may be used to distinguish between physical and chemical adsorption processes. Enthalpy change values range from 10.6 to 9.1 kJ/mol. Based on these values, the adsorption of Cr(VI) by CCC could be a physical adsorption process. But the positive values of standard enthalpy change suggest that the process is endothermic nature. The standard entropy change values for the adsorption suggests a high degree of disorder at the solid-liquid interface during the adsorption of Cr(VI) onto CCC<sup>27</sup>.

#### Kinetics of adsorption studies

The kinetic results obtained from batch experiments were analyzed using different kinetic models such as Lagergren pseudo first-order<sup>28</sup>, pseudo second-order<sup>29</sup> models. The integrated form of the pseudo first-order kinetic model is given by

$$\log(q_e - q_t) = \log q_e - \frac{k_1}{2.303} t \quad (7)$$

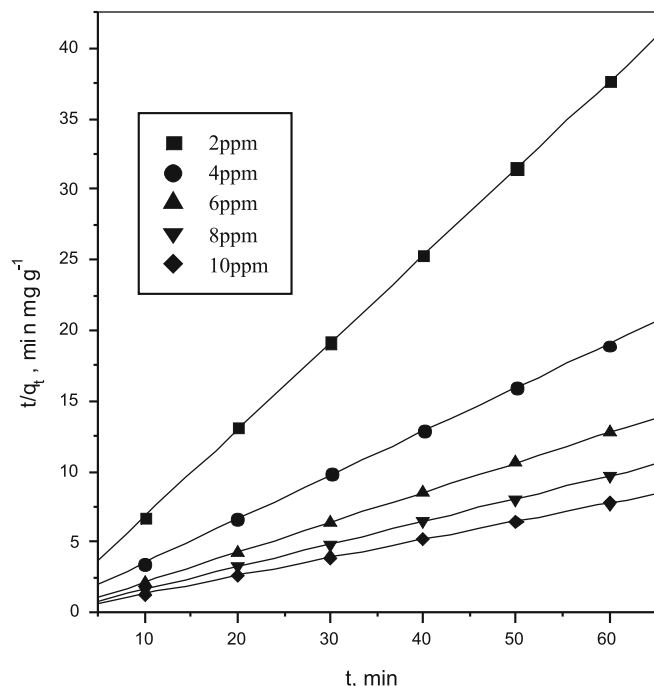
Here, a linear trace is expected between the two parameters,  $\log(q_e - q_t)$  and  $t$ , provided the adsorption follows first order kinetics. The values of  $k_1$  and  $q_e$  can be determined from the slope and its intercept. The adsorption may also be described by the pseudo second-order kinetic model if the adsorption does not follow the first order kinetics.

The linearized form of the pseudo second-order model is

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e} t \quad (8)$$

A plot of  $t/q_t$  and  $t$  should give a linear relationship if the adsorption follows the second order,  $q_e$  and  $k_2$  can be calculated from the slope and the intercept of its plot.

Fig. 4 shows the pseudo second order model of the removal of Cr(VI) from aqueous solution by activated carbon prepared from *Cajanus Cajan(L)* Milsp seed shell. The pseudo- first ( $k_1$ ), The pseudo second order rate constants ( $k_2$ ) and correlation coefficients are shown in the Table 5.



**Figure 4.** Pseudo second order kinetics plot for the removal of Cr(VI) by CCC

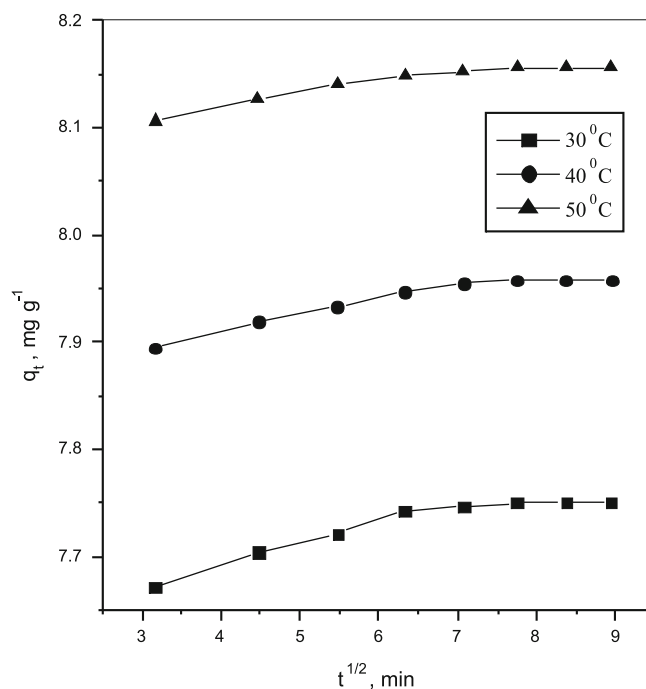
A good agreement between the calculated and experimental results was found in the pseudo-second order model. The experimental data for the adsorption of Cr(VI) with high correlation co-efficient ( $r^2 = 1.0000$ ) is seen from the pseudo-second order model. It is also to be noted that the experimental adsorption capacities ( $q_e$ ) are very close to the adsorption capacities calculated by the pseudo-second order kinetic model<sup>30</sup>. These values are also furnished in Table 5.

#### Intra particle diffusion

Weber and Morris<sup>31</sup> suggested the following kinetic model to investigate whether the adsorption is intra-particle diffusion or not. According to this theory,

$$q_t = k_d t^{1/2} \quad (9)$$

A plot of  $q_t$  versus  $t^{1/2}$  in Fig. 5. shows the intra particle



**Figure 5.** Intra particle diffusion plot for the removal of Cr(VI) by CCC

diffusion rate constant calculated from the slope of the linear portion of curves. The initial curve portions show the boundary layer diffusion and the final linear portions show the intra-particle diffusion effect. Also it could be seen that the linear portions of the traces do not pass through the origin. This indicates that the mechanism of removal of Cr(VI) by CCC is complex and both the surface adsorption as well as intra-particle diffusion contribute to the rate-determining step.

#### Fourier transform infrared spectroscopy (FT-IR) investigations

Numerous chemical functional groups like carboxyl, hydroxyl, amide, halogens etc. have been identified as potential adsorption sites that are responsible for binding the metallic ions to the activated carbon. FT-IR spectrum of activated carbon shows a peak at  $3367 \text{ cm}^{-1}$  indicating the presence of a hydroxyl group. The absorption peaks at  $2923 \text{ cm}^{-1}$ ,  $1623 \text{ cm}^{-1}$ ,  $1559 \text{ cm}^{-1}$ ,  $1099 \text{ cm}^{-1}$  and  $760\text{--}656 \text{ cm}^{-1}$  correspond to carboxylic, amides, halogens and amines, respectively. The region between  $3000\text{--}2800 \text{ cm}^{-1}$  exhibits the C-H stretching vibrations of  $\text{CH}_3$  and  $\text{CH}_2$  functional groups<sup>32</sup>. FT-IR spectrum of loaded Cr(VI) carbon shows that the main adsorption peaks of CCC activated carbon spectrum has not changed much compared to the spectrum of CCC before-adsorption. The results clearly indicate that the adsorption process between CCC activated carbon and Cr(VI) is a physical adsorption and not a complex reaction.

**Table 5.** Pseudo- first and second order constants for the removal of Cr (VI) by CCC

Adsorbent	$C_0$ , ppm	First order kinetic model				Second order model		
		$q_e(\text{exp})$ mg/g	$q_e(\text{cal})$ mg/g	$k_1(\text{min}^{-1})$	$r^2$	$q_e(\text{Cal})$ mg/g	$k_2(\text{g.mg}/\text{min}^{-1})$	$r^2$
CCC	2	1.595	0.228	0.069	0.998	1.620	0.6080	0.999
	4	3.175	0.371	0.039	0.978	3.224	0.2206	0.999
	6	4.709	0.394	0.144	0.935	4.721	1.500	1.000
	8	6.201	0.159	0.074	0.970	6.219	1.002	1.000
	10	7.749	0.213	0.081	0.981	7.770	0.846	1.000

### Scanning Electron Microscopic (SEM) studies

The SEM micrograph (Fig. 6a) clearly shows the porous structure of the active carbon. There are holes and cave type openings on the surface of the specimen which would definitely have increased the surface area available for adsorption. In Fig. 6b depicting the surfaces of particles after adsorption, it is clearly seen that the caves, pores and surfaces of adsorbent were covered by adsorbate and consequently the surface has become smooth. It is evident that upon adsorbing the Cr(VI) the adsorbent structure has changed.

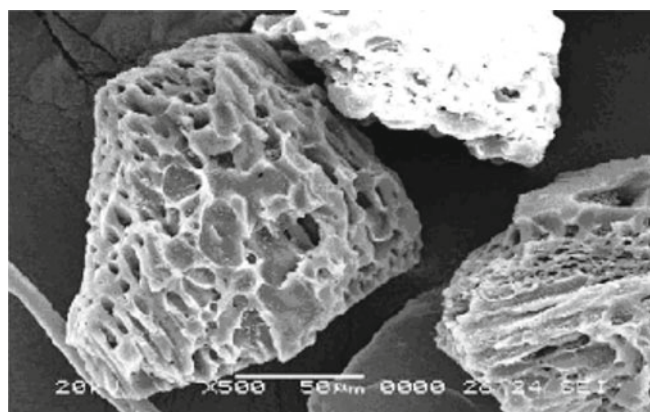


Figure 6a. SEM Photograph of adsorbent before adsorption of Cr(VI)

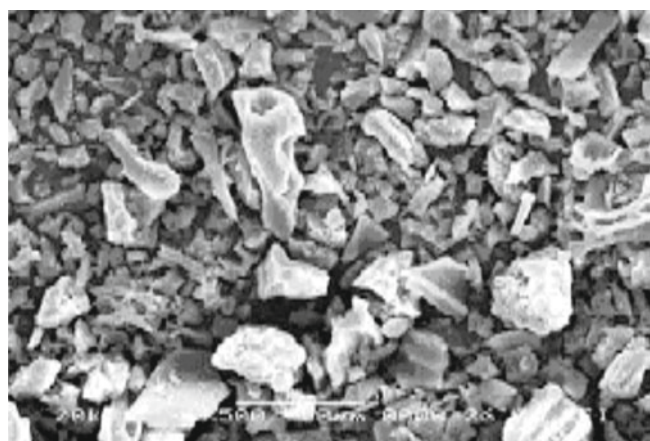


Figure 6b. SEM Photograph adsorbent after adsorption of Cr(VI)

### Test with field samples

Ten water samples were collected in and around the District of Namakkal. As few samples contained moderate heavy metals concentrations, these were treated with CCC. After treatment, no heavy metals concentration was found in these water samples (0.0000 mg/L). The quality parameters of the treated water were in good agreement with the WHO and BIS standards.

### Comparison of Cr(VI) removal with different adsorbents

The adsorption capacity of the adsorbents for the removal of Cr(VI) have been compared with those of others as reported in literature and the values of the adsorption capacities are presented in Table. 6. The experimental data of the present investigation was also compared with the reported values. The results of our investigation revealed that CCC has the highest percent removal and adsorption capacity.

Table 6. Comparison of adsorption capacities of different adsorbents for the removal of Cr(VI)

Adsorbents	Adsorption capacity (mg/g)	References
Raw rice bran	0.07	[33]Oliveria et al.(2005)
Riverbed sand	0.15	[34]Sharma and Weng(2007)
Activated rice husk carbon	0.8	[35]Bishnoi et al.(2004)
Wollastonite	0.83	[36]Sharma(2001)
Coconut shell powder	1.23	[37]Pino et al.(2006)
Flyash	1.4	[38]Banarjee et al.(2004)
Activated alumina	1.6	[35]Bishnoi et al.(2004)
Nanoiron	3.56	[39]Y.C. Sharma et al.(2009)
Saw dust	3.6	[40]Baral et al.(2006)
Distillery sludge	5.7	[41]Selvaraj et al.(2003)
Cajanus cajan seed shell	7.7	Present study

### CONCLUSION

Cajanus Cajan(L) Milsp seed shell activated carbon(CCC) that was prepared from an abundant, environmentally friendly and cheap agricultural waste, could be used as a potential adsorbent for the removal of Cr(VI) from aqueous solution containing heavy metals and polluted water. The Freundlich adsorption isotherm model describes the adsorption behavior with good correlation coefficient. The adsorption of Cr(VI) depended on the pH of the solution. Based on the results, the optimum contact time is 60 min and adsorbent dosage is 50 mg. The metal ion adsorption obeyed the pseudo- second order kinetic model. The removal of Cr(VI) simultaneously increased with increase in the temperature from 30°C to 50°C.

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