

## Removal and recovery of nitrate from water by ZnCl<sub>2</sub> activated carbon from coconut coir pith, an agricultural solid waste

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Nitrate removal from aqueous solution was investigated using ZnCl<sub>2</sub> activated carbon developed from coir pith. Influence of contact time, adsorbent dose, nitrate concentration, pH and temperature were investigated. Two theoretical adsorption isotherms namely Langmuir and Freundlich were used to describe the experimental results. The Langmuir adsorption capacity ( $Q_0$ ) was found to be 10.3 mg nitrate per g of the adsorbent. Adsorption followed second order kinetics. Adsorption was maximum in the pH range 3-10. pH effect and desorption studies showed that ion exchange mechanism might be involved in the adsorption process. Effects of foreign ions such as chloride, sulphate, phosphate and perchlorate on the removal of nitrate have also been investigated. Removal of nitrate from ground water was also tested. Results show that ZnCl<sub>2</sub> activated coir pith carbon is effective for the removal of nitrate from water.

**Keywords:** Coir pith, ZnCl<sub>2</sub> activated carbon, nitrate, adsorption isotherms

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High nitrate level in drinking water supplies represents a significant risk to human health, as they are directly responsible for methemoglobinemia in infants (blue baby syndrome)<sup>1</sup>. Nitrate is consequently absorbed by hemoglobin to form methaemoglobin. Nitrite, formed by bacteria from nitrate, can also induce gastric cancer by reacting in stomach with agents of human gastric cancer<sup>2</sup>. Due to nitrate, other symptoms such as abdominal pain and diarrhoea have also been observed in animals<sup>3</sup>. The World Health Organization<sup>3</sup> and the European Community<sup>4</sup> have set a limit of 50 mg/L nitrate (11.3 mg/L NO<sub>3</sub>-N) in drinking water, whereas USEPA<sup>5</sup> and Bureau of Indian Standards<sup>6</sup> have set a limit of 45 mg/L nitrate (10.2 mg/L NO<sub>3</sub>-N).

Wastes from the production of the explosives, fertilizers, nitro organic compounds and pharmaceuticals are sources of nitrate pollution<sup>7</sup>. Additional sources of nitrate contamination include landfill leachate, leaking septic tank and municipal storm water run off<sup>8</sup>. Nitrate is also a by-product of many industrial processes, including paper and munitions manufacturing. Hence, effluent containing nitrate should be treated before they are discharged into the environment. When the nitrate concentration of the drinking water exceeds the maximum

admissible concentration, the nitrate removal becomes a technical challenge. There are biological and physicochemical methods for the removal of nitrate. Nitrate degradation processes include biological and catalytic nitrate reduction, and separation processes include distillation<sup>9</sup>, electro dialysis<sup>10</sup>, ion exchange<sup>11</sup>, Donnan dialysis<sup>12</sup>, electro deionization<sup>13</sup> and reverse osmosis<sup>14</sup>. For removal of nitrate from industrial wastewater, adsorption has become one of the most economic and effective method. The process is superior to many other methods of water reuse by virtue of its low initial cost, low energy requirements, simplicity of design and possibility of reusing the spent carbon via regeneration<sup>15</sup>. Thus, this process has aroused considerable interest during recent years. Treatments of nitrate containing effluent by high-area carbon cloth<sup>16</sup>, protonated cross-linked chitosan<sup>17</sup> and Zeolite Y<sup>18</sup> have been reported.

Coir pith is an agricultural solid waste indigenously available in coconut fiber industries. Annual production of coir pith is around 7.5 million tons<sup>19</sup>. Accumulation of coir pith around coir fiber industries is creating a menace. This solid waste has been used in this laboratory for the removal of dyes<sup>20</sup>, heavy metals<sup>15</sup> and phenols<sup>21</sup>. This abundant lignocellulosic waste was used to develop ZnCl<sub>2</sub> activated carbon and applied to the removal of phosphate from water<sup>22</sup>.

The objective of this work was to evaluate the potential of ZnCl<sub>2</sub> activated coir pith carbon for the

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adsorption of nitrate. Adsorption isotherms were performed at different nitrate concentrations. Desorption was performed under controlled conditions to check the reversibility in the adsorption process: desorption yield from a loaded adsorbent was measured at different pH values. Effects of foreign anions in the aqueous solution such as  $\text{ClO}_4^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{Cl}^-$  and  $\text{PO}_4^{3-}$  on the adsorption of  $\text{NO}_3^-$  have also been examined. Effects of pH and adsorbent dose on the removal of nitrate in synthetic ground waters containing nitrate have been investigated.

## Experimental Procedure

### Materials and methods

Coir pith was collected from nearby coir industries. It was dried in sunlight for 5 h and then zinc chloride activated coir pith carbon was prepared. Coir pith was stirred into a boiling solution containing zinc chloride in the weight ratio of 2:1. The filtered material after drying was carbonized at 700°C under controlled conditions. After cooling, the excess zinc chloride present in the carbonized material was leached out using dilute HCl. Then the carbon was repeatedly washed to get rid of excess  $\text{ZnCl}_2$  and dried. The carbonized material was sieved to 250-500  $\mu\text{m}$  size and used for adsorption. The characteristics of  $\text{ZnCl}_2$  activated coir pith carbon in comparison with coir pith carbon in the absence of  $\text{ZnCl}_2$  activation are presented in Table 1. Specific surface area and porous properties were determined using Quantachrome surface area analyzer and mercury porosimeter, respectively. Surface functional groups and other parameters were determined using standard methods<sup>23,24</sup>. The material has a higher surface area compared to the activated carbon prepared from coir pith in the absence of  $\text{ZnCl}_2$  (167  $\text{m}^2/\text{g}$ )<sup>21</sup>. Most of the surface (90%) and pore volume (75%) is made up by pores smaller than 2 nm in pore width, the so-called micropores. The carbon has a sponge like structure, due to the very high value of the fractal dimension with 2.93. The pore size distribution supports the above statements. The acidic surface functional groups present on the carbon are: carboxylic, 0.282 (19.4%); lactones, 0.234 (16.1%); phenolic 0.90 (64.6%) and basic groups, 0.77  $\text{meq g}^{-1}$ . The SEM photographs of the carbon before (a) and after adsorption (b) of nitrate are shown in Figs 1 and 2.

Nitrate solutions were prepared from analytical grade potassium nitrate. Synthetic ground waters containing 10 and 20 mg/L nitrate were prepared and

Table 1—Characteristics of activated coir pith carbons

Physical parameter	Presence of $\text{ZnCl}_2$	Absence of $\text{ZnCl}_2$
Specific surface area ( $\text{m}^2 \text{g}^{-1}$ )	910	167
Total pore volume ( $\text{mL g}^{-1}$ )	0.363	0.1217
Micropore area ( $\text{m}^2 \text{g}^{-1}$ )	284	89.3
Micropore volume ( $\text{mLg}^{-1}$ )	0.131	0.0913
Average pore diameter (nm)	1.6	2.75
Average micropore diameter (nm)	0.9	1.2
pH <sub>ZPC</sub>	3.2	8.0
pH (1% solution)	3.27	10.1
Conductivity (1% solution) (mS/cm)	0.255	2.3
Bulk density ( $\text{g mL}^{-1}$ )	0.1012	0.12
Mechanical moisture content (%)	12.67	6.0
Ash content (%)	3.2	80
Specific gravity	1.285	1.74
Porosity (%)	92.12	93
Volatile matter (%)	19.25	58
Fixed carbon (%)	80.73	41
Water soluble matter (%)	0.999	-
Acid soluble matter (%)	1.5	-
Decolorizing power ( $\text{mg g}^{-1}$ )	137	21
Chemical parameter		
Iodine number ( $\text{mg g}^{-1}$ )	203	101
Phenol number ( $\text{mg g}^{-1}$ )	30	
Ion exchange capacity ( $\text{meq g}^{-1}$ )	0.107	Nil
Zinc (%)	0.0218	-
Zinc leached (%)	0.0095	-
Ash analysis:		
Sodium (%)	0.09	0.14
Potassium (%)	0.1	0.18
Calcium (%)	0.78	0.22
Phosphorous (%)	0.009	0.01
Iron (%)	3.7	0.18

the composition of other ions was chloride, 63.6; sulphate, 55.1; phosphate, 34.9; sodium, 43.4; potassium, 65.6 and calcium 36.4 mg/L.

### Adsorption studies

Adsorption experiments were carried out by agitating 200 mg of adsorbent with 50 mL of nitrate solution of desired concentration and pH at 200 rpm, 35°C in a thermostated rotary shaker (ORBITEK, Chennai, India). Concentration of nitrate was estimated spectrophotometrically by monitoring the absorbance at 220 nm using UV-VIS spectrophotometer (Hitachi, model U-3210, Tokyo)<sup>23</sup>. pH was measured using pH meter (Elico Instruments, model LI-107, Hyderabad, India). The samples were withdrawn from the shaker at predetermined time intervals and the supernatant solution was separated from the adsorbent by centrifugation at 20,000 rpm for 20 min. The absorbance of supernatant solution was measured. Effect of pH was studied in the pH

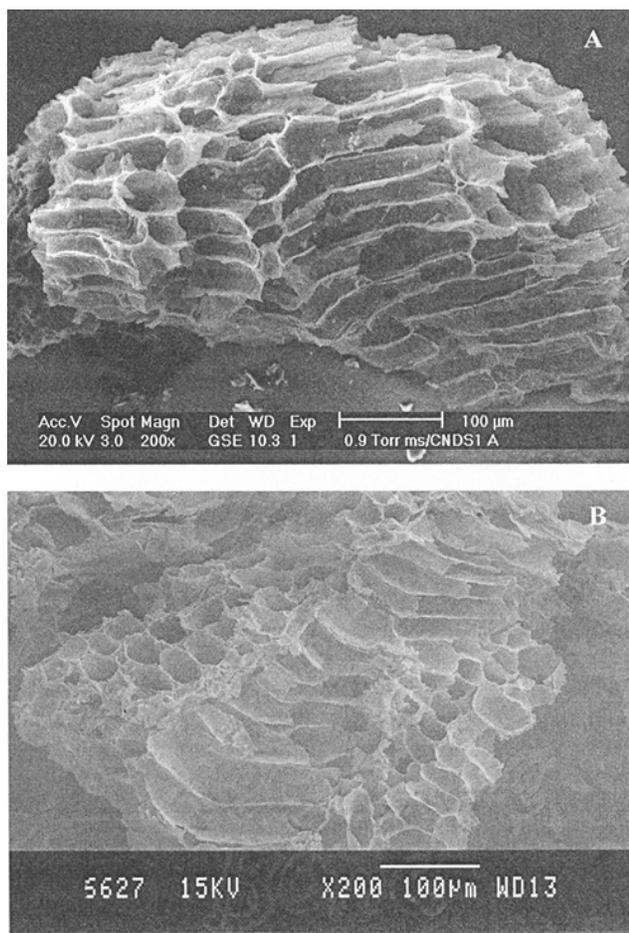


Fig. 1—SEM photographs of the carbon (200 X) before(A) and after adsorption of nitrate(B).

range 2.0 to 11.0 by adjusting the pH of nitrate solutions using dilute HCl and NaOH solutions. Effect of adsorbent dosage was studied by agitating 50 mL of 10, 20, 30 or 40 mg/L nitrate solutions with different adsorbent doses (25-700 mg) at time intervals longer than the equilibrium time. Langmuir and Freundlich isotherms were employed to study the adsorption equilibrium.

#### Desorption studies

The adsorbent (200 mg/50 mL) that was used for the adsorption of 10 to 40 mg/L of nitrate solution was separated from the solution by centrifugation. The nitrate loaded adsorbent was filtered using Whatman filter paper and washed gently with water to remove any unadsorbed nitrate. Several such samples were prepared. Then the spent adsorbent was mixed with 50 mL of distilled water, adjusted to a pH value in the range 2.0 to 11.0 and agitated at time intervals

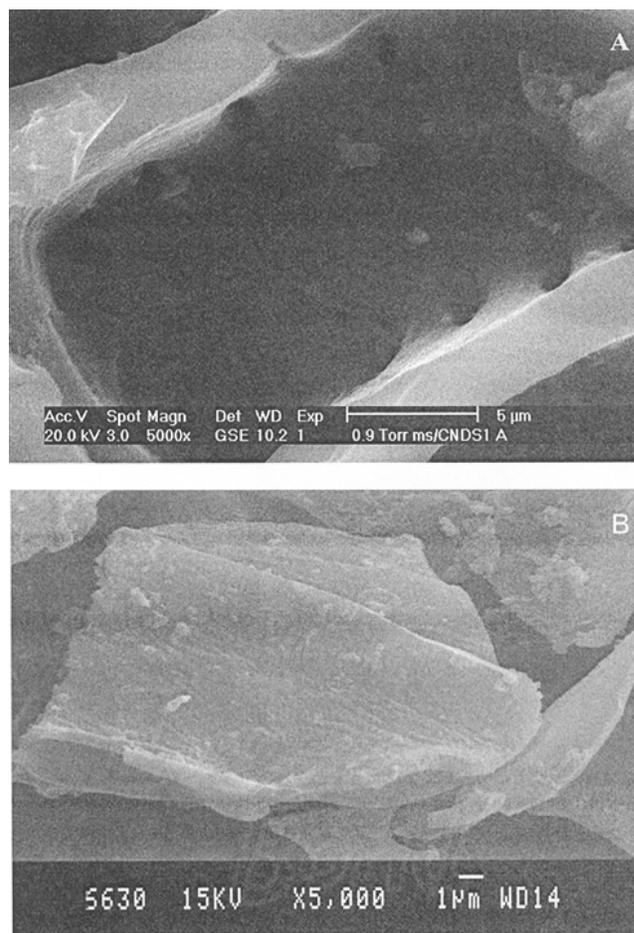


Fig. 2—SEM photographs of the carbon (5000 X) before(A) and after adsorption of nitrate(B).

longer than the equilibrium time. The desorbed nitrate was estimated as before.

#### Temperature studies

Effect of temperature was studied using 10 mg/L of nitrate and 200 mg of adsorbent at 35, 40, 50 and 60°C in the thermostated rotary shaker.

Preliminary experiments showed that there was no adsorption due to container walls. Experiments were carried out in duplicate and mean values were taken for calculations. Maximum deviation was 3%.

## Results and Discussion

#### Effect of agitation time and initial nitrate concentration

The amount of nitrate adsorbed (mg/g) increased with increase in nitrate concentration and remained nearly constant after equilibrium time (Fig. 3). The equilibrium time was found to be 4 min for all the concentrations studied. The amount of nitrate

adsorbed at equilibrium ( $q_e$ ) increased from 1.94 to 6.24 mg/g as the concentration was increased from 10 to 40 mg/L. The plots are smooth and continuous leading to saturation, suggesting the possible monolayer coverage of nitrate on the surface of the adsorbent.

#### Adsorption kinetics

The adsorption kinetic data of nitrate is analyzed using the Lagergren first order rate equation<sup>25</sup>,

$$\log(q_e - q) = \log q_e - k_1 t / 2.303 \quad \dots(1)$$

where  $q_e$  and  $q$  are the amount of nitrate adsorbed (mg/g) at equilibrium and at time  $t$  (min) respectively, and  $k_1$  is the Lagergren rate constant of pseudo first order adsorption (1/min). Values of  $k_1$  calculated from the slope of the plot of  $(q_e - q)$  versus  $t$  are shown in Table 2. It was found that the calculated  $q_e$  values do not agree with the experimental  $q_e$  values. This

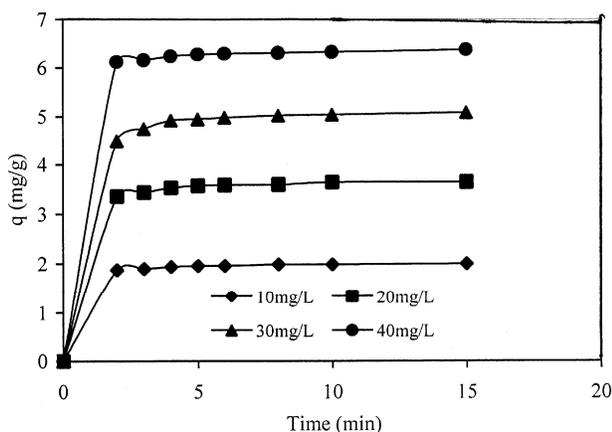


Fig. 3—Effect of agitation time and concentration of nitrate on removal: Adsorbent dose, 200 mg/50 mL; pH, 3.0; Temp, 35°C.

suggests that the adsorption of nitrate does not follow pseudo first order kinetics<sup>26</sup>.

The second order kinetic model<sup>27</sup> can be represented as

$$t/q = 1/k_2 q_e^2 + t/q_e \quad \dots(2)$$

where  $k_2$  is the equilibrium rate constant of pseudo second order adsorption (g/mg/min). Values of  $k_2$  and  $q_e$  were calculated from the plot of  $t/q$  versus  $t$  (Fig. 4). The calculated  $q_e$  values agree with experimental  $q_e$  values and also the correlation coefficients for the second order kinetic plots at all the studied concentrations were above 0.99 (Table 2). These results indicate that the adsorption system studied, belongs to the second order kinetic model. Similar phenomenon has been observed in the adsorption of Cr(VI) by used tires and saw dust<sup>28</sup>, congo red on coir pith carbon<sup>20</sup> and adsorption of phosphate on calcined alunite<sup>29</sup> and ZnCl<sub>2</sub> activated coir pith carbon<sup>22</sup>.

#### Adsorption isotherms

Langmuir and Freundlich isotherms were applied to study the adsorption equilibrium. Langmuir isotherm is based on the assumption that (i) maximum adsorption corresponds to a saturated monolayer of adsorbate molecules on the adsorbent surface, (ii) that the energy of adsorption is constant and (iii) that there is no transmigration of adsorbate molecules in the plane of the adsorbent surface.

Langmuir isotherm<sup>30</sup> is expressed as,

$$C_e/Q_e = 1/Q_0 b + C_e/Q_0 \quad \dots(3)$$

where  $C_e$  is the concentration of nitrate solution (mg/L) at equilibrium and  $Q_0$  and  $b$  are Langmuir

Table 2—Comparison of the first and second order adsorption rate constants and calculated and experimental  $q_e$  values for different initial nitrate concentrations and temperatures

Parameter	$q_e$ (exp) (mg/g)	First order kinetics			Second order kinetics		
		$k_1$ (1/min)	$q_e$ (cal) (mg/g)	$R^2$	$k_2$ (g/mg/min)	$q_e$ (cal) (mg/g)	$R^2$
Initial nitrate conc (mg/L)							
10	1.94	0.3818	0.14	1	3.1969	2.01	0.9998
20	3.53	0.6759	0.67	1	1.1896	3.72	0.9999
30	4.92	0.9046	0.39	1	0.4423	5.43	0.9999
40	6.24	0.4056	0.27	1	1.8146	6.37	0.9999
Temp (°C)							
35	1.94	0.3818	0.14	1	3.1973	2.01	0.9998
40	2.10	0.5967	0.52	0.999	1.5361	2.22	0.9998
50	2.19	0.367	0.37	0.997	1.2724	2.31	0.9991
60	2.23	0.725a	0.60	0.989	1.8458	2.33	0.999

constants related to adsorption capacity (mg/g) and energy of adsorption (L/mg), respectively. Plot of  $C_e/q_e$  versus  $C_e$  is linear (Fig. 5). The values of the Langmuir constants  $Q_0$  and  $b$  are 10.3 mg/g and 0.096 L/mg, respectively shown in the Table 3. The adsorption capacity of activated coir pith carbon in the absence of ZnCl<sub>2</sub> was found to be negligible. The essential characteristics of the Langmuir isotherm can be expressed by a dimensionless constant called equilibrium parameter  $R_L$ <sup>31</sup>.

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

where  $b$  is the Langmuir constant and  $C_0$  is the initial nitrate concentration (mg/L).  $R_L$  values indicate the type of isotherm. An  $R_L$  value between 0 and 1

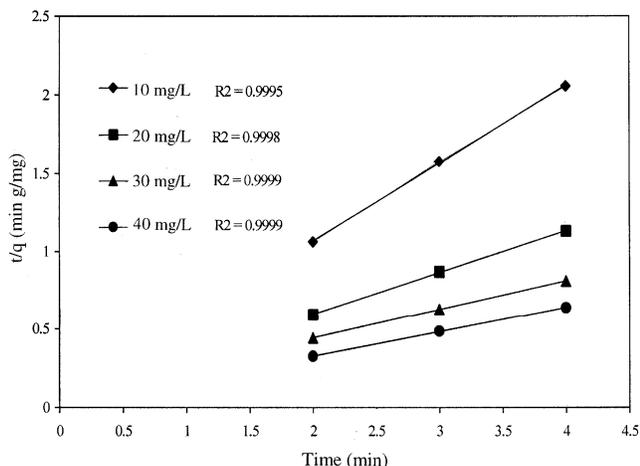


Fig. 4—Plots of the pseudo second-order model at different initial nitrate concentrations: Adsorbent dose, 200 mg/50 mL; pH, 3.0; Temp, 35°C.

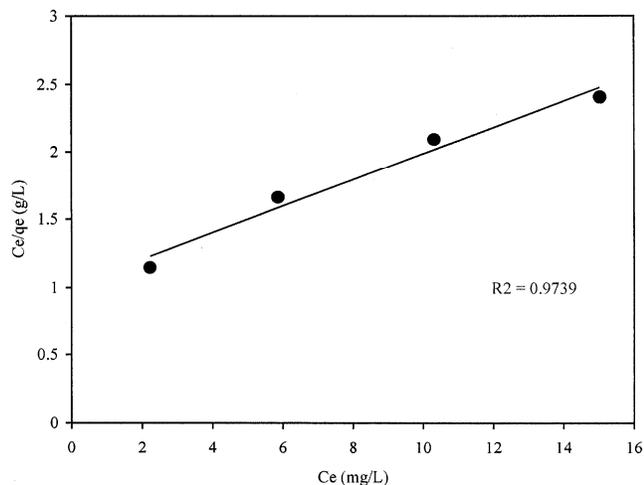


Fig. 5—Langmuir plot for adsorption of nitrate.

indicates favourable adsorption. Values of  $R_L$  are found to be between 0 and 1 for nitrate concentration of 10, 20, 30 and 40 mg/L.

The Freundlich isotherm equation<sup>32</sup> is expressed as,

$$\log(x/m) = \log k_f + 1/n \log C_e \quad \dots(5)$$

where  $x$  is the amount adsorbed (mg),  $m$  is the weight of the adsorbent used (g),  $k_f$  is the Freundlich constant related to sorption capacity and  $n$  is a constant related to energy or intensity of adsorption. This gives an expression encompassing the surface heterogeneity and the exponential distribution of active sites and their energies. This isotherm does not predict any saturation of the adsorbent surface. The Freundlich exponents  $k_f$  and  $n$  can be determined from the linear plot of  $\log(x/m)$  versus  $\log C_e$  (Fig. 6). Values of Freundlich constants increase with increase in concentration of nitrate as shown in Table 4. The results show that the adsorption also follows Freundlich isotherm.

**Effect of adsorbent dose**

Effect of adsorbent dose on the uptake of nitrate shows that the percentage removal increases with an increase in the dose of adsorbent. A maximum removal of 95% was obtained at 700 mg/50 mL of

Table 3—Langmuir constants

Nitrate conc (mg/L)	$Q_0$ (mg/g)	$b$ (L/mg)	$R_L$
10	10.3	0.096	0.5092
20			0.3415
30			0.2569
40			0.2059

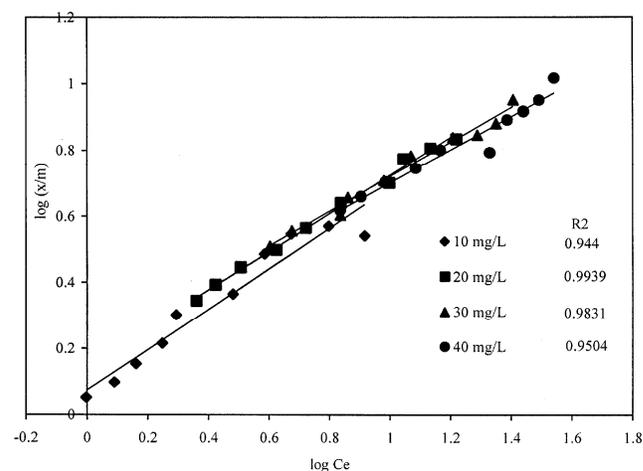


Fig. 6—Freundlich plots for adsorption of nitrate.

adsorbent dose for nitrate concentrations of 10 to 40 mg/L.

#### Effect of temperature

Increase of temperature slightly increased the percent removal (Fig. 7). The change in standard free energy, enthalpy and entropy of adsorption were calculated using the following equations,

$$\Delta G^0 = -RT \ln K_c \quad \dots (6)$$

where  $R$  is the gas constant,  $K_c$  is the equilibrium constant and  $T$  is the temperature in °K.

Table 4—Freundlich constants

Nitrate conc (mg/L)	$k_f$ (mg <sup>1-1/n</sup> L <sup>1/n</sup> g <sup>-1</sup> )	$n$	$R^2$
10	1.1836	1.629	0.9716
20	1.4057	1.7376	0.9969
30	1.5747	1.9139	0.9915
40	1.5809	1.9932	0.9749

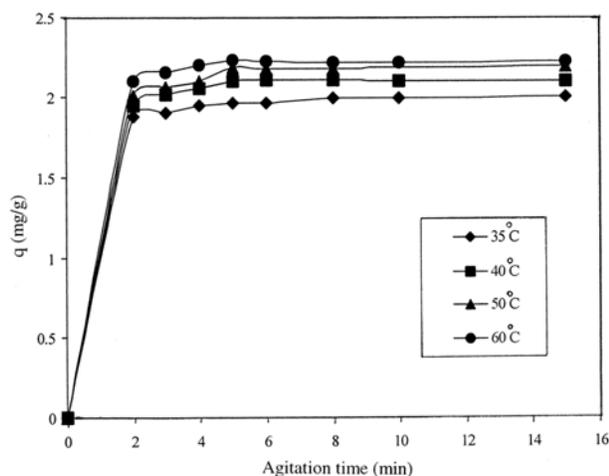


Fig. 7—Effect of temperature and agitation time on removal of nitrate: Adsorbent dose, 200 mg/50 mL; nitrate concentration, 10 mg/L; pH 3.0.

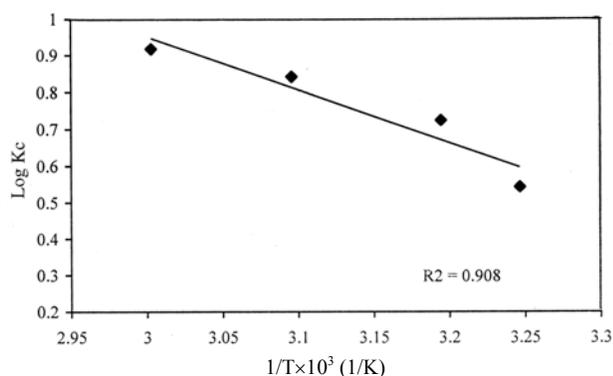


Fig. 8—Van't Hoff plot for nitrate adsorption.

According to van't Hoff equation,

$$\log_{10} K_c = \Delta S^0 / 2.303R - \Delta H^0 / 2.303RT \quad \dots (7)$$

where  $\Delta S^0$  and  $\Delta H^0$  are change in entropy and enthalpy of adsorption, respectively. A plot of  $\log K_c$  versus  $1/T$  is linear (Fig. 8). Values of  $\Delta H^0$  and  $\Delta S^0$  were evaluated from the slope and intercept of van't Hoff plots. The positive values of  $\Delta H^0$  confirm the endothermic nature of adsorption. The negative values of  $\Delta G^0$  at 35, 40, 50 and 60°C indicate spontaneous nature of adsorption for nitrate (Table 5). The positive values of  $\Delta S^0$  suggest the increased randomness at the solid/solution interface during the adsorption of nitrate on ZnCl<sub>2</sub> activated coir pith carbon.

The first order rate constants of adsorption ( $k_1$ ) were evaluated from the plots of  $\log(q_e - q)$  versus  $t$  for different temperatures using the Lagergren first order rate expression. The calculated  $q_e$  values obtained from the first order kinetic model do not agree with the experimental  $q_e$  values. This shows that the adsorption of nitrate on ZnCl<sub>2</sub> activated coir pith carbon at different temperatures does not follow the first order kinetic model. Linear plots of  $t/q$  versus corresponding to the second order kinetic model (Fig. 9) were obtained. The calculated values of  $q_e$  agree very well with the experimental data. The

Table 5—Thermodynamic parameters

Temp (°C)	$\Delta G^0$ (kJ/mol)	$\Delta H^0$ (kJ/mol)	$\Delta S^0$ (J/K/mol)
35	-3.1969		
40	-4.335		
50	-5.2018	27.54	100.82
60	-5.846		

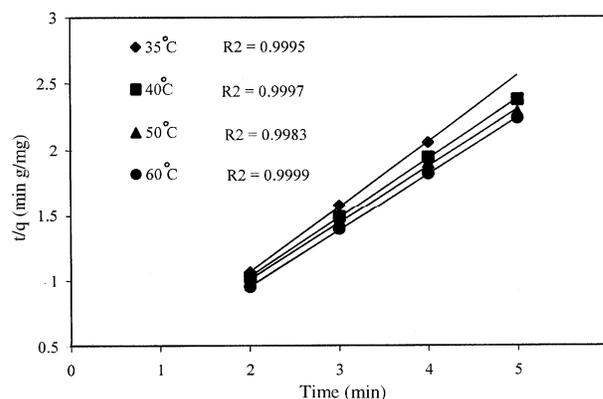


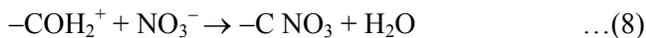
Fig. 9—Plots of the pseudo second-order model at different temperatures: Adsorbent dose, 200 mg/50 mL; nitrate concentration, 10 mg/L; pH, 3.0.

correlation coefficients are greater than 0.9998. This indicates that the adsorption follows second-order kinetic model at different temperatures used in this study.

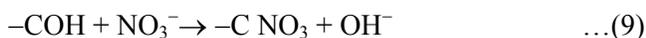
**Effect of pH**

The initial concentration of 10, 20, 30 and 40 mg/L of nitrate and 200 mg/50 mL of adsorbent dose were used to examine the pH effect (Fig. 10). Maximum removal (81%) of nitrate occurs in the pH range 3.0 to 10.0. At pH 2.0 and 11.0 the removal was lower (56 and 14%). Lower removal at pH 2 is due to the competition of Cl<sup>-</sup> ions (from HCl added externally to adjust the pH) with nitrate anions for the adsorbent sites. At pH 11.0, the highly negatively charged adsorbent surface sites do not favour the adsorption of oxianion due to the electrostatic repulsion.

At pH < p*H*<sub>zpc</sub> (3.2), the adsorbent surface moves towards more positively charged one and NO<sub>3</sub><sup>-</sup> adsorption occurs by electrostatic attraction. At pH 2.0, the per cent adsorption is less than at pH ≥ 3.0.



At pH > p*H*<sub>zpc</sub> the degree of protonation does not immediately drop to zero. Therefore, sorption of anions is still possible. Nitrate can also be adsorbed on the neutral surface of the adsorbent by ion-exchange mechanism<sup>33</sup>:



This is also evidenced by the experimentally observed increase in the final pH after adsorption with

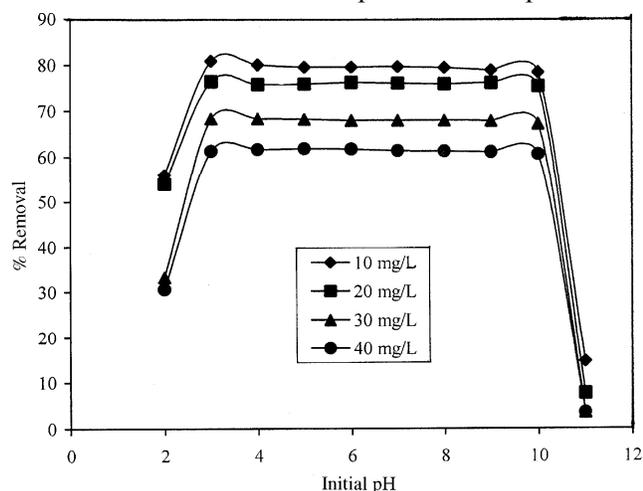


Fig. 10—Effect of pH on removal of nitrate: Adsorbent dose, 200 mg/50 mL; agitation time, 20 min; Temp, 35°C.

increase in the nitrate concentration in the initial pH range 2.0-10.0 with respect to the blank (in the absence of NO<sub>3</sub><sup>-</sup>).

At pH >> p*H*<sub>zpc</sub> the adsorbent surface moves towards more negatively charged one. Nitrate may be adsorbed by the available positively charged and neutral adsorbent sites as above. When the adsorbent is highly negatively charged (at high basic pH), adsorption is not favourable due to electrostatic repulsion between the negatively charged adsorbent surface and the anion. Hence, adsorption is not possible by ion-exchange mechanism, but only by another mechanism, namely, chemisorption<sup>34</sup> such as surface complex formation of nitrate with Zn<sup>2+</sup>.

**Desorption studies**

To make the adsorption process more economical, it is necessary to regenerate the spent carbon and nitrate. Desorption was higher at pH 2 (>58%) and pH 11(>92%) for 10 to 40 mg/L nitrate concentrations. This is due to the addition of Cl<sup>-</sup> in the form of HCl at pH 2.0 and OH<sup>-</sup> at pH 11.0. In the pH range 3.0 to 11.0 desorption was negligible for all the concentrations of nitrate studied (Fig. 11). Effect of pH and desorption studies show that chemisorption (Eq. 8) and ion exchange mechanism (Eq. 9) are operative in the adsorption process. Only the nitrate ions that are adsorbed by ion exchange mechanism are desorbed and the nitrate that is removed by surface complex formation (chemisorption) is not desorbed.

**Effect of foreign ions**

Systematic examination and quantitative information on the relative competition for adsorption

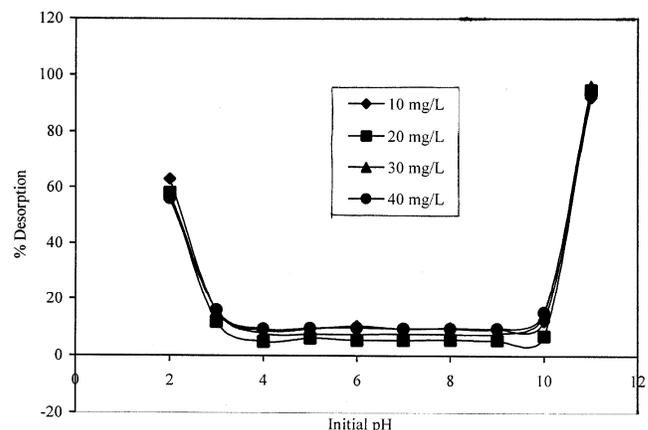


Fig. 11—Effect of pH on desorption of nitrate: Adsorbent dose, 200 mg/50 mL; agitation time, 20 min; Temp, 35°C.

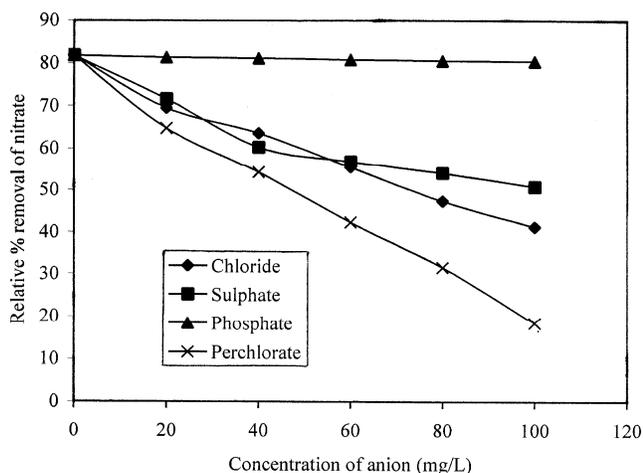


Fig. 12—Effect of different concentration of foreign ions on adsorption of nitrate.

onto activated carbon among the anions with different binding affinities are rather scarce. Adsorption of nitrate was studied in the presence of foreign anions – perchlorate, chloride, sulphate and phosphate (Fig. 12). Nitrate adsorption is reduced by perchlorate, chloride and sulphate. Phosphate hardly interferes in the adsorption of nitrate. Increase in concentration of the foreign ion further decreased the per cent adsorption of nitrate. This shows that the nitrate adsorption is not specific. Partitt<sup>35</sup> reported that anion adsorption by soil decreased in the order:  $\text{H}_2\text{PO}_4^- > \text{HAsO}_4^- > \text{HSeO}_3^- = \text{MoO}_4^{2-} > \text{SO}_4^{2-} > \text{Cl}^- > \text{NO}_3^-$ . Similar results were also reported for the adsorption of anions by hydrous ferric oxide gel<sup>36</sup>. In the present work other anions decreased nitrate removal in the order:  $\text{ClO}_4^- > \text{Cl}^- > \text{SO}_4^{2-} > \text{PO}_4^{3-}$ .

#### Tests with synthetic ground water

##### Effect of pH

Effect of pH on the adsorption of nitrate from the ground water is similar to pure nitrate solutions for the concentrations of 10 and 20 mg/L and an adsorbent dose of 200 mg/50 mL. Maximum removal was observed in the pH range 3.0 to 10.0. The per cent removal in the pH range 3.0 to 7.0 was 53 and 42%, respectively, for the concentrations 10 and 20 mg/L in the ground water compared to 80 and 76% in pure nitrate solutions. The decrease in per cent removal of nitrate in ground water compared to pure nitrate solutions is attributed to the presence of other competing anions like chloride, sulphate in the ground water.

##### Effect of adsorbent dose

Effect of adsorbent dose on adsorption of nitrate from the ground water is similar to the pure nitrate solutions for nitrate concentrations of 10 and 20 mg/L and pH 3.0. Ninety four per cent removal was observed at an adsorbent dose of 700 mg/50 mL for the nitrate concentrations of 10 and 20 mg/L in the ground water compared to 600 mg/50 mL in pure nitrate solutions. Higher adsorbent doses were required for the ground water due to the presence of other competing anions like chloride, sulphate in the ground water.

#### Conclusion

This study shows that the zinc chloride treated activated carbon developed from agricultural waste, coir pith, is an effective adsorbent for the removal of nitrate from aqueous solution. Adsorption followed both Langmuir and Freundlich isotherms. Langmuir adsorption capacity was found to be 10.3 mg/g. Adsorption kinetics obeyed second order kinetic model. Adsorption was found to be maximum in the pH range 3 to 10. Increase in temperature increased the removal. The positive values of  $\Delta H^0$  confirm the endothermic nature of adsorption. Desorption was found to be maximum at pH 2.0 and 11.0. The pH effect and desorption studies show that ion exchange might be involved in the adsorption process. Addition of different concentrations of perchlorate, sulphate and chloride reduced the removal of nitrate, whereas phosphate hardly influenced the removal. Tests with synthetic ground water shows that the per cent removal of nitrate by zinc chloride activated carbon is lower compared to pure nitrate solutions due to the presence of other competing anions.

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