

## Saw Dust Derived Activated Carbon in Different Impregnation Ratio and its Application in De-fluoridation of Waste Water

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### Abstract

In the era of continuous advancement in science and technology lead to the increase in global pollution in aquatic environment. Due to the presence of emerging contaminants water bodies poses serious threat toward human beings as well other aquatic animals. Among all the contaminants, there are significant amount of fluoride is reported in many literature study. In this work, activated carbon is synthesized from low cost starting material which is a waste product for studying. The magnesium chloride ( $MgCl_2$ ) is used in different weight in the activation process i.e. ( $MgCl_2$ ) is an activating agent. Comparative batch study were performed for estimation of the significance of process parameter on adsorption. Comparative study on adsorption model and the adsorption kinetic were done. The mechanism of fluoridation adsorption was further analysed from thermodynamics and kinetics point of view. The parameters at which fluoride removal efficiency was maximum are 60 min, 1 g/lit, 2.00 pH. The maximum removable percentage for I.R 1.0 is 92.4%.

**Keywords:** De-fluoridation; Activated Carbon; Impregnation Ratio; Isotherm Model; Kinetics; Thermodynamics

### Introduction

For many years, groundwater is assumed to be as the most safe for drinking without any treatment. But now it is considered to be polluted as because of presence of fluoride ion, arsenic ions. Due to consumption of fluoridated water over prolonged period, resulting in chronic fluorosis [1-3]. Fluoride naturally exists as ionic form in minerals sedimentary and granite rocks. The permissible limit of fluoride in drinking water is 1.5 mg/L according to the guidelines of water quality [4]. In India, contamination of water usually happened due to different factors like effluent discharge, processing of coke, glassware, electronics, steel and aluminum, HF, and different preservatives. In steel making industry both fluorspar ( $CaF_2$ ) and limestone are among the starting materials for the preparation of steel. So, these are the source of fluoride contaminated water. There are different materials used for used for de-fluoridation technique [5,6] such as activated carbon (AC), ion exchangers, lime activated alumina etc. Among different method such as electroly-

sis [7], precipitation, adsorption, Donann electrolysis, adsorption is one of the efficient methods for de-fluoridation of water. Recent studies revealed that there are different type of low cost materials [8-10] such as fly ash, carbon nanotubes, slurry, ionic resins, bentonite, kaolinite, zeolite etc. activated carbon is the cheapest and environmentally safe material for de-fluoridation in waste water. Activated carbon is the most useful adsorbent for its huge capacity of adsorption. Practically, various materials like walnut, rice husk, wheat bran, saw dust lemon shell etc. [11] are utilized for preparation of activated carbon. Activated carbon is very useful substance for waste water treatment.

The present study highlights on fluoride uptake where activated carbon is used, prepared from saw dust [12] which is impregnated by magnesium chloride in different ratio and synthesized chemically.

## Objective of the Study

The present de-fluoridation study was performed followed by the synthesis of chemically activated carbon from saw dust [13] using magnesium chloride as an activating agent. The physico-chemical properties of the synthesized activated carbon were studied and de-fluoridation efficiency was calculated using different experimental procedure by adsorption as a function of contact time, adsorbent dose and pH using thermodynamic and kinetic studies.

## Materials and Methods

### Materials

Magnesium chloride ( $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ ) [Merck, Germany], Saw dust (available in local market) are collected for preparation of activated carbon. The required chemicals are of analytical grade and double distilled water were used in throughout synthesis.

### Preparation of adsorbents

In this present study activated carbon [14] was synthesized from saw dust using magnesium chloride ( $\text{MgCl}_2$ ) as an activating agent. The particular quantity of washed and dried saw dust was mixed with required amount of activating agent ( $\text{MgCl}_2$ ), according to different impregnation ratio (I.R = 0,25, 0.50, 1.0).

$$\text{Impregnation ratio (I.R)} = \frac{\text{Weight of active agent added}}{\text{Weight of carbonising material added}}$$

The required quantity of distilled water was added and boiled until slurry like mixture was obtained. Then the mixture was dried in a container for one day at  $105 \pm 5^\circ\text{C}$ . Then these three containers were placed in Muffle furnace at  $800^\circ\text{C}$  for 4 hours. After that when these containers were attained steady state temperature, these were kept in cool environment for about 10 hours. Finally, the synthesized activated carbon was washed by dilute HCl to remove impurities present in the activated carbon. Then these impregnated activated carbon were dried in hot air-oven and cooled in desiccators for further batch study.

### Physicochemical properties of adsorbents

The different physicochemical [15,16] properties of the synthesized activated carbons were calculated using standard protocols. Then the essential experiments were conducted thrice and results are given in table 1.

Serial. No.	Characteristics	Chemically Activated ( $\text{MgCl}_2$ )		
		0.25	0.5	1.0
1	Moisture content (%)	6.21	5.32	3.87
2	Ash content (%)	16.24	15.06	13.07
3	Decolorizing power, (mg/g)	30.87	35.83	43.64
4	pH	7.8	7.6	7.2
5	Yield of carbon (%)	61	72	86
6	Bulk Density	0.67	0.73	0.78
7	Porosity	0.63	0.69	0.75

**Table 1:** Physicochemical analysis.

### Yield of carbon

The percentage yield of carbonizing was achieved by applying this formula:

$$\% \text{ yield of carbon} = \frac{\text{weight of char}}{\text{weight of raw material}}$$

### Determination of bulk density

The bulk density was calculated using the following equation:

$$\text{Bulk Density} = \frac{W_2 - W_1}{\text{volume of centrifuge tube}}$$

### Porosity determination

The porosity of the activated carbon was estimated using the formula:

$$\text{Porosity} = \frac{\text{pore volume}}{\text{total volume}}$$

The pore volume of prepared activated carbon was achieved using the formula:

$$\text{Pore volume} = \frac{\text{Bulk density of activated carbon}}{\text{density of water}}$$

$$\text{Hence, porosity} = \frac{\text{Bulk density of activated carbon}}{\text{density of water} \times \text{Total volume}}$$

### Determination of moisture content

The measurement of moisture content ( $X_o$ ) of the activated carbon was estimated using the formula:

$$X_o = \frac{W_2 - W_3}{W_2 - W_1} \times 100$$

**Determination of ash content**

The oven dried empty crucible was cooled in a desiccator and weighed (W1). The known weight of synthesized dried activated carbon powder was kept in the crucible and weighed (W2) keeping in the muffle furnace at 1000 C for 1 hour and then allowed to cool. Finally, the crucible was reweighed (W3). The percentage ash content of activated carbon sample was achieved from the equation:

$$\text{Ash\%} = \frac{W_{\text{ash}}}{W_0} \times 100 = \frac{W3 - W1}{W2 - W1} \times 100 ;$$

Where  $W_{\text{ash}}$  = weight of ash (g).

**Determination of pH**

1g activated carbon from saw dust was dissolved in 10 ml distilled water. The mixture was heated and stirred for few minutes followed by filtration and finally pH was estimated using a digital pH meter.

**Preparation of synthetic fluoride solutions**

Sodium fluoride (Merck, Germany) was used in this study. Experimental fluoride ion solution (1000 mg L<sup>-1</sup>) was synthesized by dissolving accurately weighed quantity in double-distilled water. Then different concentrations were made by diluting the main solution with suitable volume of distilled-water.

**Experimental**

**Experimental set up**

Experiments were performed in temperature controlled incubator shaker (Innova 4430, New Brunswick Scientific, Canada). The samples were collected for stirring for particular time interval. The dissolved fluoride in each conical flask was calculated by using ion-meter [17] (Thermo Scientific Orion ion-meter, USA).

**Batch sorption experiment**

In this present batch study, the required quantity of activated carbon was added to the fluoride solution, then it was stirred for different contact time with different dosage of adsorbent in different pH of solution. This powder like activated carbon is very suitable for batch sorption studies.

**Thermodynamic and kinetics studies**

**Adsorption isotherm**

The Langmuir and Freundlich isotherms [18] study were carried out by using AC (different IR ratio) for de-fluoridation in water.

The chemical reaction or adsorption between fluoride ions and adsorbents can be better explained by these isotherm models.

**Langmuir isotherm**

The simplified form of Langmuir model is expressed by the following equation

$$\frac{C_e}{Q_e} = \frac{1}{Q_0 b} + \frac{C_e}{Q_0} \dots\dots\dots (2)$$

Here,  $C_e$  indicates the residual fluoride concentration at equilibrium,  $Q_e$  indicates fluoride concentration adsorbed on the sorbent at equilibrium,  $Q_0$  indicates maximum fluoride concentration and  $b$  denotes Langmuir constant.

**Freundlich isotherm**

From the following equation Freundlich constants are calculated as follows

$$\ln Q_e = \ln K_f + \left(\frac{1}{n}\right) \ln C_e \dots\dots\dots (3)$$

Here  $Q_e$  denotes the amount of fluoride adsorbed at equilibrium, and  $K_f$  and  $n$  indicates Freundlich constants expressing adsorption capacity and adsorption intensity respectively.

**Adsorption kinetics**

The adsorption process is carried out at various temperatures to determine the optimum temperature for maximum adsorption efficiency and for obtaining the reaction rate constant activation energy. 50 mg/L, 100 ml of fluoride solution was experimented in PTFE conical flask adding 1 g adsorbent to it. Then this mixture was stirred at 150 rpm for 1 hour. From this experiment kinetic rate constant [19] at different temperatures were calculated.

**Pseudo first order kinetics**

Following the rate constant equation:

$$\frac{dq_t}{dt} = k_1 (q_e - q_t) \dots\dots\dots (4)$$

Where,  $q_e$  = fluoride adsorbed at equilibrium/unit weight of adsorbent (mg/g),  $q_t$  is the amount of fluoride adsorbed at any instant (mg/g) and  $k_1$  is the rate constant (min<sup>-1</sup>).

Integrating at these conditions as  $t=0$  and  $q_t=0$  to  $t=t$  and  $q_t=q_t$ , the final equation is written as given below:

$$\text{Log} (q_e - q_t) = \text{log} q_e - \frac{k_1 t}{2.303} \dots\dots\dots (5)$$

**Pseudo second order kinetics**

The model equation is described as follows:

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + 1/q_e (t) \dots\dots\dots (6)$$

Where  $k_2$  denotes the pseudo-second-order rate constant of adsorption ( $g\ mg^{-1}\ min^{-1}$ ) and  $q_e$  and  $q_t$  are the amounts of fluoride adsorbed ( $mg/g$ ) at equilibrium and at time  $t$  respectively.

**Activation energy**

From the achieved rate constant, activation energy of the adsorption of fluoride was obtained using Arrhenius Eq (7). as follows:

$$\ln k_2 = \ln A_0 - \frac{E_a}{RT} \dots\dots\dots (7)$$

Here  $E_a$  = activation energy ( $kJ\ mol^{-1}$ );  $R$ = gas constant ( $8.314\ J\ mol^{-1}\ K^{-1}$ ); and  $A_0$  = Arrhenius constant.

**Adsorption thermodynamics**

The adsorption thermodynamic parameters of fluoride are calculated using the following equation:

$$K_c = \frac{C_a}{C_e} \dots\dots\dots (8)$$

Here,  $K_c$  = coefficient of distribution for the adsorption;  $C_a$  = fluoride adsorbed per unit mass of the adsorbent ( $mg\ L^{-1}$ );  $C_e$  = equilibrium concentration of adsorbate in aqueous phase ( $mg\ L^{-1}$ ).

$$\Delta G_0 = -RT \ln K_c \dots\dots\dots (9)$$

Here,  $G_0$  ( $kJ\ mol^{-1}$ ) = change of Gibb’s free energy;  $R$  = universal gas constant; and  $T$  = absolute temperature ( $K$ ); and

$$\ln K_c = \frac{\Delta S_0}{R} - \frac{\Delta H_0}{RT} \dots\dots\dots (10)$$

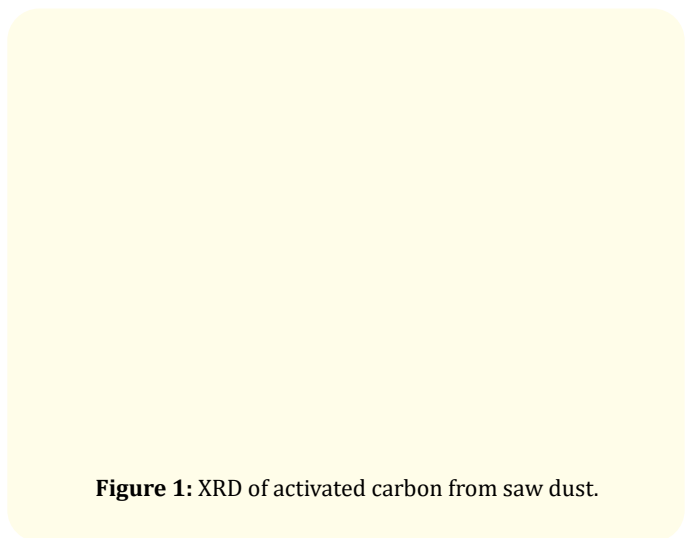
Here  $\Delta H_0$  ( $kJ\ mol^{-1}$ ) = change of enthalpy;  $\Delta S_0$  ( $J\ mol^{-1}\ K^{-1}$ ) = change of entropy.

**Results and Discussion**

**Characterisation of activated carbon (saw dust)**

**XRD (X-ray diffraction) analysis**

X-ray diffraction analysis of activated carbon was conducted using X-ray diffractometer equipment (Bruker, D8 Advance) with a Cu  $K\alpha$  radiation. The diffraction pattern of activated carbon from saw dust (IR:1.0) as prepared, represented in figure 1.



**Figure 1:** XRD of activated carbon from saw dust.

**Boehm titration**

The acidic and basic functional groups of surface of the samples were estimated by the Boehm Titration method. In this method, 0.2g AC (different impregnation ratio) sample was added to 25 ml of 0.1 M  $NaHCO_3$  and similarly to 25 ml of 0.1M  $Na_2CO_3$ . The mixtures were agitated for 24 hours and then it was filtered. After removal of carbon, the excess of base and acid was titrated with 0.1M HCl solution and 0.1M NaOH solution, respectively. Chemically number of acidic sites were estimated by chemical neutralization of carboxyl, phenolic and lactonic groups by NaOH; carboxyl and lactonic groups by  $Na_2CO_3$ ; and carboxyl groups by  $NaHCO_3$ . Similarly, the number of basic sites was estimated from the amount of consumed hydrochloric acid by AC (Table 2).

Sample: (AC from saw dust)	Groups			Total acidity (meq g <sup>-1</sup> )	Total basicity (meq g <sup>-1</sup> )
	Carboxylic (meq g <sup>-1</sup> )	Phenolic (meq g <sup>-1</sup> )	Lactonic (meq g <sup>-1</sup> )		
IR: 0.25	0.16	0.2	0.24	0.86	0.98
IR: 0.5	0.17	0.23	0.22	0.87	0.99
IR: 1.0	0.18	0.27	0.23	0.85	1.01

**Table 2:** Acidic and basic surface characteristics of the activated carbons.

### Determination of optimum contact time

Contact time play a significant role in adsorption study. In order to investigate the effect of contact time, 100 ml of fluoride solution of 100 mg/L and pH  $2.0 \pm 0.02$ , was stirred with 1g activated carbon, stirred at different contact times (10 - 100 min) and then filtered. These filtrates were experimented for the measurement of concentration of residual fluoride using ion-meter.

### Determination of optimum dosage of adsorbent

The optimum dosage of activated carbon was put in the conical flask in different dosage like 200 - 1500 mg which contains 100 ml of 50 mg/L fluoride solution having pH as  $2.0 \pm 0.02$ . The solution in the PTFE conical flask is subjected to stirring for optimum contact time and then filtered, and finally analyzed. The maximum de-fluoridation efficiency of dosage is indicated as optimum dosage of adsorbent.

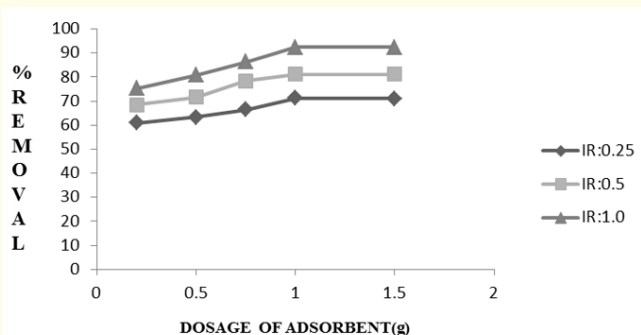
### Determination of optimum pH

The effect of pH on fluoride adsorption was experimented by performing equilibrium adsorption at different pH (2.00, 4.00, 6.00, 8.00, 10.00) values. The pH at which maximum fluoride removal happened that is optimum pH.

### Interaction effect

#### Effect of adsorbent dose

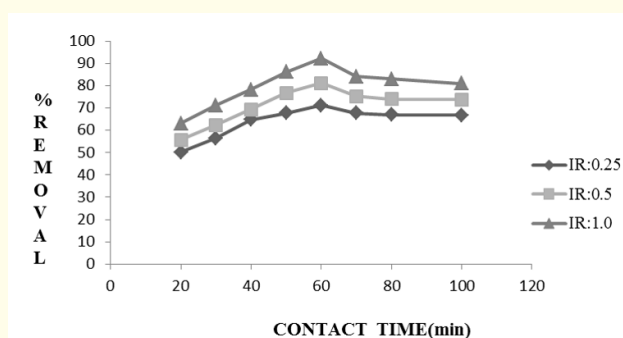
Within the particular range of adsorbent dose in between 0.2g - 1.5g/100 ml, percent removal of fluoride firstly rises (upto 1.0 g/100 ml), then inclines slowly. The adsorbent dose in the range of 0.2 - 1.0g/100 ml, de-fluoridation efficiency increases due to the number of ions increases on the adsorbent surface as the attraction force between adsorbate ions and adsorbent. While increasing dosage of adsorbent higher than 1.0g /100 ml, it indicates decrease in removal on the adsorbent surface due to saturation of surface of adsorbent by adsorbate ions, and because of the repulsive force between fluoride ions and adsorbent surface. Comparing three adsorbents (different IR ratio), weight of active agents are increasing according to the increased ratio. So the adsorption capacity of adsorbate is higher, with increasing ratio. From figure 2, it was shown that the removal efficiency of fluoride rises with increasing IR, so it can be concluded that activated carbon (IR = 1.0) is the best adsorbent for de-fluoridation among three adsorbents.



**Figure 2:** Effect of adsorbent dose on de-fluoridation by AC-Saw Dust (IR: 0.25, 0.5, 1.0).

### Effect of contact time

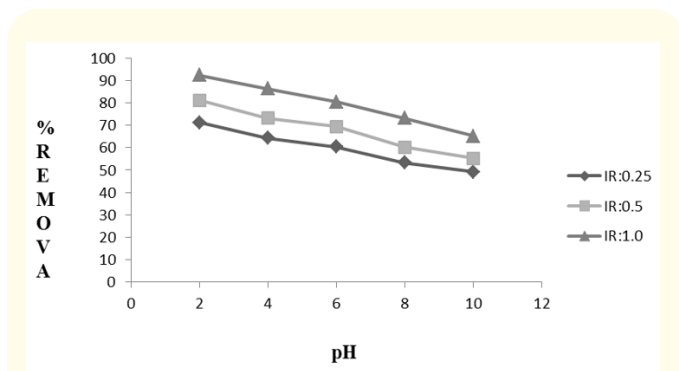
It is observed from (Figure 3) the experimental results that on increasing the contact time at pH 2 and optimum dosage of adsorbent, de-fluoridation efficiency increases. As the contact time increases, higher the number of fluoride ions attached on the adsorbent surface. Due to accumulation of fluoride ions on adsorbent surface consequence of attractive force gives rise to increasing the de-fluoridation in solution. But after certain point (60 min), de-fluoridation efficiency inclined. The reason behind this phenomena is that maximum number of the fluoride ions attached on adsorbent surface when reaction time was 60 minutes. Comparing three adsorbents (IR: 0.25, 0.5, 1.0), the number of pores are higher (IR:1.0) than two other adsorbents due to presence of more activating agents for preparation of carbon, consequently the adsorption capacity is the highest for that activated carbon (IR: 1.0). As a consequence of contact time, adsorption capacity reflects highest by AC (IR: 1.0) than other two adsorbents. From figure 3, it was inferred that the removal efficiency of fluoride increased in case of AC (IR:1) which was observed in the plot.



**Figure 3:** Effect of contact time on de-fluoridation by AC-Saw Dust (IR: 0.25, 0.5, 1.0).

### Effect of pH

In this present investigation, it was proved that with increasing pH, the percent removal of fluoride remarkably decreases for three adsorbents. Following the adsorption process, increasing the pH the acidity of the medium increases, which is the feasible condition for de-fluoridation (Figure 4). Consequently, the de-fluoridation efficiency decreases. As the adsorption capacity of activated carbon (IR:1) is the highest than other two adsorbents (explained before), so at particular pH (optimum dosage of adsorbent and optimum contact time) the number of adsorbate ions increased on AC (IR: 1) than AC (IR: 0.25) and (IR: 0.5). Overall, AC (IR: 1) is the best adsorbent among three for further experiment.



**Figure 4:** Effect of pH on de-fluoridation by AC-Saw Dust (IR: 0.25, 0.5, 1.0).

**Thermodynamics and kinetics study**

**Estimation of thermodynamic parameters of three activated carbon for de-fluoridation**

From this research study following equation (8-10) it was revealed that the negative value of  $\Delta G^0$  increases with increasing in the temperature (up to 333 K). It implies that the adsorption is

thermodynamically feasible in nature and the positive values of  $\Delta H^0$  indicates endothermic nature of the reaction due to consuming energy from the reaction system. The values of  $\Delta H^0$  and,  $\Delta S^0$  are estimated from the slopes and intercept of the plot  $\ln K_c$  vs.  $(1/T)$  (Figure not given) and the values are listed in table 3. It is observed that the negative value of  $\Delta G^0$  at all temperatures represents that the de-fluoridation reaction is spontaneous in nature. In this case  $\Delta G^0$  decreases up to 333K and after that it increases which denotes that the adsorption reaction is feasible up to 333K. As a consequence, Brownian motion between fluoride ion and activated carbon surface is increased. From thermodynamic point of view, it is endothermic reaction because adsorption capacity of fluoride ions by activated carbon is increasing with temperature. After certain temperature (333K), the reverse reaction happens. According to thermodynamics, entropy of the reaction is calculated from the experimentally obtained data that is positive for these adsorbents. So, it can be concluded that for increased temperature (above 333K), the desorption phenomena takes place on the adsorbent surface, consequently the concentration of fluoride in solution is increased in small amount in solution.

Serial No.	T, K	$\Delta G, \text{kJ/mol}$			$\Delta H, \text{kJ/mol}$			$\Delta S, \text{J mol}^{-1} \text{K}^{-1}$		
		IR:0.25	IR:0.5	IR:1.0	IR:0.25	IR:0.5	IR:1.0	IR:0.25	IR:0.5	IR:1.0
1	293	-8.93	-9.13	-9.83	62.33	72.19	79.43	252.11	257.13	267.39
2	313	-10.23	-10.86	-11.93						
3	333	-12.45	-12.97	-13.54						
4	343	-13.32	-13.86	-14.29						
5	353	-11.45	-11.74	-12.56						

**Table 3:** Thermodynamic parameters for the adsorption of fluoride onto AC-Saw dust (IR: 0.25, 0.5, 1.0).

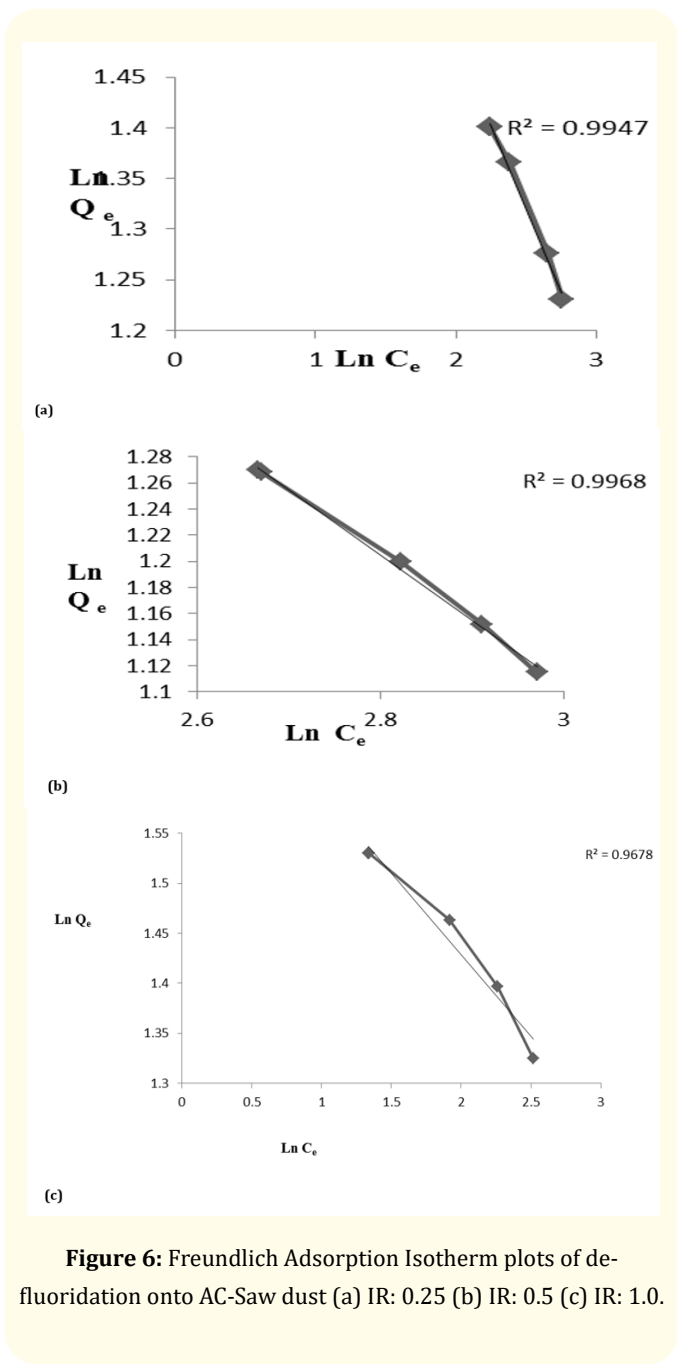
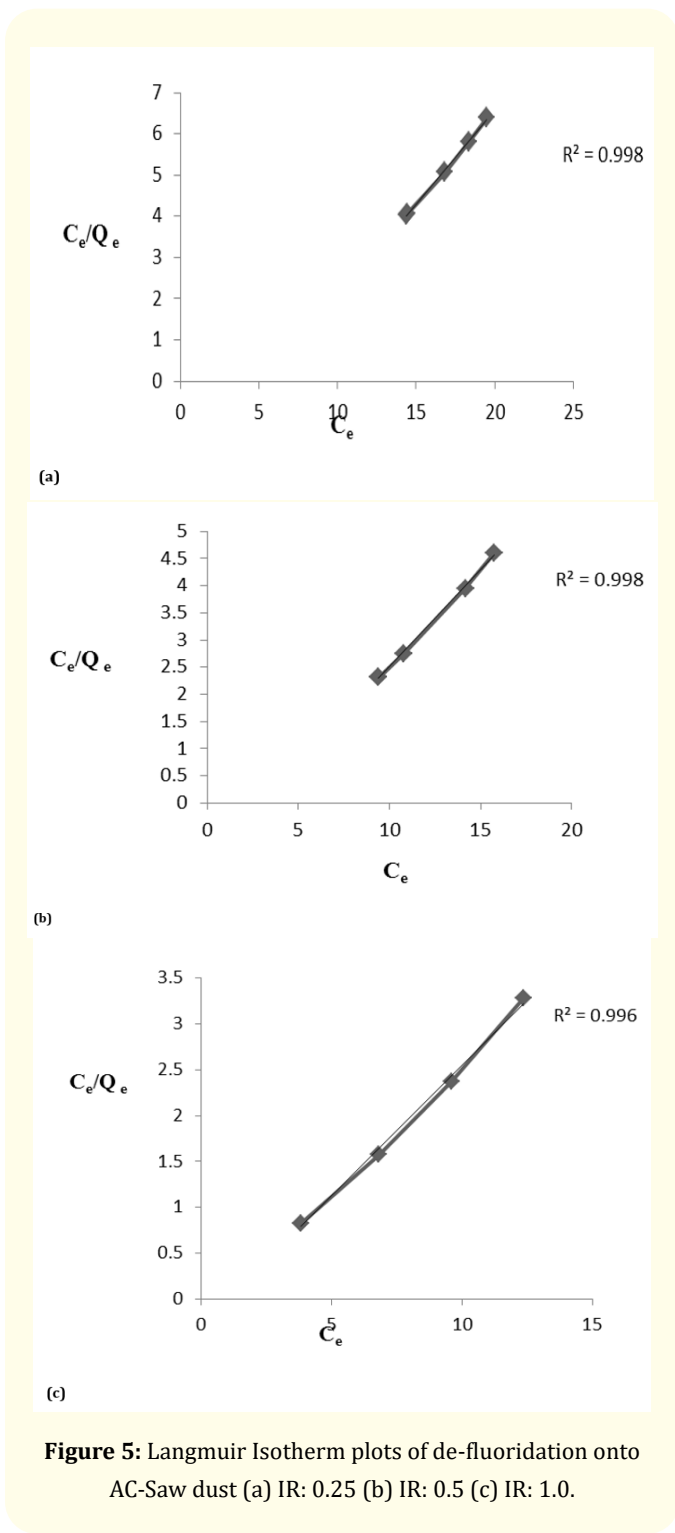
**Batch adsorption isotherm**

The estimated adsorption equilibrium data for AC (IR:0.25,0.5,1.0) was modeled applying Langmuir (Figure 5a-5c) and Freundlich isotherms model (Figure 6a-6c). Using these two models the probable mechanism of interaction between fluoride

ions and prepared adsorbents are well explained. The isotherm parameters were shown in table 4. From that table 4 it is illustrated that Langmuir model is very well fitted with three adsorbents than Freundlich model in present study of fluoride sorption. Following Langmuir model, the monolayer fluoride adsorption happened in these three adsorbents which is dependent on the nature of surface.

Adsorbents	Langmuir			Freundlich		
	$Q_e(\text{mg g}^{-1})$	$b(\text{L mg}^{-1})$	$R^2$	$K_f(\text{mg g}^{-1})$	$n(\text{L mg}^{-1})$	$R^2$
(1)AC(IR:0.25)	24.52	0.31	0.998	41.54	3.23	0.9968
(2)AC(IR:0.5)	31.23	0.41	0.998	43.13	3.03	0.9947
(3)AC(IR:1.00)	34.52	0.47	0.996	45.82	3.85	0.9678

**Table 4:** Langmuir and Freundlich isotherm model constants and correlation coefficients for fluoride adsorption onto AC-Saw Dust (IR: 0.25, 0.5, 1.00) at optimized conditions.



**Batch adsorption kinetics**

The present adsorption kinetics studies were conducted for de-fluoridation using three adsorbents having different IR ratio of AC. The parameters of kinetic studies are shown in table 5. From this

study, it is observed that pseudo second order kinetics study are well fitted than pseudo first order reaction. From the pseudo second order kinetic reaction it is indicated that adsorption capacity of both adsorbent are dependent on available binding site. The plot of  $t/q_t$  Vs  $t$  (Figure 7) in pseudo second order kinetic modeling are represented. From the pseudo second order rate constant  $k_2$  at different temperatures, the activation energy  $E_a$  (Activated carbon) is determined using the Arrhenius energy equation (Equation 7). The comparative study of adsorption capacities, isotherm and kinetic models of various adsorbents which were already reported for fluoride removal with these three adsorbents in the present study, represented in the table 5.

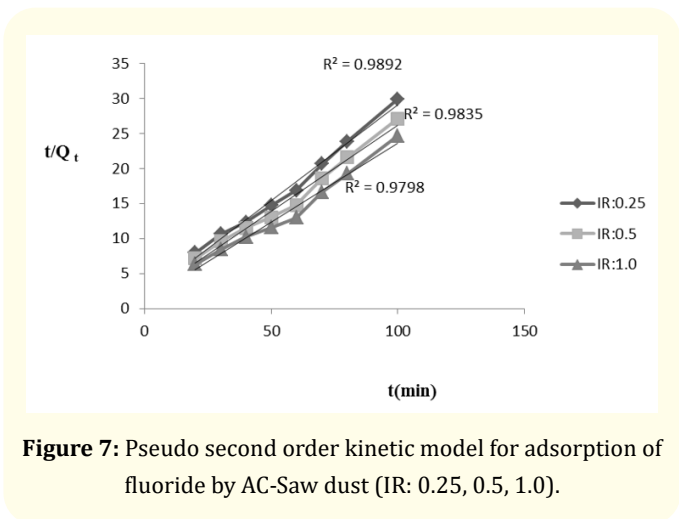


Figure 7: Pseudo second order kinetic model for adsorption of fluoride by AC-Saw dust (IR: 0.25, 0.5, 1.0).

Adsorbents	Pseudo first order kinetics			Pseudo second order kinetics		
	$k_1$ (min)	$q_e$ (mg g <sup>-1</sup> )	R <sup>2</sup>	$k_2$ (g mg <sup>-1</sup> )	$q_e$ (mg g <sup>-1</sup> )	R <sup>2</sup>
(1)AC(IR:0.25)	0.0033	19.21	0.9237	0.0821	36.72	0.9892
(2)AC(IR:0.5)	0.0011	22.11	0.9311	0.0782	29.79	0.9835
(2)AC(IR:1.00)	0.0009	25.54	0.9362	0.0652	23.49	0.9798

Table 5: Comparison of pseudo first order and pseudo second order rate constants for AC-Saw dust (IR: 0.25, 0.5, 1.00) at optimized conditions.

### Regeneration study

The regeneration study of adsorbent in water treatment method is very important. As the activated carbon (IR: 1.0) prepared from saw dust show higher de-fluoridation efficiency (92.4%) compared to other activated carbon (IR: 0.25, 0.5), so its desorption study was determined by 5 adsorption-desorption cycles. This research study of adsorption-desorption was conducted with 100 ml of 50 mg.L<sup>-1</sup> of synthetic fluoride solution at the starting of each cycle. The study was performed with 1% sodium hydroxide (NaOH) as desorbing agent. The adsorption capacities of each cycle were 90.92%, 86.46%, 80.13%, 71.01%, and 62.53%. These experimental results (Figure 8) proved that activated carbon (IR:1.0) prepared from saw dust can be reused for de-fluoridation in water.

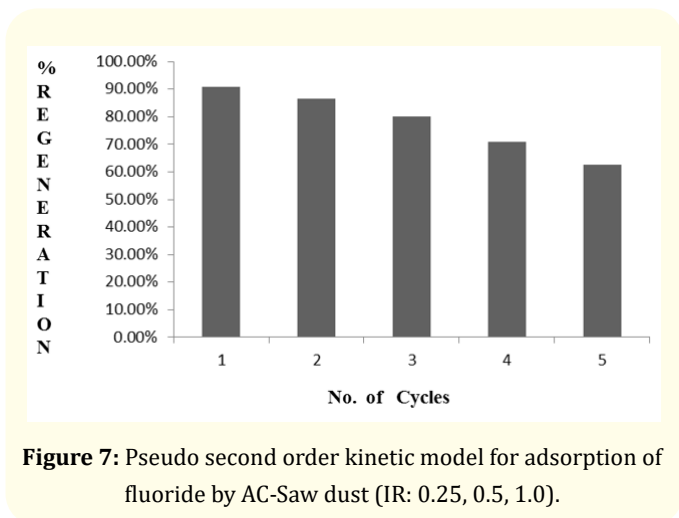


Figure 7: Pseudo second order kinetic model for adsorption of fluoride by AC-Saw dust (IR: 0.25, 0.5, 1.0).



### Comparative adsorption capacity, isotherm of various adsorbents with AC synthesized in this study:

Sorbent	Maximum adsorbent capacity	Isotherm	Reference
Activated Carbon (Rice straw)	18.9 mg·g <sup>-1</sup>	Langmuir	[20]
Activated Carbon ( <i>Moringa Indica</i> )	0.2314 mg·g <sup>-1</sup>	Langmuir	[21]
Activated carbon ( <i>Acacia farnesiana</i> )	2.622 mg·g <sup>-1</sup>	Freundlich	[22]
Activated carbon ( <i>Pithecellobium dulce</i> )	1.9333 mg·g <sup>-1</sup>	Freundlich	[23]
Activated carbon ( <i>Arachis hypogea</i> )	14.79 mg·g <sup>-1</sup>	Freundlich	[24]
Activated carbon ( <i>Cynodon dactylon</i> )	4.755 mg·g <sup>-1</sup>	Langmuir	[25]
Activated carbon ( <i>Anacardium occidentale</i> )	1.95 mg·g <sup>-1</sup>	Langmuir	[18]
Activated carbon (pecan nut shells)	2.3 mg·g <sup>-1</sup>	Langmuir	[26]
Activated Carbon (Saw dust, IR:1.0)	19.59 mg·g <sup>-1</sup>	Langmuir	Present Study

Table 6

### Conclusion

The present work deals with the aim of studying fluoride adsorption process onto activated carbon prepared from saw dust in different impregnation ratio. The adsorption studies were carried out as a function of pH, contact time and dosage of adsorbent. The following conclusions may be inferred on the basis of following experiment:

- It is proved that the adsorption equilibrium data are well fitted to the Langmuir adsorption model rather than Freundlich adsorption model at different pH for three adsorbents.
- The obtained experimental results showed satisfactory results with pseudo-second order kinetic model in case of three adsorbents.
- Thermodynamic parameters such as change in Gibbs free energy ( $\Delta G^0$ ), enthalpy ( $\Delta H^0$ ), and entropy ( $\Delta S^0$ ) were estimated from thermodynamic point of view. Moreover the nature of the adsorption process is spontaneous and endothermic.
- The desorption study was carried out using 1% NaOH as desorbing agent onto activated carbon (IR:1.0) in 5 cycles. The results showed that this adsorbent can be reused for further de-fluoridation.

As saw dust is eco-friendly and environment friendly, so the adsorbents are synthesized chemically from these materials which can be treated as efficient adsorbent for de-fluoridation in aqueous solution. Additionally, from comparative study it is shown that this is better adsorbent for de-fluoridation in water.

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