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Adsorption of chromium (VI) ion from aqueous solution onto H_2SO_4 activated carbon prepared from *Erythrina indica* bark

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Abstract

Activated carbon prepared from *Erythrina indica* Bark was used as adsorbent for the removal of chromium (VI) ion from aqueous solution. Batch mode adsorption experiments were conducted. The characteristics of the EIBC were determined by SEM, XRD, FTIR, BET analysis and pH_{ZPC}. The maximum removal efficiency of Cr(VI) ion was 68.20% at pH 2. Under the chosen conditions, Experimental data obtained were fitted with linearised forms of Legergren and Ho kinetic models. The Sum of Error Squares Percentage (SSE%) for first order and second order kinetics were 1.21 & 0.09 respectively. Thus this adsorption followed second order kinetics. The equilibrium adsorption data were analyzed with four isotherm models. Order of best fitting isotherm models were found to be Tempkin>Freundlich>Langmuir>DubininRaduskevich. Thermodynamic parameters for such as ΔH, ΔS and ΔG were determined using Van't Hoff plots. Analysis of these values inferred that the adsorption was endothermic, spontaneous with increased randomness. The FTIR, XRD, EDX and SEM studies confirmed that adsorption was physisorption with partial chemisorption. The results in this study indicated that EIBC could be employed as an adsorbent for the removal of Cr(VI) ions from an aqueous solution.

Keywords: Adsorption; *Erythrina indica* Bark activated Carbon (EIBC); Cr(VI)ion removal; Kinetics models; Isotherm studies, Thermodynamic studies; Instrumental studies.

1.0. Introduction

Heavy metals are major pollutants in marine; ground and industrials, and even in treated wastewater. The presence of these metals in the environment has been a great concern because of their toxic nature and other adverse effects on receiving waters. Among these heavy metals are chromium, copper and zinc, and ingestion beyond the permissible quantities can cause various chronic disorders in human beings. It is well known that heavy metals can damage/harm nerves, liver and bones, and they also block functional groups of essential enzymes[1]. Also, acute systemic poisoning can result from high exposure to hexavalent chromium[2]. Most of the chromium ions in wastewater, especially hexavalent chromiumoriginates from industries such as electroplating, metal finishing and magnetic tape manufacturing. For these industrial groups, chromium is a problematic one. Tanning is one of the oldest and fastest growing industries in India. Chromium, which is on the top priority list of toxic pollutants defined by the US Environmental Protection Agency (EPA) exists in nature mainly in two oxidation states +3 and +6. It is a bio element in the +3 state but mutagenic in the +6 state. Therefore, the speciation of chromium in contaminated environment becomes critical for understanding its fate and exposure. The hydrolysis behavior of Cr (III) is complicated and it produces mononuclear species $Cr(OH)^{2+}$, $Cr(OH)^{2+}$, $Cr(OH)^{4-}$ and $Cr(OH)_3^0$, the polynuclear species $Cr_2(OH)_2$ and neutral species $Cr_3(OH)_4^0$. The hydrolysis of Cr^{6+} produces only neutral and anionic species. At pH greater then 6.5, Cr (VI) exists in the form of CrO_4^{2-}.

Chromium (VI) compounds are found to be more toxic than Cr(III) compounds because of their high solubility in water and consequently high mobility. The drinking water guideline recommended by the US EPA is 100µg/L Cr(VI). Several metal ion removal techniques have been targeted as possible solutions. Ion exchange[3], reduction[4], chemical precipitation[5], polymer based membrane separation[6],[7], adsorption[8], electrochemical precipitation[9], solvent extraction[10], cementation[11]and electro kinetic remediation[12] are among the available methods to accomplish the reduction of metal concentration. Nevertheless many of these approaches are marginally cost effective or difficult to implement in developing countries. Therefore, the need arises for a treatment strategy that is simple and robust, and also addresses local resources availability and constraints. Adsorption is an effective and that versatile method for removing chromium particularly when combined with appropriate regeneration steps. This solves the problems of sludge disposal and renders the system more economically viable especially if low cost adsorbents are used. Varieties of activated carbons are commercially available but very few of them are selective for heavy metals and most of them are very costly/expensive[13]. Despite the prolific use of activated carbon[14], in wastewater treatment the price of this material is quite expensive and there is a definite need for substitute materials to suit these demanding applications. The solid materials should be able to be regenerated with simultaneous quantitative recovery. For the past few years there has been developing interest in the preparation of low cost adsorbents as alternatives to activated carbon in water and wastewater treatment processes. In several previous reports, many investigators have studied the feasibility of less expensive materials such as alginate beads[15], wheat straw[16], carbon develop from waste material[17], biosorbents[18], activated sludge[19], fly ash[20] and agricultural waste[21], for the removal of chromium from waste water. However the problems associated with these adsorbents are the regeneration and recovery processes, which made them unattractive for wider commercial applications. This calls for a research effort to develop an industrially viable, cost effective and environmentally compatible technology for the removal of chromium from wastewater.

In this study, we have derived a low cost activated carbon from agricultural waste, namely *Erythrina indica* Bark activated Carbon (EIBC)for the removal of hexavalent chromium ions from industrial waste water.

Table:1.0 Nomenclature

Nomenclature	
C_i	Liquid phase initial concentrations of the adsorbate (mg/L)
C_t	Liquid phase concentrations of the adsorbate at time "t" (mg/L)
C_e	Liquid phase concentrations of the adsorbate at equilibrium (mg/L)
V	Volume of the adsorbate solutions in liter (L)
W	Mass of the adsorbent (g)
q_e	Quantity adsorbed at equilibrium (mg/g)
q_t	Quantity adsorbed at time "t" (mg/g)
T	Time in minutes
Q_e	Amount of solute adsorbed per unit weight of adsorbent (mg/g)
C_e	Equilibrium concentration of solute in the bulk solution (mg/L)
Q_0	Langmuir adsorption efficiency
B	Langmuiradsorption energy
R_L	Langmuirseparation factor
C_0	Initial concentration of the adsorbate
K_f and n	Freundlich constants incorporating all factors affecting the adsorption capacity and intensity of adsorption respectively
B_1	Tempkinconstant related to heat of sorption (J/mol)
K_T	Tempkin equilibrium binding constant
q_D	D-R isothermtheoretical saturation capacity (mg/g)
B	D-R isothermconstant related to the mean free energy
E	D-R isotherm polanyi potential
E	D-R isothermmean free energy of adsorption
R	Gas Constant
T	Temperature (K)
k_1	Rate constant of adsorption (l/min)
k_2	Second-order constants
h	Initial adsorption rate (mg/g min)
N	Number of data points

2.0. Materials and Methods

2.1 Materials:

All the chemicals used for these experiments are analytical grade. Activated Carbon was prepared from *Erythrina indica* Bark.$K_2Cr_2O_7$, complexing reagent used as Diphenyl Carbazide purchased from Merck Company.

2.2 Preparation of Stock solution:

Cr(VI) was determined spectrophotometrically using diphenyl carbazide. 2.5ml of the filtered sample solution containing Cr(VI) was transferred to 25ml standard flask. 3ml of 2N H_2SO_4 and 0.5ml of diphenyl carbazide solution (0.5% in acetone) were added and made up to 25ml with double distilled water. The absorbance of red-orange Cr(VI)-diphenyl carbazide complex was measured at 540 nm.

2.3 Preparation of Adsorbent:

Activated carbon sorbent derived from the barks *Erythrina indica* (Indian coral tree) by sulphuric acid treatment. The barks of *Erythrina indica* were cut into smaller pieces, dried in sunlight for 8 hours and then soaked in concentrated H_2SO_4 acid at 1:1 ratio (W/V) for 48 hours and activated at 160°C in air oven for 6 hours. The activated carbon was repeatedly washed with distilled water until the pH of the wash water become neutral. The carbon obtained was dried at 110 ± 0.5° C for nearly 2 hours to remove the moisture. The dried material was ground well to a fine powder and sieved using the sieves of desired particle size range. The particles in between the sizes of 0.106 and 0.212 mm were taken. The above prepared carbon was designated as *Erythrina indica* Bark Carbon (EIBC) and kept in a desiccator.

2.4 Physico - chemical characteristics of Adsorbent:

The activated carbon prepared from *Erythrina indica* barks was designated as *Erythrina indica* Barks Carbon (EIBC). The various characteristics of the EIBC determined were collected in the Table: 2.0.

Table: 2.0 Physico - chemical characteristics of EIBC

S.No.	Properties	Values
1.	Surface area (BET), m^2/g	483.52
2.	Bulk density, g/mL	0.4210
3.	Particle size (mm)	0.106 -0.212
4.	Moisture content, %	3.98
5.	pH_{zpc}	6.42
6.	Pore volume, cm^3/g	0.448
7.	Fixed Carbon, %	76.32
8.	Pore size (Pore width), nm	2.436

2.5 Batch Adsorption procedure:

Batch adsorption studies were carried out in 250 mL iodine flasks with 50 mL of the Cr(VI) ion solution of different concentrations ranging from 10 mg/L to 20 mg/L. Known amount of adsorbent was added to the solution. The flasks were agitated at a constant speed of 180 rpm. Samples were collected from the flasks at predetermined time intervals for analyzing the residual Cr(VI) ion concentration in the solution. The amount of Cr(VI) ions adsorbed in milligram per gram of adsorbent was determined by using the following mass balance equation:

$$q_e = (C_i - C_e)V/W$$

Where C_i and C_e are Cr(VI) ion concentrations (mg/L) before and after adsorption, respectively, V (L) is the volume of adsorbate in litre and W (g) is the weight of the adsorbent in grams. The percentage of removal of Cr(VI) ions was calculated using the following equation:

$$\text{Removal (\%)} = (C_i - C_e)/C_i \times 100$$

3.0. Results and Discussion

3.1 Effect of Contact time and initial concentration:

The effect of contact time on percentage removal of Cr(VI) ion for different initial concentration have been shown in figure 1. Adsorption of Cr(VI) ion from the solution increases with the time and finally attains equilibrium at 80,80 and 100 minutes for the initial concentrations 10,15 and 20 mg/L respectively. The percentage of removal increased with the increase in contact time and decreased with the increase of initial concentration of the Cr(VI) ion. However the amount of metal ion adsorbed on the adsorbent increased with the increase of initial concentration of the Cr(VI) ion solution [22]. This is depicted in figure 1 and given in table 4.

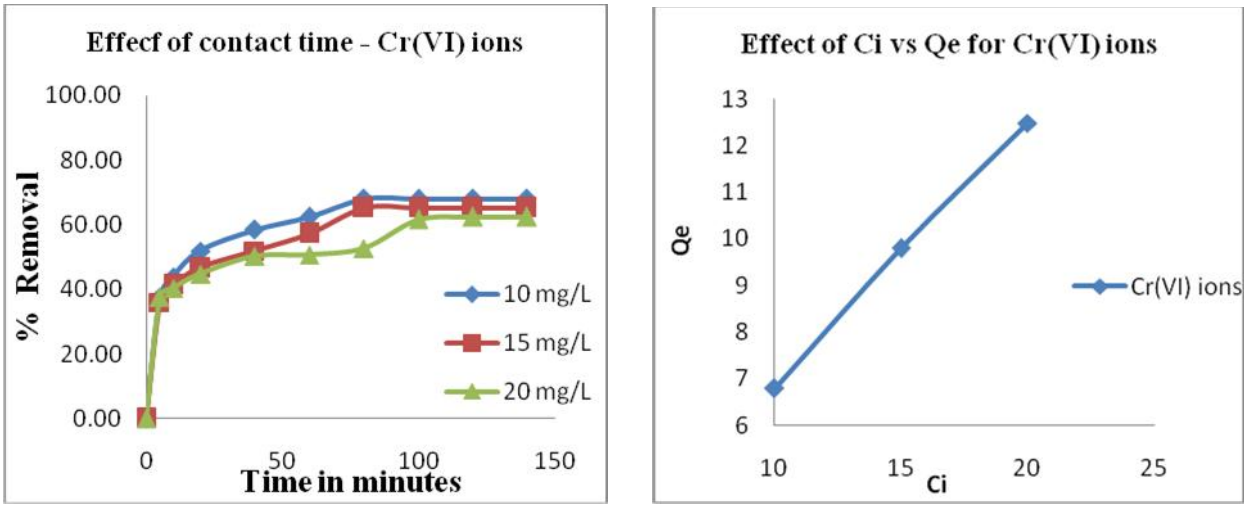


Figure: 1 Effect of Contact time and Ci vs Qe for Cr(VI) ion onto EIBC

Table:4 Percentage of removal of metal ion and amount of metal ion adsorbed

C_i (mg/L)	% of Removal of metal ion at equilibrium	Adsorbed amount of Cr(VI)ion at equilibrium (mg/g)
10	68.00	06.80
15	65.33	09.80
20	61.60	12.48

3.2 Effect of pH:

The pH of the solution plays a major role in determining the amount of solute adsorbed because the pH of the solution affects the functional groups of the adsorbents, alters the surface charge of the adsorbent and also governs the speciation of the solute. In this present investigation, adsorptions of chosen adsorbates were studied in the pH range of 2-7. Solution pH beyond 7 was not studied as the heavy metal ions get precipitated at alkaline pH. Maximum Cr (VI) ion removal was 68.20 % at pH 2. For pH > 2, the uptake is decreased. The reason for the high percent of removal of Cr (VI) at lower pH range was explained as below. The Cr (VI) exists in different forms such as $HCrO_4^-$, $Cr_2O_7^{2-}$ and CrO_4^- ions in aqueous solution and the stability of these forms is dependent on pH of the system. The active form of Cr (VI) ion adsorbed is $HCrO_4^-$ ions. This form is stable at only lower pH range which leads to high removal of chromium. The concentration of this form decreases with the increase of pH[23].

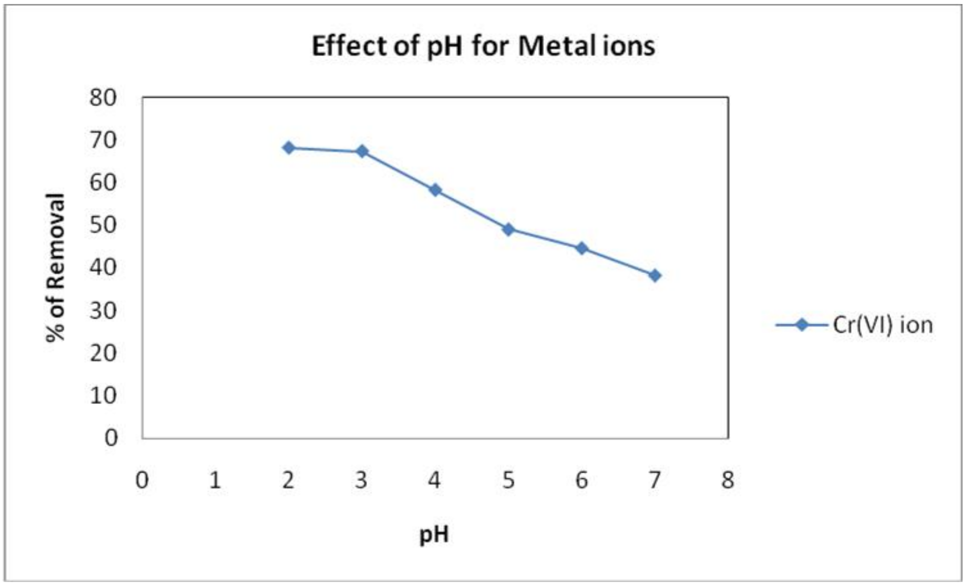


Figure:2 Effect of pH for Cr(VI) ion onto EIBC

Table: 3 Data processing Tools

S. No.	Parameters		Formulae
1.	**Kinetic Models & SSE %**	Pseudo First order kinetics (Legergren equation)	$\log (q_e-q_t) = \log q_e - k_1/2.303 \times t$
		Pseudo Second order kinetics (Ho equation) The initial adsorption rate h	$t/q_t=1/k_2.q_e^2 +1/q_e t$ $h = k_2q_e^2$
		Sum of error squares	SSE (%)= $\sqrt{\sum[(q_e)_{exp}-(q_e)_{cal}]^2/ N}$
2.	**Isotherms**	Langmuir Separation factor	$C_e/Q_e = 1/Q_0b + C_e /Q_0$ $R_L = 1 / (1+ bC_0)$
		Freundlich	$\log Q_e = \log K_f + 1/n \log C_e$
		Tempkin	$q_e = B_1 \ln K_T + B_1 \ln C_e$
		Dubinin – Raduskevich, Polanyi potential Mean free energy of adsorption	$\ln q_e = \ln q_D - B\varepsilon^2$ $\varepsilon = RT \ln (1+1/C_e)$ $E = 1/ (2B)^{½}$

3.3 Effect of Temperature:

It is well known that temperature plays an important role in the adsorption process. The metal ions removal increase rapidly from 305K, 315K and 325K 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[24].

4.0 Adsorption Kinetics:

The adsorption kinetics shows the evolution of the adsorption capacity through time and it is necessary to identify the types of adsorption mechanism in a given system. Plots of different kinetic models applied were given in the Figure: 3 and the kinetic parameters calculated were given in the Table 5. Between the first order and second order, second order kinetic model seems to best describe the above adsorption system as its R^2 values were very close to unity. Moreover, difference between qe (cal) and qe (exp) values of second order is small when compared to first order kinetic model. Statistically it is tested with the tool Sum of error squares (SSE%) [22].The Δqe and SSE % values were given in the Table: 5 from which it was concluded that second order kinetic model was more appropriate rather than first order kinetic model.

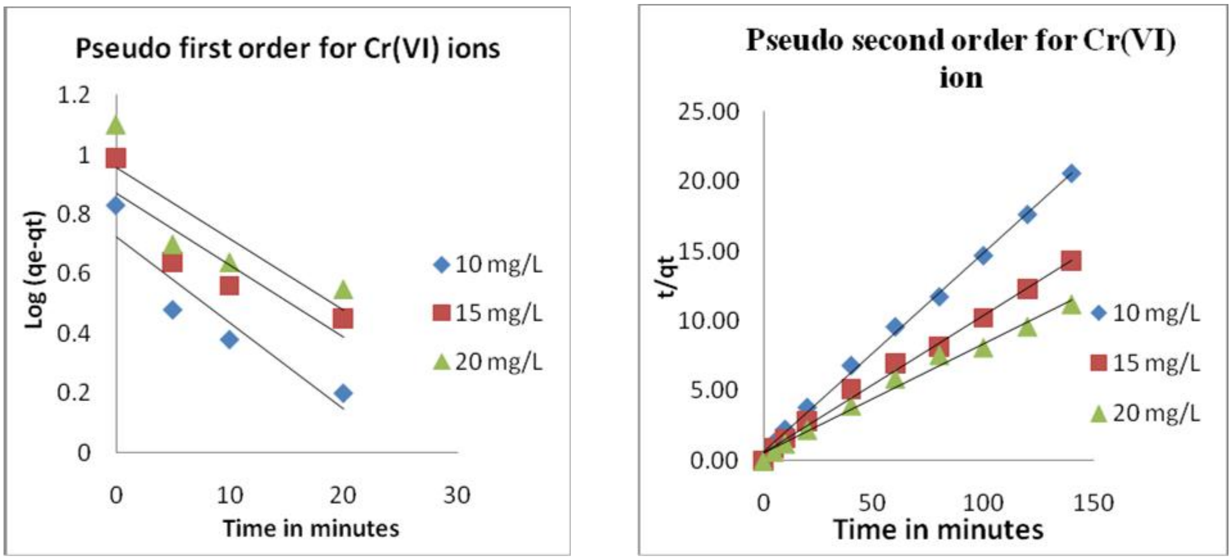


Figure: 3 Pseudo first and second order kinetics

Table: 5 Kinetic parameters for Cr(VI) ions onto EIBC

Ci mg/L	Rate constants		$q_{e(cal)}$ mg/g		$q_{e(exp)}$ mg/g		Δq_e		R^2		(SSE %)	
	k_1 (10^{-2}) (min^{-1})	k_2 (10^{-3}) $(g mg^{-1} min^{-1})$	First Order	Second order	First order	Second Order	First order	Second Order	First order	Second order	First order	Second Order
10	6.66	3.20	5.3	7.0	6.8	6.8	1.5	0.2	0.86	0.99	1.21	0.09
15	5.64	1.40	7.2	10.2	9.9	9.9	2.7	0.3	0.79	0.99		
20	5.57	1.20	8.8	12.7	12.4	12.4	3.6	0.3	0.71	0.98		

5.0 Adsorption Isotherm Studies:

The existence of equilibrium between the liquid and solid phase is well described by adsorption isotherms. Equilibrium data collected at different temperatures were fitted in Langmuir, Freundlich, Tempkin and Dubinin-Raduskevich adsorption isotherm models. These isotherms are depicted in Figure: 4. The R^2 values of these isotherm plots reveal that Freundlich isotherm well describes the present system that is the possibility of multilayer adsorption. R^2 value of Dubinin-Raduskevich isotherm is very low. In Dubinin-Raduskevich isotherm, the very low value of the constant ‘B’ related to the mean free energy of adsorption per mole of the adsorbate and the adsorption is physical in nature[24]. Results of various isotherms are presented in Table: 6.

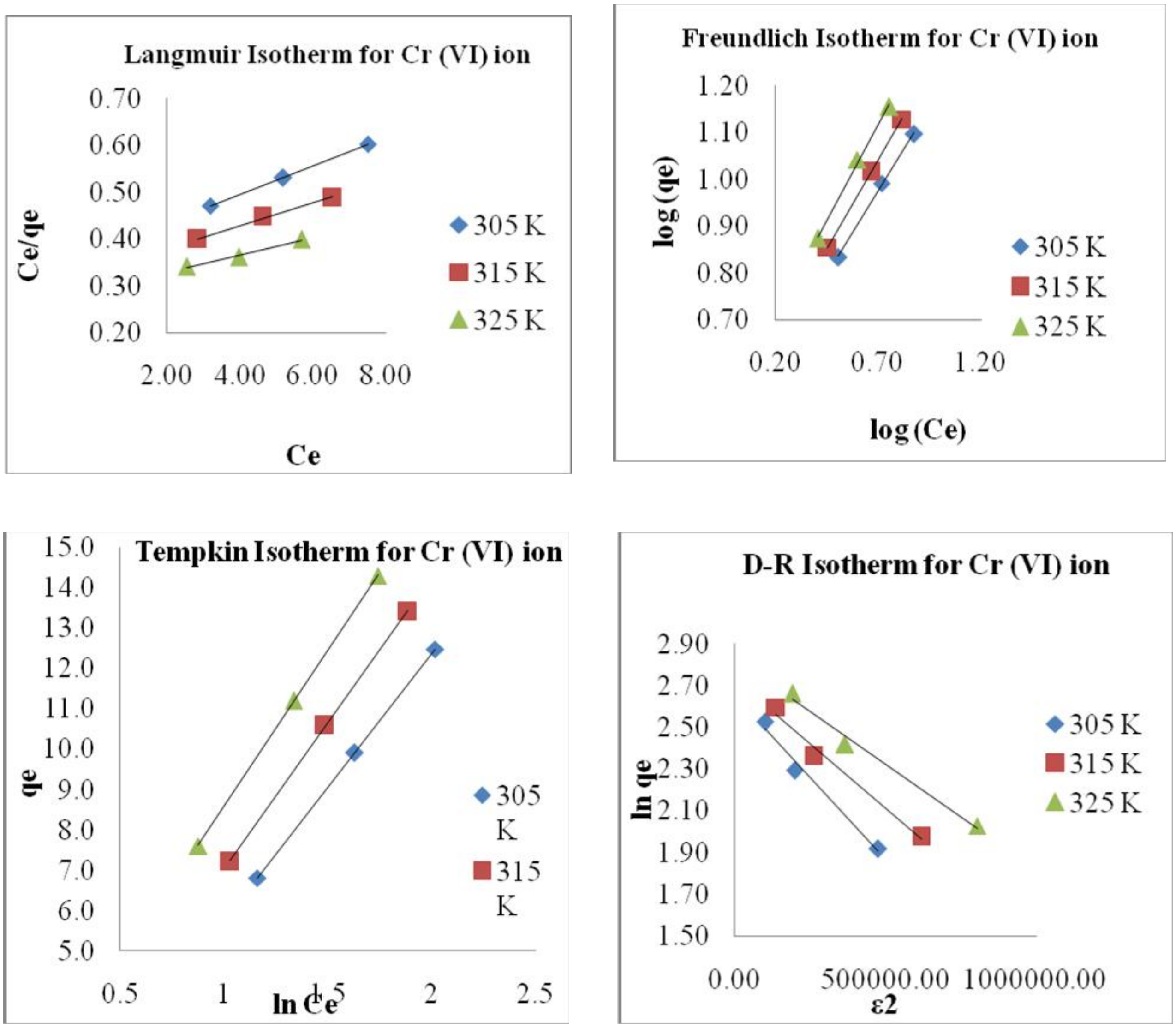


Figure: 4 Langmuir, Freundlich, Tempkin and Dubinin-Raduskevich for the adsorption of Cr(VI) ion onto EIBC

Table: 6 Results of various isotherms plots for the adsorption of Cr(VI) ion onto EIBC

Isotherm Models	**Temp (K)**	**Parameters and their results**			
		Q_0 (mg/g)	b	R_L	R^2
Langmuir	305	32.680	0.08	0.57	0.9900
	315	41.494	0.07	0.48	0.9900
	325	54.054	0.06	0.43	0.9800
Freundlich		K_f (mg/g^{-1})	n		R^2
	305	2.9	1.4		0.9900
	315	3.2	1.3		0.9900
	325	3.5	1.2		0.9900
Tempkin		B_1 (J/mol)	K_T (L/g)		R^2
	305	381.508	0.0608		1.000
	315	362.058	0.0134		0.990
	325	348.014	0.0463		1.000
DubininRaduskevich		q_D (mg/g)	E (kJ/mol)	B × 10^{-4} (mol^2/J^2)	R^2
	305	14.1	0.500	0.0012	0.9800
	315	15.3	0.707	0.0015	0.9800
	325	16.8	0.707	0.0032	0.9800

6.0 Thermodynamic study

Thermodynamic parameters like ΔH°, ΔS° and ΔG° were measured based on van't Hoff's plot.

K_d=Csolid/ Cliquid

$\Delta G° = -RT \ln k_d$

$\text{Log } K_d = \Delta S°/(2.303R) - \Delta H°/(2.303R)T$

Where, K_d is the equilibrium constant, ΔH° and ΔS° are the standard enthalpy and entropy changes of adsorption respectively and The values of ΔH° and ΔS° are calculated from the slopes and intercepts of the linear plot of ln K_d vs 1/T. The free energy of specific adsorption ΔG° (kJ/mol) is calculated from the following expression

$\Delta G° = \Delta H° - T\Delta S°$

The thermodynamically parameters calculated from van'thoff's plot are given in table 7. Negative ΔG° of adsorption indicates that the adsorption process is favorable and spontaneous in nature. The endothermic nature of adsorption is confirmed by the positive ΔH° values. The bonding between Cr(VI) ions and EIBC surface is very weak, since ΔH° values are found to be in between 14.1005 to 17.0188kJ/mol. Positive values of ΔS° suggested good affinity of the dye towards the adsorbent and the adsorption is spontaneous in nature[22].

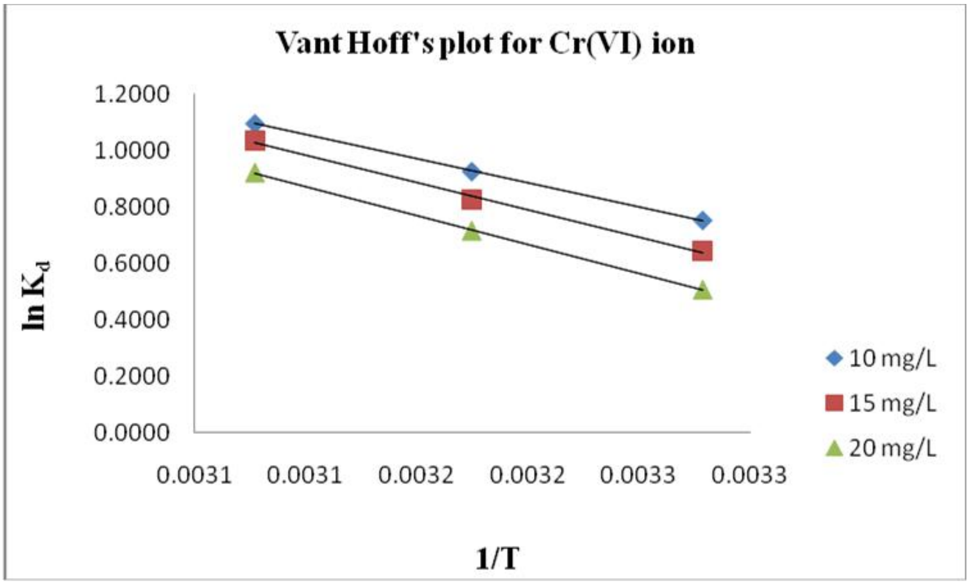


Figure 5: Thermodynamics for the adsorption of Cr(VI) ions onto EIBC

Table:7 Thermodynamics parameters for the adsorption of Cr(VI) ions onto EIBC

Ci mg/L	$-\Delta G^0$kJ/mol			ΔH^0 kJ/mol	ΔS^0 kJ/mol
	305K	315K	325K		
10	-1.9117	-2.4275	-2.9619	14.1005	52.4904
15	-1.6330	2.1647	-2.7961	16.2372	58.0500
20	-1.2848	-1.8709	-2.4858	17.0188	60.0204

7. 0 Instrumental Analysis:

7.1 FT-IR spectrum study:

The FTIR spectrum of EIBC and Cr(VI) loaded EIBC were shown in figure 6. The peaks positions of the above spectrum were given in table 8.

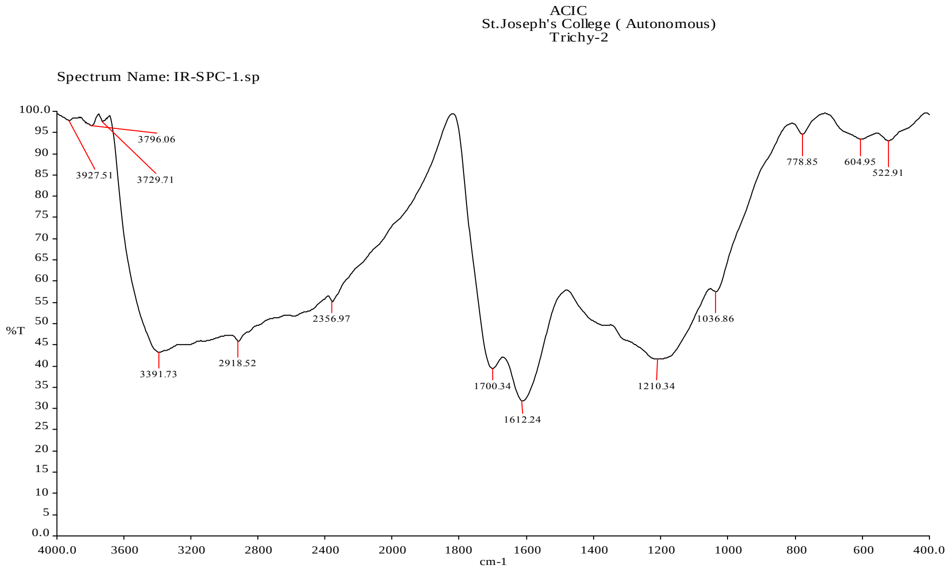
Table: 8 FTIR study of Cr(VI) ions loaded EIBC

S.No.	**Band position cm^{-1}**		**Observation**
	EIBC	**Cr(VI)loaded EIBC**	
1.	3846.29 May be due to water adsorption	3963.23	Peaks were slightly shifted
2	3777.27 May be due to water adsorption	3775.87	
3.	3372.27	3368.82	
4.	2923.85	2921.17	
5.	--------	2365.88 O-H stretch in acid group (2350-3300)	New peak Formed
6.	1704.45(1650-1730) C=O stretch in acid group	-------	Peak Disappeared
7.	1612.52(1600-1675) C=C symmetric stretch	1601.12	Peaks were slightly shifted
68.	1378.48 (1300-1410) C-O stretch in phenol	1385.21	
9.	1212.91(1020-1220) C-N stretch in amine	1213.38	
8	1037.69(1020-1250) C-O stretch in ether or ester	-------	Peak Disappeared
11.	777.56 (750-800) C-H stretch in di substituted benzene	769.40	Peak slightly shifted

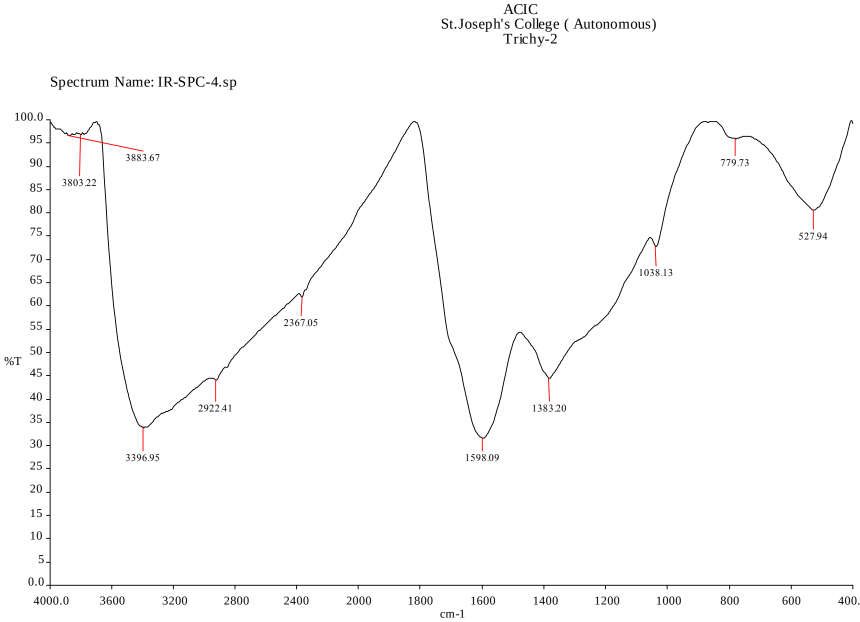
The band at 3372.87 cm^{-1} for EIBC was due to the O-H stretch vibrations and was shifted to 3368.82cm^{-1} for Cr(VI) ions loaded EIBC.The bands at2923.85cm^{-1} ,1612.52 cm^{-1}1378.48 cm^{-1} 1212.91 cm^{-1} were due to the C – H ,C=C symmetric stretch C-Ostretch C-N stretch were slightly shifted to 2921.17cm^{-1},1601.12 cm^{-1},1385.21 cm^{-1} 1213.38 cm^{-1} respectively for Ni (II) ions loaded adsorbent. These results indicated the involvement of C-H,C-O,C = C, C – N functional group in adsorption process.

The characteristics adsorption peaks detected in EIBC at 1037.69 cm^{-1} due to C-O stretch was not detected in Cr(VI)loaded EIBC. This infers that C-O functional group was involved in binding the Ni (II) ions. The one new peak was formed at 2365.88 cm^{-1} for Cr(VI) loaded EIBC corresponding to N-H stretch which may be due to formation of new chemical bonds between the metal and adsorbent.

It is noticed that there is no change in the FTIR pattern of EIBC and Cr(VI) ions loaded EIBC adsorption between the range 400-4000 cm^{-1}. Thus this FTIR spectral study supports physisorption.



FTIR of EIBC



FTIR of Cr(VI) ion loaded EIBC

Figure: 6.FT-IR spectrum for before and after adsorption of Cr(VI) ion onto EIBC

7.2 Energy Dispersive X-ray Spectroscopy (EDX) study:

Energy Dispersive X-ray Spectroscopy (EDX) is an analytical capability that can be coupled with several applications including Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM) and Scanning Transmission Electron Microscopy (STEM). EDX, when combined with these imaging tools, can provide elemental analysis on areas as small as nanometers in diameter. The impact of the electron beam on the sample produces x-rays that are characteristic of the elements present on the sample. EDX Analysis can be used to determine the elemental composition of individual points or to map out the lateral distribution of elements from the imaged area.

EDX analysis of Cr (VI) ion loaded EIBC was shown in Figure 7. The well-defined peak of adsorbent loaded with Cr(VI) ion shows that Cr(VI) ions were bound onto the EIBC surface. Peaks of certain Cr(VI) ion are very small which infers the surface adsorption through Vander Walls force.

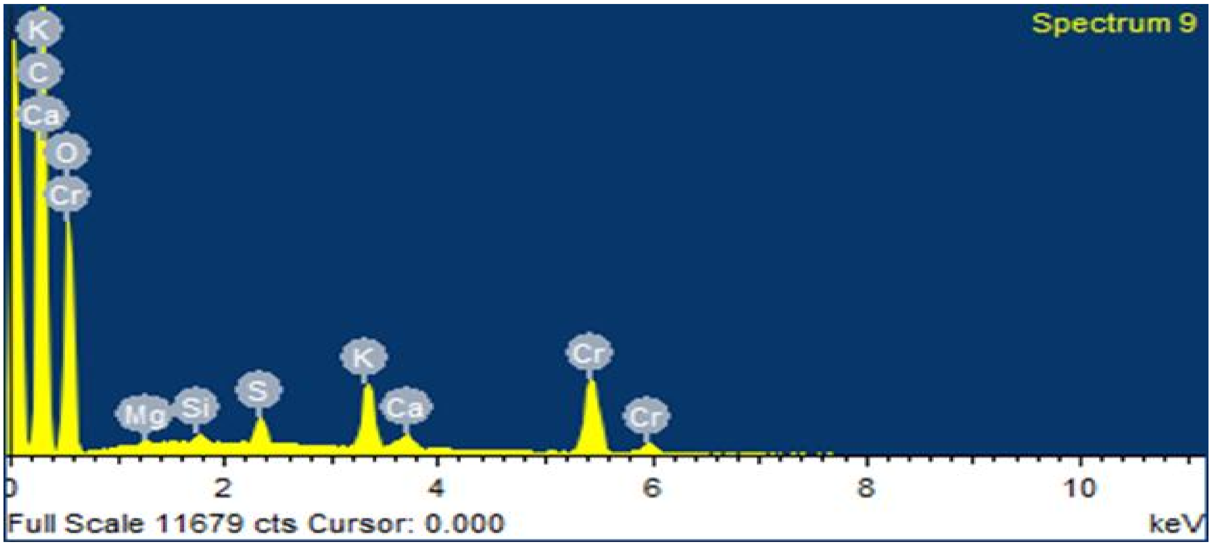


Figure: 7.EDX for adsorption of Cr(VI) ion onto EIBC

7.3 SEM Analysis:

The surface morphology of the EIBC carbon was examined using scanning electron microscopy (SEM), the corresponding SEM Micrographs being obtained using at an accelerating voltage of 10 kv at 2400 x and 10kv at 3830 x magnifications (Figure 8). At such magnification, the activated carbon particle showed rough areas of surface on which micro pores and macro pores were clearly identifiable.

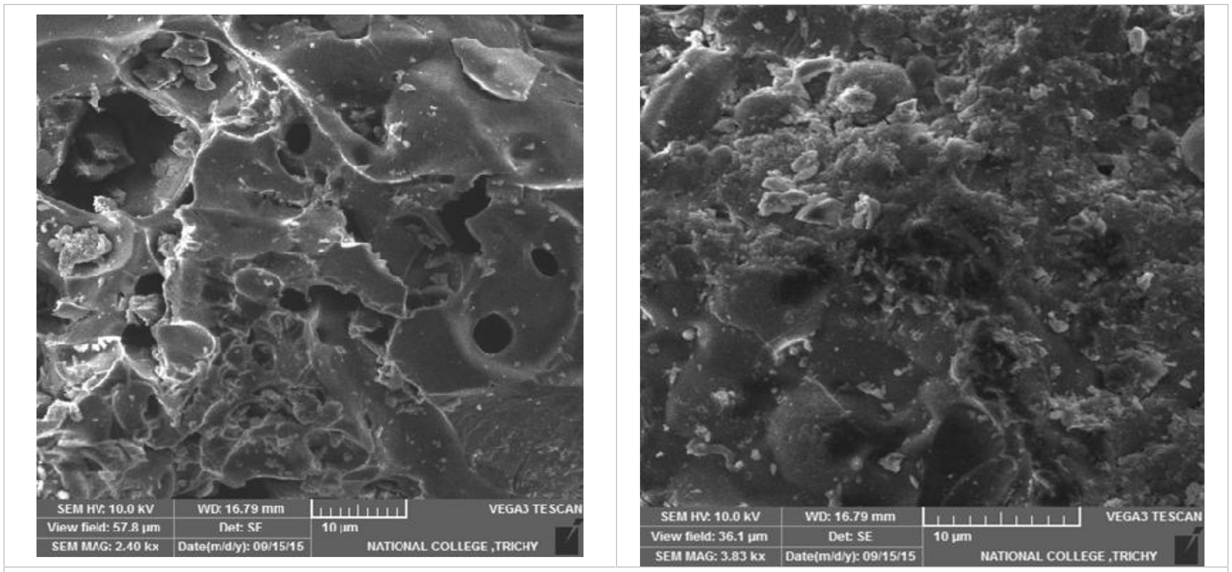


Figure: 8 SEM images of EIBC

7.4 XRD spectrum study:

X-ray Diffraction pictures of EIBC and EIBC loaded with the adsorbates are shown in figure:9.Inwhich there is no appreciable change in the before and after XRD patterns. Peak positions only slightly found to be changed. This study supports the predominant physisorption.

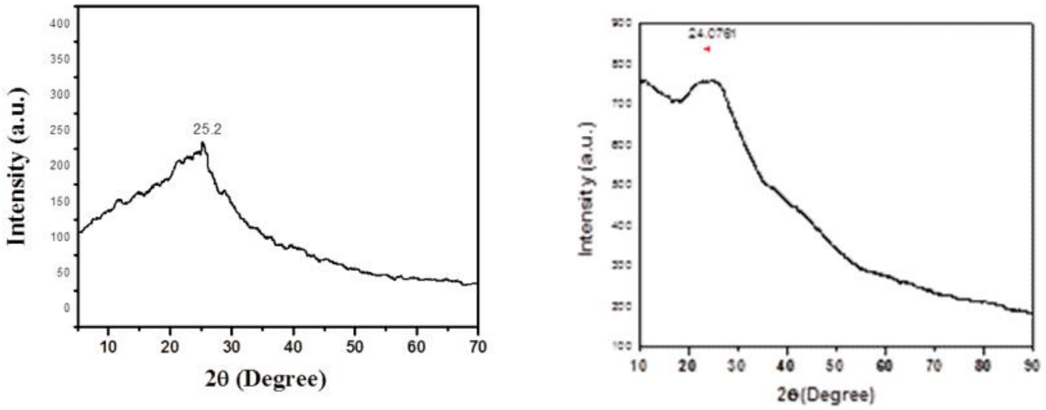


Figure: 9 XRD pattern for before and after adsorption of Cr(VI) ions onto EIBC

8.0 Analysis of Isotherm:

8.1 Langmuir isotherm:

In the present study Q_0 value ranges from 32.680 to 54.054 as the temperature increases the monolayer adsorption capacity also found to increase. This kind of results was obtained in various similar studies [25].The separation factor R_L values were in between 0 to 1 which indicates that favourable adsorption. The R^2 values from 0.9800 to 0.9900.

8.2 Frendlich isotherm:

The values of n were between 1 and 10 which indicates cooperative adsorption [26]. The R^2 values ranged in 0.9900.

8.3 Temkin Isotherm:

B_1-Temkin constant is related to the heat of adsorption. This B_1 value increased from 381.508 to 348.014 as the temperature of adsorption increased. The temkin parameter K_T values give an idea about nature of adsorption [27]. In our present study the K_T values ranged from 0.0134 to 0.0608 which indicates that adsorption is physical nature. The R^2 values were close to unity which revealed the good fitting into temkin isotherm.

8.4 Dubinin-Raduskevich:

The activation energy E value ranges from 0.500 to 0.707 and B value from 0.0012 to 0.0032 indicates the physisorption[28]. The R^2 value was very low when compared to other three isotherms.

In general the fitting data in isotherm equation were in the following order: Temkin>Frendlich> Langmuir>Dubinin-Raduskevich.

9.0. Conclusion

The result of this investigation show that activated carbon developed *Erythrina indica* Barks has a suitable adsorption capacity for the removal of Chromium metal ion from aqueous solutions. The experimental results were analyzed by using Langmuir, Freundlich, Tempkin and Dubinin-Radushkevich isotherm models and the correlation coefficients for Tempkin, Freundlich and Langmuir equations fitted better than Dubinin- Radushkevich equations. The kinetics study was performed based on pseudo-second order equation. The maximum removal of chromium metal was found to be 68.20% at pH 2. Thermodynamic parameters such as ΔH^o, ΔS^o, ΔG^o values inferred that the adsorption was spontaneous, endothermic and physical nature. The instrumental analysis FTIR, XRD studies gives an idea that adsorption was physisorption with partial chemisorption. SEM pictures described the porosity of *Erythrina indica* Barks Carbon (EIBC). Based on the above investigations, the present study suggests that EIBC could be employed as a promising low-cost adsorbent for the removal of Chromium metal ions from aqueous solution.

10.0. References

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