

INTERNATIONAL JOURNAL OF CURRENT RESEARCH IN CHEMISTRY AND PHARMACEUTICAL SCIENCES

(p-ISSN: 2348-5213; e-ISSN: 2348-5221)
www.ijrcrps.com



Research Article

ADSORPTIVE REMOVAL OF FERROUS ION BY LOW COST ACID ACTIVATED CYNODON DACTYLON CARBON

U. GAYATHRI^{1*}, B. R. VENKATRAMAN² AND S. ARIVOLI³

¹Department of Chemistry, S.T.E.T. Women's College, Mannargudi, Tamil Nadu, India

²PG & Research Department of Chemistry, Periyar E.V.R.College (Autonomous), Tiruchirappalli, Tamil Nadu, India

³Department of Chemistry, Thiru. Vi. Ka. Govt. Arts College, Thiruvarur, Tamil Nadu, India

Corresponding Author: niranjangayathri@gmail.com

Abstract

Cynodondactylon plant which have been chemically modified in acidic condition were used as adsorbent for the removal of ferrous ions from aqueous solution. The adsorbent was characterized by SEM images, FT-IR and XRD analysis. Effecting parameters like initial pH, initial concentrations of metal ions and contact time were investigated. The adsorption data were well fitted by Langmuir and Freundlich isotherm model. Kinetic data were best described by Reversible First - order model. Thermodynamic studies showed spontaneous and endothermic nature in the adsorption of Fe (II) ions by the modified acid activated Cynodondactylon carbon.

Keywords: Activated Cynodondactylon carbon (CDC), ferrous ion, adsorption isotherm, equilibrium, kinetic and thermodynamic parameters, intraparticle diffusion, regeneration pattern.

Introduction

Toxic metal compounds coming to the earth's surface not only reach the earth's water (seas, lakes, ponds and reservoirs) but can also contaminate ground water in trace amounts by leaching from the soil. Therefore, the earth's water may contain various toxic metals. Metal ion such as ferrous ion produces undesirable effects on human and animal life even in low concentrations. In recent years many researchers have studied the removal of different heavy metal ions including iron, chromium, nickel and copper from the water. Wastewaters from industries released in to nearby land or rivers without any treatment because the conventional treatment methods are not cost effective in the Indian context. On the other hand, low cost technologies never allow a wishful metal ion removal and it has certain disadvantages. Adsorption is one of the most effective methods and activated carbon is the preferred adsorbent widely employed to treat wastewater containing different classes of metal ions recognizing the economic drawback of commercial activated carbon.

Many investigators have studied the feasibility of using inexpensive alternative materials like pearl millet husk, date pits, saw dust, buffing dust of leather industry, coir pith, crude oil residue, tropical grass, olive stone and almond shells, pine bark, wool waste, coconut shell *etc.*, as carbonaceous precursors for the removal of metal ion from water and wastewater [1-4]. The present study was undertaken to evaluate the efficiency of a carbon adsorbent prepared from acid activated *Cynodondactylon* carbon for the removal of Fe(II) ion in aqueous solution. The effects of parameters such as initial copper ion concentration, pH, adsorbent dosages, contact time, other ions and temperature were studied by using Batch technique. In this paper, we have reported the applicability of kinetic and mass transfer models for the adsorption of Fe(II) ion onto acid activated *Cynodondactylon* carbon.

Experimental Methods

Preparation of acid activated carbon

Carbon was prepared by treating air dried *Cynodondactylon* with con sulphuric acid in a weight ratio of 1:1. The resulting black product was kept in a furnace maintained at 500 °C for 12 hr followed by washing with water until free from excess acid and dried at 150 ± 5 °C. The carbon product obtained was ground and the portion retained between 10 and 50 mm sieves was used in all the experiments. All chemicals supplied by S.d. fine chemicals with high purity.

Batch equilibration method

All experiments were carried out at 30, 40, 50 and 60 °C temperature in batch mode. Batch model was selected because of its simplicity and reliability. The experiments were done in different Erlenmeyer glass flasks of 100 mL capacity. Prior to each experiment, a predetermined amount of adsorbent was added to each flask. The stirring was kept constant (120 rpm) for each run throughout the experiment to ensure equal mixing. Each flask was filled with a known volume of sample before commencing stirring such as metal solutions with an initial concentration of 5 mg/L to 25 mg/L. The flask containing the sample was withdrawn from the shaker at the predetermined time interval, filtered and the residual concentration of the ferrous ion was measured by UV-visible double beam Spectrophotometer.

Effect of variable parameters

Dosage of adsorbents

Different doses consisting of 10 to 250 mg/50 mL of the adsorbent is mixed with the ferrous ion and the mixture was agitated in a mechanical shaker. The percentage of adsorption for different doses was determined by keeping all other factors constant.

Initial concentration

In order to determine the rate of adsorption, experiments were conducted with different initial concentrations of ferrous ions ranging from 5 to 25 mg/L. All other factors were kept constant.

Contact time

The effect of period of contact between the adsorbent and adsorbate on the removal of the ferrous ions in a single cycle was determined by keeping particle size, initial concentration, dosage, pH and temperature constant.

Initial pH

Adsorption experiments were carried out at a range of pH of the solution *i.e.* 3-10. The acidic and alkaline pH of the medium was maintained by adding the required amounts of hydrochloric acid and sodium hydroxide solutions. The parameters like particle size of the adsorbent and temperature were kept constant while carrying out the experiments.

Other ions

Adsorption studies of a specific metal ion in the presence of chloride ions were experimentally verified using the adsorbents. This involved the determination of the percentage of ferrous ion adsorbed from 15 mg/L of initial concentration of the ferrous ion solution with varying concentration of the added ion keeping all other factors constant.

Temperature

The adsorption experiments were performed at four different temperatures *viz.*, 30, 40, 50 and 60 °C in a thermostated shaker machine (Remi, India). The constancy of the temperature was maintained with an accuracy of ± 0.5 °C.

Regeneration studies

The regeneration of the adsorbed carbon is done by using 0.2 M mineral acids and sodium chloride solutions.

Results and Discussion

Properties of the Adsorbent

The chemical nature and pure structure usually determines the sorption activity. The physical and chemical property of the *Cynodondactylon* was listed in Table 1.

Effect of Carbon concentration

The adsorption of the metal ion on carbon was studied by varying the carbon concentration (10-100 mg/50ml) for Fe (II) ion concentrations of 30 mg /L. The percentage of adsorption increased with increase in the carbon concentration (Figure 1). This has attributed to increased carbon surface area and availability of more adsorption sites [5, 6]. Hence, the remaining parts of the experiments are carried out with the adsorbent dose of 25 mg /50ml.

Effect of contact time and initial Fe (II) ion concentration

The experimental results of adsorptions of Fe (II) ion on the activated carbon at various concentrations (10, 20, 30, 40, 50 and 60 mg/L) with contact time are shown in the figure (Fig. 2). The equilibrium data were presented in (Table 2). It revealed that, percentage of adsorption decreased with increase in initial Fe (II) ion concentration, but the actual amount of Fe (II) ion adsorbed per unit mass of carbon increased with increase in Fe (II) ion concentration. It means that the adsorption was highly dependent on initial concentration of metal ion. It was because of that at lower concentration, the ratio of the initial number of metal ion to the available surface area was low. Subsequently, the fractional adsorption becomes independent of initial concentration. However, at high concentration, the available sites of adsorption become fewer and hence the percentage removal of Fe (II) ion was dependent upon initial concentration. Equilibrium have established at 40 minutes for all concentrations. (Fig. 2) revealed that, the curves were single, smooth and continuous; it was leading to saturation, suggesting the possible monolayer coverage of the metal ion on the carbon surface.

Adsorption isotherm

The experimental data were analyzed by using linear form of the Langmuir and Freundlich isotherms [7, 8]. The linear plots of C_e/Q_e versus C_e suggested the applicability of the Langmuir isotherms (Figure 5.3.3). Values of (Q_m) and (b) were determined from slope and intercepts of the plots and are presented in the table (Table 3). From the results, it was clear that, the value of adsorption efficiency (Q_m) and adsorption energy (b) of the carbon increases on increasing the temperature. From the values it can concluded that the maximum adsorption corresponds to a saturated monolayer of adsorbate molecules on adsorbent surface with constant energy and no transmission of adsorbate in the plane of the adsorbent surface. The trend showed that the adsorbent prefers to bind acidic ions and that speciation predominates on adsorbent characteristics, when ion exchange was the predominant mechanism. Further, it confirmed the endothermic nature of the processes involved in the system. To confirm the favourability of the adsorption process, the separation factor (R_L) had been calculated and presented in the table (Table 4). The values were found to be between 0 and 1 which confirmed that the ongoing adsorption process was favourable [9 - 11]. The Freundlich equation have also employed for the adsorption of ferrous ion on the adsorbent. Linear plot of $\log Q_e$ versus $\log C_e$ showed that the adsorption of Fe (II) ion follows the Freundlich

isotherm (Figure 4). Values of K_f and n were found and given in the table (Table 5), showed the increase of negative charge on the surface that enhances the electrostatic force like van der Waals between the carbon surface and metal ion, which increases the adsorption of Fe (II) ion. The values clearly indicated that dominance in adsorption capacity. The intensity of adsorption was an indicative of the bond energies between Fe (II) ion and adsorbent and the possibility of slight chemisorption rather than physisorption. The possibility of multilayer adsorption of Fe (II) ion through the percolation process cannot be ruled out. However, the values of n was greater than one, indicating the adsorption was much more favourable [10 - 12].

Kinetics of adsorption

In the present study, the kinetics of the Fe (II) ion removal has carried out to understand the behaviour of this low cost carbon adsorbent. The adsorption of Fe (II) ion from an aqueous solution follows reversible first order kinetics, when a single species considered on a heterogeneous surface. The calculated values presented in the table (Table 6). The result indicated that K_0 values decreased with increase in the concentration of the Fe (II) ion and increased with increase in temperature. A clear examination of the effect of Fe (II) ion concentrations on the rate constant K_{ad} (Fig. 5 and Table 7) helped to describe the mechanism of Fe (II) ion removal taking place. In cases of strict surface adsorption, a variation of rate should be proportional to the first power of concentration. However, when pore diffusion limits the adsorption process, the relationship between initial Fe (II) ion concentration and rate of reaction will not be linear. It represented the pore diffusion limits of the overall rate of Fe (II) ion adsorption [13].

The rate constant for intraparticle diffusion K_p (mg/g/min). The K_p values obtained from the slope of the linear portions of the curves at Fe (II) ion concentrations at 35°C (Fig. 6) were 0.118, 0.176, 0.235, 0.294, 0.588 and 0.647 mg/g/min. The K_p values increased with increase in the Fe (II) ion concentration, which revealed that the rate of adsorption was governed by the diffusion of adsorbed Fe (II) ion within the pores of the adsorbent.

Effect of temperature

The adsorption capacity of the carbon increased with increase in the temperature of the system from 35°-50°C. The H° and S° values obtained from the slope and intercept of van't Hoff plots are presented in the tables (Table 6 and Fig. 7). The values were within the range of 1 to 93 KJ/mol indicated the favourability of

Table - 1 Characteristics of the adsorbent

Properties	CDC
Particle size (mm)	0.025
Density (g/cc)	0.1528
Moisture content (%)	0.98
Loss on ignition (%)	82
Acid insoluble matter (%)	3.2
Water soluble matter (%)	0.39
pH of aqueous solution	6.3
pH _{zpc}	5.4
Carboxylic acid	0.325
Lactone, lactol	0.074
Phenolic	0.067
Basic (pyrones and chromenes)	0.026

Table – 2 Equilibrium parameters for the adsorption of Fe (II) ion by activated CDC

Fe (II) ion concentration mg/L	Temperature °C											
	35	40	45	50	35	40	45	50	35	40	45	50
	C _e (mg/L)				Q _e (mg/g)				Fe (II) ion Removed (%)			
10	0.5942	0.5506	0.5048	0.4602	18.8116	18.8988	18.9904	19.0796	94.05	94.49	94.85	95.39
20	1.3259	1.3163	1.2245	1.1318	37.3482	37.3674	37.5510	37.7364	93.37	93.41	93.87	94.34
30	3.2846	3.0924	2.9007	2.7015	53.4308	53.8152	54.1986	54.5970	89.05	89.69	90.33	90.99
40	5.9457	5.6125	5.3089	5.0018	68.1086	68.7750	69.3822	69.9964	85.13	85.96	86.72	87.49
50	8.2117	7.8012	7.4117	7.0181	83.5766	84.3976	85.1706	85.9638	83.57	84.39	85.17	85.96
60	13.1487	12.6898	12.1992	11.6176	93.7026	94.6204	95.6016	96.7648	78.08	78.85	79.66	80.63

Table – 3 Langmuir isotherm results for the adsorption of Fe (II) ion by CDC

S.No.	Temp., °C	Statistical parameter, r ²	Langmuir constants	
			Q _m	b
1.	35	0.9940	115.07	0.3039
2.	40	0.9949	116.41	0.3164
3.	45	0.9949	116.68	0.3428
4.	50	0.9948	117.37	0.3690

Table – 4 Dimensionless separation factor (R_L) for the adsorption of Fe (II) ion by CDC

Fe (II) concentration (mg/ L)	Temp., °C			
	35°	40°	45°	50°
10	0.248	0.240	0.226	0.213
20	0.141	0.136	0.127	0.119
30	0.097	0.095	0.088	0.082
40	0.076	0.073	0.068	0.063
50	0.062	0.059	0.055	0.051
60	0.052	0.050	0.046	0.043

Table – 5 Freundlich isotherm results for the adsorption of Fe (II) ion by CDC

S.No.	Temp., °C	Statistical parameter, r^2	Freundlich constants	
			K_f	n
1.	35	0.9759	1.6180	2.0781
2.	40	0.9882	1.6581	1.9774
3.	45	0.9884	1.6497	1.9976
4.	50	0.9986	1.6421	2.0161

Table – 6 Equilibrium constant and thermodynamic parameters for the adsorption of Fe (II) ion by activated CDC

Fe (II) ion concentration (mg/ L)	Temp., °C								H° KJ/mol	S° KJ/mol
	35	40	45	50	35	40	45	50		
	K_0				- G° KJ/mol					
10	15.82	17.16	18.81	20.72	7.07	7.39	7.75	8.14	14.97	71.45
20	14.08	14.19	15.33	16.67	6.77	6.91	7.21	7.55	9.69	53.21
30	8.13	8.70	9.34	10.10	5.36	5.62	5.90	6.21	11.36	54.24
40	5.72	6.13	6.53	6.99	4.46	4.71	4.96	4.86	11.05	50.33
50	5.08	5.41	5.74	6.12	4.16	4.39	4.62	4.86	10.24	46.71
60	3.56	3.73	3.92	4.16	3.25	3.42	3.61	3.83	8.65	38.56

Table – 7 Rate constants for the adsorption of Fe (II) ion ($10^3 k_{ad}, \text{min}^{-1}$) and the constant for forward ($10^3 k_1, \text{min}^{-1}$) and reverse ($10^3 k_2, \text{min}^{-1}$) process

Fe (II) ion concentration (mg/L)	Temp., °C											
	35	40	45	50	35°		40°		45°		50°	
	K_{ad}				k_1	k_2	k_1	k_2	k_1	k_2	k_1	k_2
10	14.94	16.69	18.45	20.37	13.61	0.88	15.77	0.92	17.52	0.93	19.43	0.94
20	14.02	14.58	15.37	16.29	13.09	0.93	13.63	0.95	14.43	0.94	15.37	0.92
30	8.75	9.18	9.68	10.16	7.80	0.95	8.24	0.94	8.75	0.93	9.25	0.91
40	6.52	6.91	7.35	7.79	5.55	0.97	5.94	0.97	6.38	0.97	6.82	0.97
50	5.89	6.21	6.54	6.85	4.93	0.96	5.24	0.97	5.57	0.97	5.89	0.96
60	4.61	4.84	5.03	5.27	3.60	1.01	3.82	1.02	4.01	1.02	4.25	1.02

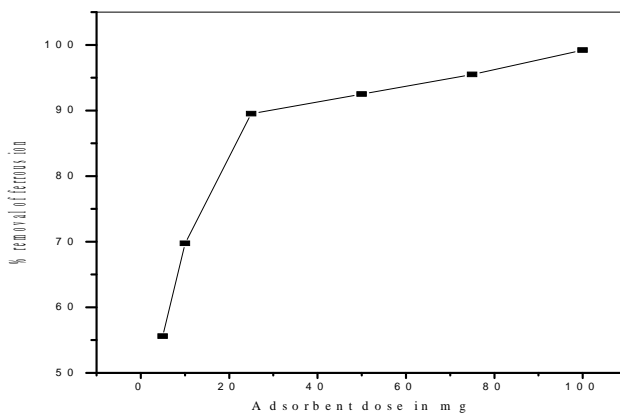


Fig. 1 Effect of adsorbent dose on the adsorption of Fe (II) ion by CDC[Fe] = 30 mg/L; Temp = 35°C; Contact time = 60 min

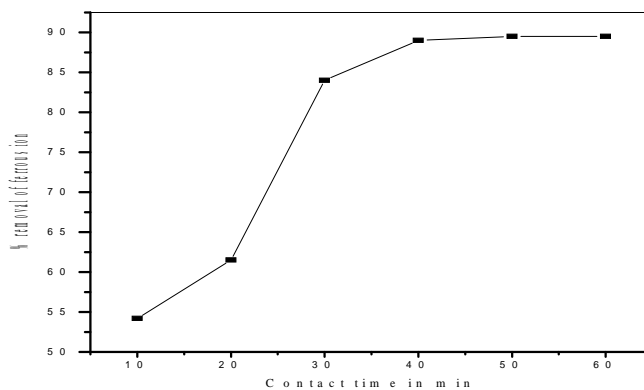


Fig. 2 Effect of contact time on the adsorption of Fe (II) ion by CDC[Fe] = 30 mg/L; Adsorbent dose = 25 mg/50 ml; Temp = 35°C

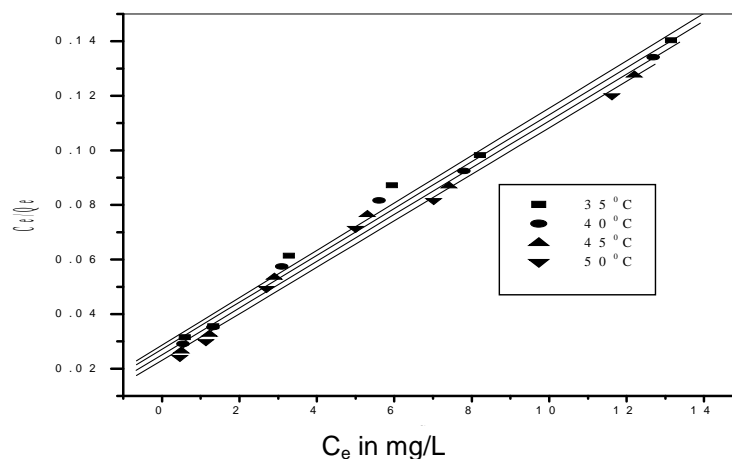


Fig. 3 Linear Langmuir adsorption isotherm for Fe (II) ion by CDC

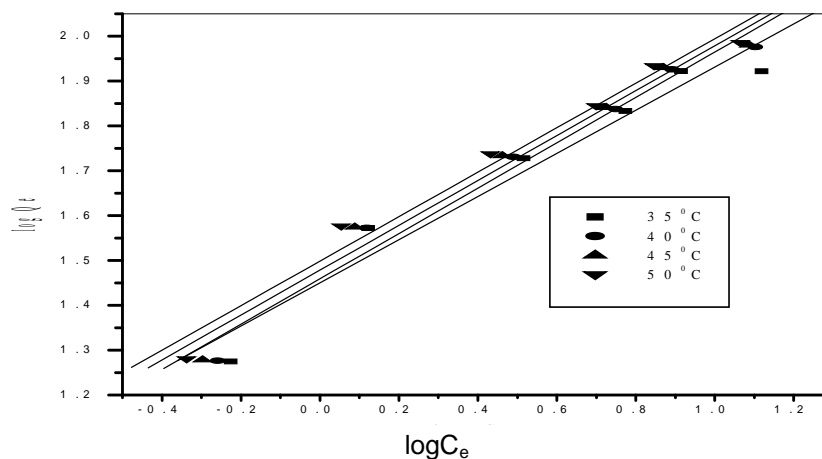


Fig. 4 Linear Freundlich adsorption isotherm for Fe (II) ion by CDC

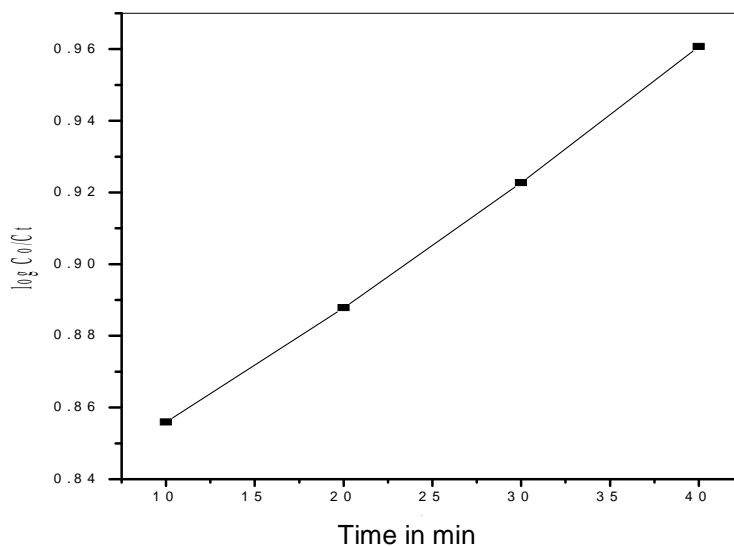


Fig. 5 Natarajan-Khalaf plot for the adsorption of Fe (II) ion by CDC
 [Fe] = 30 mg/L; Contact time = 40 min; Temp = 35°C;
 Adsorbent dose = 25 mg/50 ml

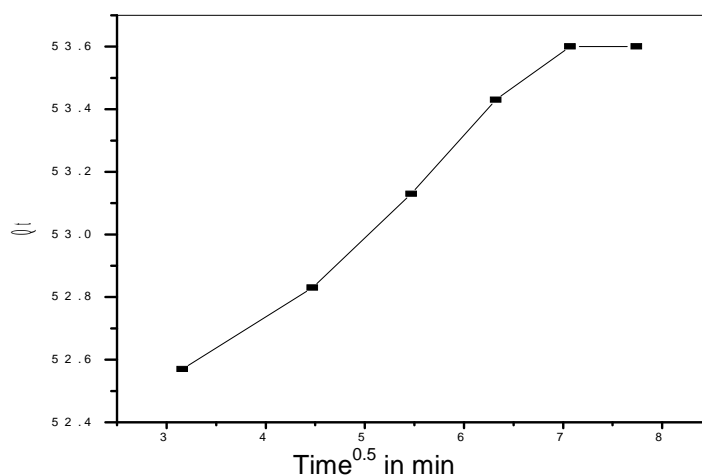


Fig. 6 Intraparticle diffusion effect for the adsorption of Fe (II) ion by CDC
[Fe] = 30 mg/L; Adsorbent dose = 25 mg/50 ml; Temp=35°C

physisorption. From the results, it could make out physisorption much more favourable for the adsorption of Fe (II) ion. The positive values of H° showed the endothermic nature of adsorption and it governs the possibility of physical adsorption. Because in the case of physical adsorption, while increasing the temperature of the system, the extent of metal ion adsorption increases, this may enable the possibility of physisorption rather than chemisorption. However, the low H° value depicts Fe (II) ion was physisorbed onto adsorbent [12 - 15]. The negative values of G° (Table 6) showed the adsorption was highly favourable for Fe (II) ion. However, it indicated that the Fe (II) ion adsorption was spontaneous. The positive values of S° (Table 6) indicated the increased disorder and randomness at the solid solution interface of with adsorbent CDC. While the adsorption there are some structural changes in the Fe (II) ion and the adsorbent occur. The adsorbed water molecules, which have displaced by the adsorbate species, gain more translational entropy than was lost by the adsorbate molecules, thus allowing the prevalence of randomness in the system. From the results, it could make out that more efficient physisorption rather than chemisorption. Enhancement of adsorption capacity of the activated carbon at higher temperatures has attributed to the enlargement of pore size and activation of the adsorbent surface [11 – 13].

Effect of pH

The experiments carried out at different pH showed that there was a change in the percent removal of Fe (II) ion over the entire pH range of 3 to 10 represented in the figure (Fig. 8). This indicated the strong force of interaction between the Fe (II) ion and the activated

carbon that, either H^+ or OH^- ions could influence the adsorption capacity. Here the interaction was more at pH 5.4, the competence of acidic H^+ ion with metal ion for the sorption sites. The percentage of sorption increased at the above pH value was due to the presence of ionic COOH, OH and SO_3H groups. The adsorption of Fe (II) ion on the activated carbon does involve ion exchange mechanism. Due to the adsorption of Fe (II) ion through ion exchange mechanism by the adsorbent, there should be an influence on the metal ion adsorption while varying the pH. This observation was in line with the Langmuir and Freundlich isotherm shown in the figures (Figures 3 and 4). The positive H° value obtained, which indicated irreversible adsorption probably due to polar interaction [16 - 18].

Effect of other ions

The effect of other ions like Ca^{2+} and Cl^- on the adsorption process studied at different concentrations.

The ions added to 30 mg/L of Fe (II) ion solutions and the contents were agitated for 60 min at 35°C. The results had shown in the (Fig. 9) revealed that low concentration of Cl^- does not affect the percentage of adsorption of Fe (II) ion on activated carbon, because the interaction of Cl^- at available sites of adsorbent through competitive adsorption was not so effective. While the concentration of other ion Ca^{2+} increases, the interference of these ions at available surface sites of the sorbent through competitive adsorption increases that, decreases the percentage adsorption. The interference was more in the presence of Ca^{2+}

compared with Cl⁻ ion. This was so because ions with smaller hydrated radii decrease the swelling pressure within the sorbent and increase the affinity of the sorbent for such ions [1, 17, 19].

Desorption studies

Desorption studies help to elucidate the nature of adsorption and recycling of the spent adsorbent and the metal ion. If the adsorbed Fe (II) ion can be desorbed using neutral pH water or by very dilute acids, then the attachment of the Fe (II) ion of the adsorbent was by weak bonds. If sulphuric acid or alkaline water desorb the Fe (II) ion, then the adsorption was by ion exchange. If organic acids, like acetic acid can desorb the metal ion, then the Fe (II) ion has held by the adsorbent through chemisorption [18]. The effect of various reagents used for desorption studies revealed that hydrochloric acid was a better reagent for desorption, because we could get more than 82% removal of adsorbed Fe (II) ion was obtained. The reversibility of adsorbed metal ion in mineral acid or base was in agreement with the pH dependent results obtained. The desorption of Fe (II) ion by dilute mineral acids and alkaline medium indicated that the Fe (II) ion was adsorbed onto the activated carbon through by physisorption mechanisms [12, 18, 19].

Evidences for adsorption

FTIR Spectral studies

The IR spectra of the raw activated carbon and after adsorption of Fe (II) ion have shown in the figures (Figures 10a and 10b). It could be seen that the slight reduction of stretching vibration adsorption bands. This clearly revealed that the adsorption of Fe (II) ion on the adsorbent by physical forces [20, 21].

XRD Spectral Studies

The XRD diagrams of activated carbon and Fe (II) ion-adsorbed carbon have shown in the figures (Figures 11a and 11b). The intense main peak represented the

presence of highly organized crystalline structure of raw activated carbon after the adsorption of Fe (II) ion, the intensity of the highly organized peaks are slightly diminished. This has attributed to the adsorption of Fe (II) ion on the upper layer of the crystalline structure of the carbon surface by means of physisorption [20, 21].

SEM images

The SEM diagrams of raw activated carbon and Fe (II) ion-adsorbed activated carbon have shown in the figures (Figures 12a and 12b). The bright spots showed the presence of tiny holes on the crystalline structure of raw activated carbon, after treatment with Fe (II) ion the bright spots became black, which indicated the adsorption of the Fe (II) ion on the surface of the carbon by means of physisorption [20, 21].

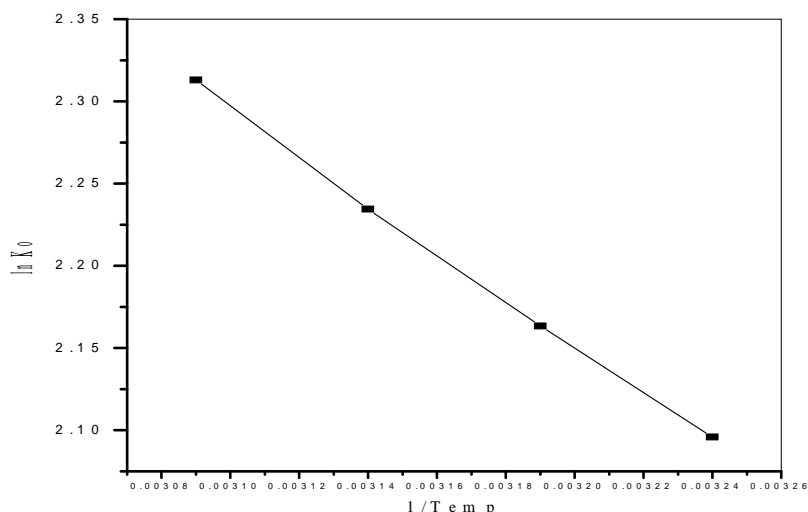


Fig. 7 van't Hoff plot for the adsorption of Fe (II) ion by CDC
[Fe] = 30 mg/L; Adsorbent dose = 25mg/50 ml; Contact time = 60 min

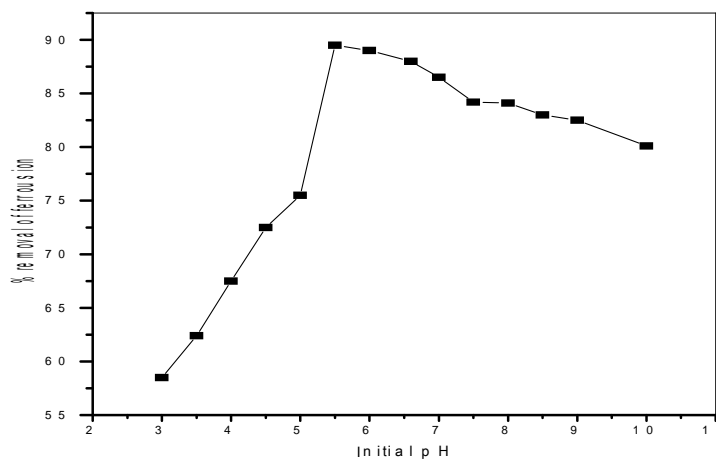


Fig. 8 Effect of pH on the adsorption of Fe (II) ion by CDC [Fe] = 30 mg/L; Adsorbent dose = 25 mg/50 ml; Temp = 35°C; Contact time = 60 min

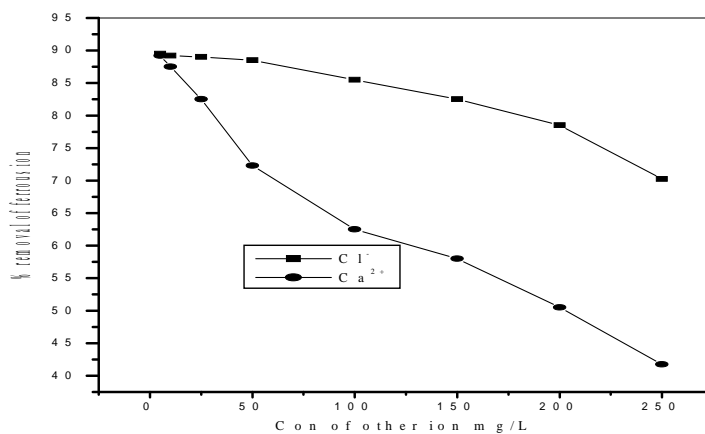


Fig. 9 Effect of other ions on the adsorption of Fe (II) ion by CDC [Fe] = 30 mg/L; adsorbent dose = 25 mg/50 ml; Temp = 35°C; Contact time = 60 min

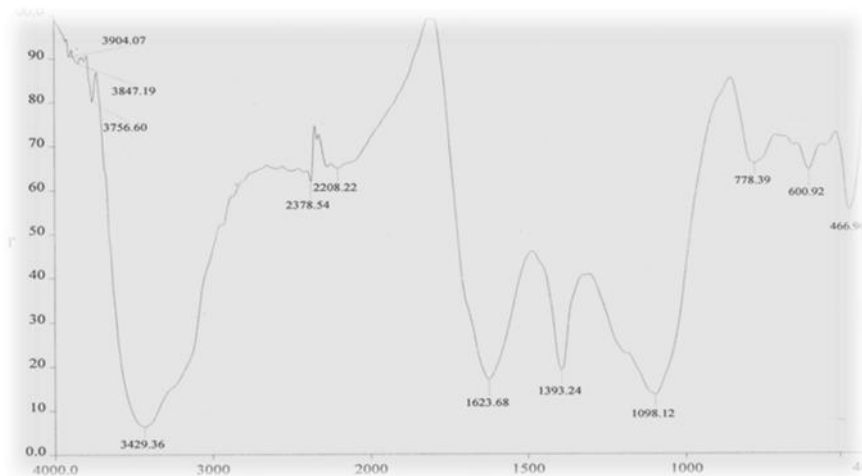


Fig. 10a FTIR Spectra for the adsorption of Raw CDC

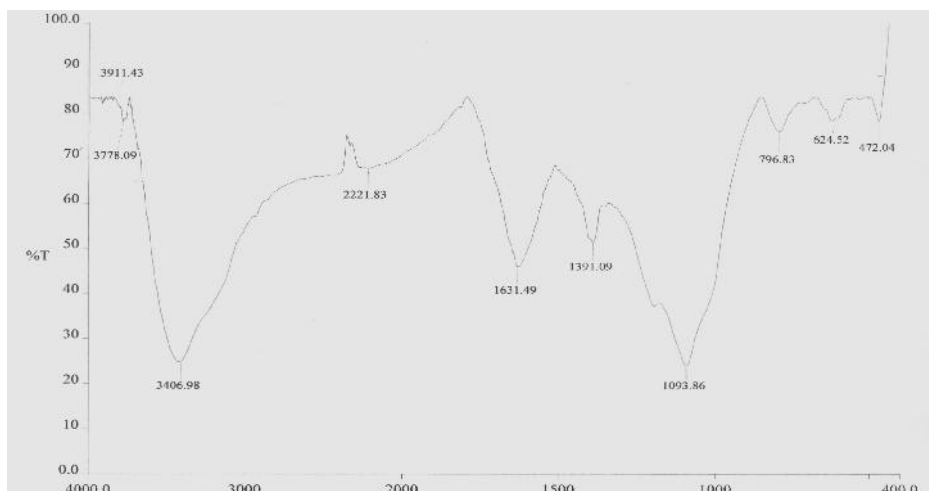


Fig. 10b FTIR Spectra for the adsorption of Fe (II) ion by CDC

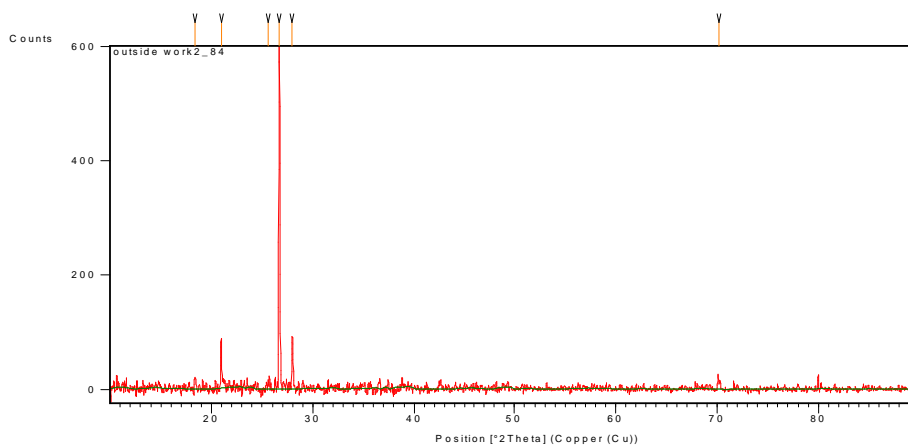


Fig. 11a XRD Spectra for the adsorption of Raw CDC

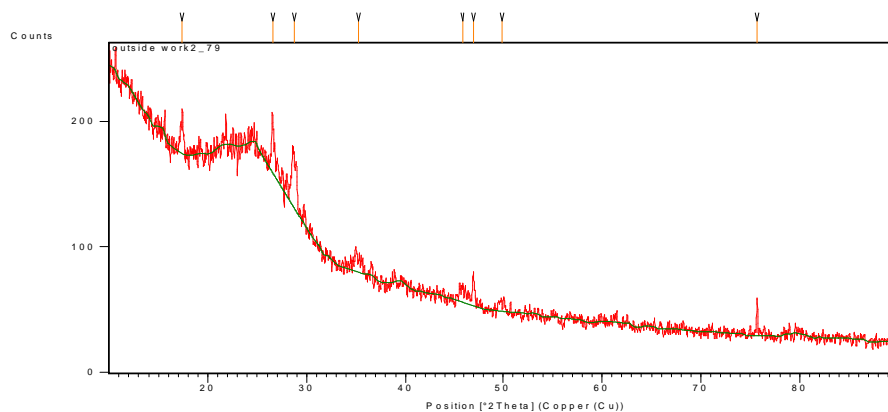


Fig. 11b XRD Spectra for the adsorption of Fe (II) ion by CDC

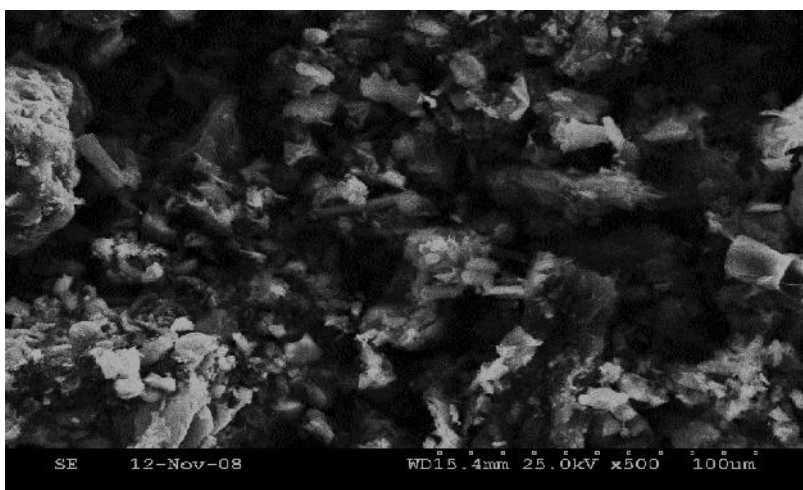


Fig. 12a SEM Images for Raw CDC

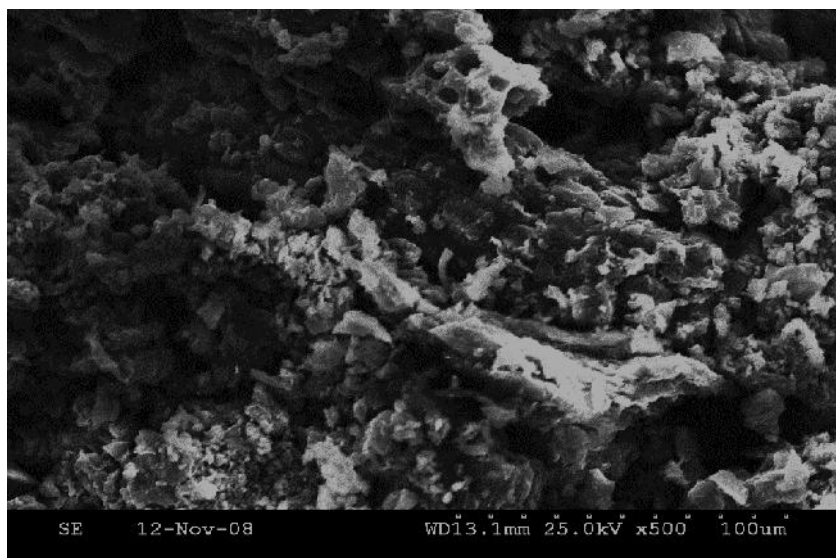


Fig. 12b SEM Images for the adsorption of Fe (II) ion by CDC

Conclusion

Activated *Cynodondactylon* has been found to be an economically viable and potential bio sorbent for the removal of ferrous ion. Sorption of ferrous ion onto activated *Cynodondactylon*, this present work has indicated that the sorbent provide an alternative or adjacent to conventional methods employed to control the level of Fe (II) ion pollution. The calculated values of the dimensionless separation factor RL from the Langmuir and Freundlich isotherm constants confirm favorable sorption of Fe (II) ion onto *Cynodondactylon*. The amount of ferrous ion adsorbed increased with increase in pH of the medium. Optimum pH for highest

Fe (II) ion adsorption was 5.9. The amount of Fe (II) ion adsorbed slightly decreased with increasing ionic strength and increased with increase in temperature. The thermodynamic calculations showed that the Fe (II) ion adsorption was spontaneous in nature and endothermic nature of the adsorption process. The contact time for the maximum adsorption required was nearly 40 minutes. Adsorption process was found to follow the reversible first order rate kinetics. The values of G° , H° and S° results shows that the carbon employed has a considerable potential as an adsorbent for the removal of Fe (II) ion.

References

- [1] Arivoli S, Ph D., Thesis, Gandhigram RuralUniversity, Gandhigram, India, 2007.
- [2] Sekaran G, Shanmugasundaram K A, Mariappan M &Raghavan K V, Indian JChem Technol., 2 (1995) 311.
- [3] Selvarani K, Ph D., Thesis, Regional Engineering College, Thiruchirapalli, India. 2000.
- [4]Jia Y F and Thomas K K, Langmuir,18 (2002) 470-478.
- [5]Namasivayam C, Muniasamy N, Gayathri K, Rani M, &Renganathan K, Biores.Technol., 57 (1996) 37.
- [6] Namasivayam C and Yamuna R.T, Environ. Pollut. 1 (1995)89.
- [7] Langmuir I, J.Am. Chem. Soc., 40 (1918)1361.
- [8] Freundlich H, Z. Phys. Chem., 57 (1906)384.
- [9] Krishna D.G and Bhattacharya G, Appl. Clay Sci., 20 (2002) 295.
- [10] Arivoli S, Viji Jain M, Rajachandrasekar T, Mat. Sci. Res. India, 3 (2006) 241.
- [11] Arivoli S and HemaM. Intern. J. Sci., 2 (2007) 10.
- [12] Arivoli S, Venkatraman B.R, Rajachandrasekar T &Hema M, J. Chem. Environ., 17 (2007) 70.
- [13] Arivoli S, Kalpana S, Sudha R &Rajachandrasekar T, E.J. Chem., 4 (2007)238.
- [14] Weber W.J, Principle and application of water chemistry, edited by SD Faust, S.D, Hunter, J.V., Wiley, New York, 1967.
- [15]Renmin Gong, YingzhisunJian Chen, Huijum Liu &Chaoyang, Dyes and Pigments, 67 (2005)179.
- [16] Vadivelan V.V and Vasanthakumar K, J. Colloid Interface Sci., 91 (2005) 286.
- [17] YupengGuo, Jingzhuzhao, Huizhang, Shaofeng Yang, Zichen Wang &Hongding X.U, Dyes and Pigments, 66 (2005) 123.
- [18] Sreedhar M.K and Anirudhan T.S, Indian J. Environ. Protect.8 (1999) 19.
- [19]Nigamananda Das &Ranjit Kumar Jana. J. Colloid Inter. Sci., 253 (2006) 293.
- [20] Venkata Mohan S, Krishna Mohan S&Karthikeyan J, J. Scientific and Indust. Res., 60 (2000) 410.
- [21] Renmin Gong, Youbin Jin, Fayang Chen, Jian Chen &Zhil Liu, J. Hazardous Mat., 137 (2006) 865.