

REMOVAL OF FLUORIDE FROM DRINKING WATER WITH ACTIVATED CARBONS PREPARED FROM HNO₃ ACTIVATION - A COMPARATIVE STUDY

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ABSTRACT

The removal of fluoride on commercial activated carbon (CAC) and indigenously prepared activated carbons (IPACs) from Pithacelobium dulce, Ipomoea batatas and Peltophorum ferrugineum have been studied. The effects of various experimental parameters like pH, dose of the adsorbent, adsorbate concentration and contact time have been investigated using a batch adsorption technique. The extent of fluoride removal increased with decrease in the initial concentration of fluoride and particle size of the adsorbent and also increased with increase in contact time, amount of adsorbent used and the initial pH of the solution. Adsorption data were modeled using the Freundlich and Langmuir adsorption isotherms and followed first order kinetic equation $-dF/dt = Kr(F)$. The experimental data produced a straight line fit with a relatively good correlation coefficient (R^2) indicating the acceptability of the model for the studied indigenously prepared activated carbons (IPACs) fluoride system. [R^2 values for PLDC=0.09967, IBC= 0.9953, PFC= 0.9946 and CAC=0.9946]. The kinetics of adsorption was found to be first ordered with regards to intra-particle diffusion rate. The adsorption capacities of PLDC (78.96), IBC (76.62), and PFC (74.48) have been compared with that of the CAC (39.20) in drinking water treatment for removal of fluoride.

Keywords: Adsorption; Fluoride; Activated carbons-indigenously prepared; Freundlich and Langmuir adsorption isotherms; Intra-particle diffusion.

INTRODUCTION

Activated carbons are the most important commercial adsorbents. Their high surface area¹ together with their surface chemical structure allows them to be used in a wide variety of industrial applications, some of the most important dealing with the environmental field and particularly with water purification and industrial wastewater cleaning²⁻⁶. In these applications adsorption with activated carbon is most commonly oriented towards the removal of species which are recognized as toxic pollutants like fluoride.

Fluoride is a natural compound present in water, soils, plants and animals and is assumed to be essential for life. A WHO experts committee⁷ considered fluorine to be one of the 14 elements that are essentially for animal life. WHO standards for drinking water is between 0.5 – 1.5 mg/L. Fluoride concentration below and above the permissible limit has an implication related to health. If fluoride is totally absent in water supply it is known to cause dental carries.

Fluoride is more toxic than lead, and just like lead, even in minute doses, accumulates in and is damaging to brain/mind development of children, i.e. produces abnormal behavior in animals and reduces IQ in humans⁸. Fluorosis is a disease caused by ingestion of fluoride in excess through water, food, and air and is a serious health problem. Fluoride ingested with water goes on accumulating in bones up to age of 55 years. At high doses fluoride can interfere with carbohydrates, lipid protein, vitamin, enzyme and mineral metabolism. Long term consumption of water containing 1 mg of fluoride per liter leads to dental fluorosis. The process of removal of fluoride is generally termed as defluoridation. Numerous methods have been described employing various materials for the fluoride removal since 1930's. Based on the nature of processes, the defluoridation can be grouped under the following categories:

De-fluoridation was reported by adsorption⁹ chemical treatment^{10,11}, ion exchange¹², membrane separation^{13,14}, electrolytic de-fluoridation¹⁵ and electro dialysis¹⁶⁻¹⁸ etc. Among various processes, adsorption was reported to be effective¹⁹. Investigators reported various types of adsorbents namely activated carbon, minerals, fish bone char coal, coconut shell carbon and rice husk carbon, with different degrees of success^{9,20-24}. R.Sai Sathish²⁵ reported that the fluoride adsorption by zirconium impregnated coconut fibre carbon (ZICFC) was above 80% for the entire pH range of 2-9 and the adsorption rate was extremely rapid with 93% of the adsorption being achieved within 10 min of ZICFC contact for an initial fluoride concentration of 20mg L⁻¹. Saritha sinha²⁶ reported that fluoride is removed by using the activated carbon prepared from *E.crassipes*. Li Y.H²⁷ reported that the activated carbon loaded with alumina successfully removed fluoride at a pH range of 6.0-9.0. Vinod kumar gupta²⁸ reported that fluoride is removed at pH 7.58 by using carbon slurry. S.Venkata mohan²⁹ reported that fluoride is removed from aqueous phase by biosorption onto algal biosorbent *spirogyra* sp.IO2 and IO1.

The purpose of the present work is to study the kinetics of adsorption of fluoride on various indigenously prepared activated carbons (IPACs) from plant materials and to compare their adsorption capacity for the removal of fluoride under optimum experimental conditions. It is found that PLDC is the best adsorbent to remove fluoride from aqueous solution when compared with other adsorbents namely IBC, PFC, and CAC. Therefore this investigation is mainly concentrating on kinetics of adsorption of fluoride on commercial activated carbon (CAC) and (IPACs) prepared from *Pithacelobium dulce* carbon (PLDC), *Ipomoea batatas* carbon (IBC) and *Peltophorum ferrugineum* carbon (PFC) to find out the possibility of using these carbonaceous materials as low-cost adsorbents for the removal of fluoride.

EXPERIMENTAL

The material Commercial Activated Carbon (CAC) was supplied by E.Merck, India. Raw materials for the preparation of ACs such as *Pithacelobium dulce*, *Ipomoea batatas* and *Peltophorum ferrugineum* were procured locally, washed with double distilled water at room temperature, dried, cut into small pieces and dried. The raw materials were then carbonised (at 300° C) and steam digested (at 700° C). About 40gm of activated carbon powder and 400ml HNO₃ were taken into 1000ml conical flask and then the mixture was gently heated to boiling for 20 minutes. It is filtered and thoroughly washed with double distilled water until maximum colour is removed. The materials were finally sieved to discrete particle size ranging from 45µ size to 150µ and 45µ is found to be optimum to carry out the experiment. IPACs thus produced and CAC were thermally activated at 120° C for 1 hr in an air oven. Anhydrous sodium fluoride of laboratory reagent quality, supplied by Ranboxy Laboratories Ltd., India was used as an adsorbate and was not purified prior to use. All the other chemicals used in this study were reagent grade and supplied by BDH (India). Double distilled water was employed for preparing all the solutions and reagents.

Adsorption Studies

Equilibrium studies have been made at room temperature (30 ± 1°C) by employing the batch adsorption technique. All the experiments were carried out at pH =9 particle size= 45 µ, contact time= 40min and dose of the adsorbent 3g/lit for PLDC, CAC and 3.5g/lit for IBC, PFC are considered as optimum conditions³⁰⁻³⁴. This is the logical choice in most applications as it minimizes the pretreatment costs in the overall purification scheme². The percentage removal of fluoride and the amount adsorbed (in mg/g) have been calculated by using the following relationships:

$$\text{Percentage removal} = 100 (C_i - C_e) / C_i \quad (1)$$

$$\text{Amount adsorbed (Qe)} = (C_i - C_e) / m \quad (2)$$

Where C_i is the initial concentration and C_e is the final concentration of the fluoride respectively, and m is the weight of adsorbent in g/L. Adsorption Experiments have been carried out with a view to determine the impacts of the effects like particle size, pH, contact time, dose and initial concentration of fluoride.

The data have been analyzed in the light of adsorption isotherms like Langmuir and Freundlich, adsorption kinetic equations and intra particle diffusion model.

RESULTS AND DISCUSSION

Effect of initial concentration

The effect of initial concentration of fluoride on the extent of removal of fluoride (in terms of percentage removal) on various adsorbents viz., CAC, PLDC, IBC and PFC was studied and the relevant data are given in Table 1. The percentage removal was found to decrease exponentially, while the amount adsorbed increased exponentially with the increase in initial concentration of fluoride. This indicates that there exist reductions in immediate solute adsorption, owing to the lack of available active sites required for the high initial concentration of fluoride. The adsorption capacities of IPACs are high and therefore they could be employed as low cost adsorbents as alternatives to CAC for the removal of fluoride. The percentage removal of fluoride by various adsorbents follows the following order PLDC (89%) > IBC (82%) > PFC (78%) > CAC (32%). From the surface area values it can be concluded that greater the surface area greater will be the adsorption. PLDC (9586.55 Å), IBC (8625.17 Å), PFC (8647.92 Å), CAC (8505.93 Å).

Adsorption isotherms

The adsorption data were analysed with the help of the following linear forms of Freundlich and Langmuir isotherms³⁵:

Freundlich isotherm:

$$\log q_e = \log K_f + (1/n) \log C_e \quad (3)$$

Langmuir isotherm:

$$q_e = a b C_e / (1 + b C_e) \quad (4)$$

where $\log k_f$ is a measure of the adsorption capacity and $1/n$, is an indicator of adsorption effectiveness; q_e is the amount of fluoride adsorbed per unit mass of adsorbent (mg/g), a and b are the Langmuir constants which are the measures of monolayer (maximum) adsorption capacity (mg/g) and energy of adsorption (g/L), respectively. The values of Freundlich and Langmuir parameters were obtained respectively, from the linear correlations between the values of (i) $\log q_e$ and $\log C_e$ and (ii) (C_e/q_e) and C_e . The adsorption isotherms parameters along with the correlation coefficients are presented in Table 2. The observed statistically significant (at 95% confidence level) linear relationships as evidenced by the r -values (close to unity) indicate the applicability of these two adsorption isotherms and the monolayer coverage on adsorbent surface.

Freundlich and Langmuir isotherm plots are shown in Figures 1 and 2. The monolayer adsorption capacities of the adsorbents are found to be of the order:

$$PLDC > IBC > PFC > CAC$$

All the three IPACs are observed to possess high adsorption capacity and hence they could be employed as low-cost adsorbents as alternatives to CAC, for the removal of fluoride. Further, the essential characteristics of the Langmuir isotherm can be described by a separation factor R_L ; which is defined by the following Eq.³⁶:

$$R_L = 1 / (1 + b C_i) \quad (5)$$

Where C is the initial concentration of fluoride (in ppm or mg/l) and b is the Langmuir constant (in g/l). The value of separation factor R_L , indicates the isotherms shape and the nature of the adsorption process

as unfavorable ($R_L > 1$), linear ($R_L = 1$), favorable ($0 < R_L < 1$) and irreversible ($R_L = 0$).

In the present study, the values of R_L (Table 2) computed are observed to be in the range of 0–1, indicating that the adsorption process is favorable for all these low-cost adsorbents (IPACs).

Effect of contact time

The effect of contact time on the amount of fluoride adsorbed was investigated at the optimum initial concentration of fluoride (Table 1) and the data are presented in Table 3. The extent of removal (in terms of q_e) of fluoride by these ACs was found to increase and has been reached to maximum value with increase in contact time. The relative increase in the extent of removal of fluoride after 40 min of contact time is not significant and hence it is fixed as the optimum contact time.

In batch type adsorption systems, monolayer of adsorbate is normally formed on the surface of adsorbent³⁷ and the rate of removal of adsorbate species from aqueous solution is controlled primarily by the rate of transport of the adsorbate species from the exterior/outer sites to the interior sites of the adsorbent particles^{38, 39}. The percentage removal of fluoride from all the parameters of adsorbents are compared and given in the table 4.

Kinetics of adsorption

The two important physical and chemical aspects for parameter evaluation of the sorption process as a unit operation are kinetics and the equilibria of sorption. Kinetics of sorption, described the solute uptake rate, which in turn governs the residence time of sorption reaction, is one of the important characteristics defining the efficiency of sorption.

The removal of fluoride is very rapid initially and decreases markedly before equilibrium is reached. The rate constant (k) is determined using the following Helffrich model (equation 1).

The rate constant (k) can be determined using Helffrich equation

$$\ln [1-U(t)] = kt \quad (6)$$

Where $U(t) = (C_i - C_t)/C_i - C_e$ C_i , C_t , C_e are the concentrations (mg/L) of adsorbent samples initially at any time 't', and at equilibrium respectively. The straight line plotted between $\ln [1-U(t)]$ and 't' indicates the applicability in aqueous system that follows reversible first order. The sorption kinetic data obtained from (IPACs) fluoride system was studied with different kinetic models^[40, 41]. The Kinetic of adsorption of fluoride and various ACs have been studied by applying the following kinetic equations proposed by Lagergren.

Lagergren equation:

$$\text{Log}(q_e - q) = \text{log } q_e - (k_{ad} \cdot t) / 2.303 \quad (7)$$

The values of first order rate constants and correlation coefficient (r-value) are given in Table 5. All the linear correlations were found to be statistically significant (as evidenced by r-values close to unity) at 95% confidence level and indicate the applicability of these kinetic equations and the first order nature of the adsorption process of fluoride on various adsorbents. The value of k calculated from the Helffrich model are found to be close to that computed from Lagergren equation for any given adsorbent. The rate of adsorption k for adsorbents like PLDC, IBC, PFC and CAC are -0.0104 min^{-1} , -0.0104 min^{-1} , -0.0108 min^{-1} and 0.0044 min^{-1} respectively. Lagergren plots, Helffrich model plots are shown, respectively, in Figures.3 and 4.

Intra-particle diffusion model

The adsorbate species are most probably transported from the bulk of the solution in to the solid phase through intra-particle diffusion/transport process, which is often the rate limiting step in many adsorption process, especially in a rapidly stirred batch reactor^{37,42}. The possibility of intra-particle diffusion was explored by using the intra-particle diffusion model^[43].

$$q_e = k_p t^{1/2} + C \quad (8)$$

Where, q_e is the amount of fluoride adsorbed per unit mass of the adsorbent (in mg / g) at time t ; k_p and C are respectively the Intra-particle diffusion rate constant ($\text{mg/g} \cdot \text{minutes}^{-1/2}$) and the intercept. The values of amount of fluoride adsorbed have been correlated with the $t^{1/2}$ ($\text{minutes}^{1/2}$) for various adsorbents. This has resulted in linear relationship as evidenced by the r -values (table 6), which indicate the existence of intra-particle diffusion process. The values of intra-particle diffusion rate constant (k_p) calculated for various adsorbents are also reported in Table 6. The calculated value of k_p for PFC is maximum (0.1092) and is minimum (0.0953) for PLDC, which indicate that the intra-particle diffusion process is more significant in PFC system than in PLDC system. The values of intercept (C) give an idea of boundary layer thickness, i.e., the larger the intercept, the greater the boundary layer effect⁴⁴. The values of intercept decrease in the order PLDC > IBC > IFC > CAC. Further confirmation of the occurrence of intra-particle diffusion has been obtained from the correlation of the values of \log (% removal) and \log (time) which has also resulted in linear relationships. This indicates that the process of intra-particle diffusion takes place in the adsorption process. The values of slope calculated for different adsorbents have been found to be widely divergent from the value of 0.5, which corresponds to intra-particle diffusion as the rate determining step^{44, 45}. The divergence of slope values from 0.5 indicates that besides intra-particle diffusion process, there may be other processes controlling the rate of adsorption, all of which may be operating simultaneously^{46, 47, 19, 41,48}. The linear relation between \log (time) versus \log (percent removal) is shown in figure 5. Intra-particle diffusion plots for the removal of fluoride by adsorption on various adsorbents are shown in Figure 5 respectively.

Effect of dose of adsorbent

The effect of dose of adsorbent on the amount of fluoride adsorbed was studied (Table 6). The equilibrium value of amount adsorbed was observed to decrease with increase in dose. The percentage removal of fluoride increased with the increase in dose of adsorbent. This may be due to the increase in availability of surface active sites resulting from the increased dose and conglomeration of the adsorbent⁴⁹. The increase in the extent of removal of fluoride is found to be not significant after a dose 3.0 gm/l for PLDC and CAC for IBC, PFC it is 3.5gm/l which are fixed as the optimum doses of adsorbent.

Effect of initial pH

The effect of initial pH of the fluoride solution on the amount of fluoride adsorbed was studied by varying the initial pH under constant process parameters. The results are shown in Figure. 6. The increase in initial pH increases the amount of fluoride adsorbed. In all the cases the percent removal increasing from acid media to basic media but after pH level 7.0 the percent removal is very little. In all the three indigenously prepared carbons the percent removal at pH 9.00 is almost double when compared with CAC. The results agree well with those reported by others. K.Muthukumar⁵⁰ reported at an optimum pH of 9.0 for fluoride adsorption on to chemically activated carbon. P. Mariappan⁵¹ reported at an optimum pH of 8.5 for fluoride adsorption on to alum activated carbons and Gibbsite.

Effect of particle size of IPAC

The effect of particle size of IPACs on the amount of fluoride adsorbed was studied for indigenously prepared ACs. The amount of fluoride adsorbed increases with the decrease in particle size of the adsorbent. This is due to the increase in available surface area with the decrease in particle size. The effect of particle size on the amount of fluoride by various IPACs is shown in Figure 7. There exists a linear relationship between the amount of fluoride adsorbed and particle size, as evidenced by the r -values close to unity (r -value for ACs: PLDC=0.9993, IBC=0.9984, PFC=0.9987 and CAC=0.9154).

CONCLUSION

The results of the experiments have shown that the percentage of fluoride removal has increased with the increase of contact time and dose of adsorbent. On the contrary the percentage of removal has decreased with the increase in initial concentration of the standard fluoride solution. The results suggest that intra-particle adsorption is very important in adsorption process. The adsorption process is found to be of first order with the intra particle diffusion as one of the rate determining steps. Among the adsorbents under consideration PLDC possesses the highest or the maximum adsorption capacity. Hence it is the best and the most effective adsorbent in the removal of the dreaded fluoride content in water. The next in the order on the basis of its efficacy in removing the fatal content is IBC and PFC. The adsorption capacity and efficacy in the removal of fluoride are far greater than CAC.

Table-1: Effect of Adsorbate concentration on percent removal of fluoride and calculation of adsorption isotherms

Adsorbent Name	C _i	C _e	%Removal	Q _e	C _e /Q _e	Log(C _e)	Log(Q _e)
PLDC	1.00	0.11	89.00	0.2967	0.3708	-0.9586	-0.5277
	2.00	0.31	84.50	0.5633	0.5503	-0.5086	-0.2492
	3.00	0.57	81.00	0.8100	0.7037	-0.2441	-0.0915
	4.00	0.80	80.00	1.0667	0.7500	-0.0969	0.0280
	5.00	1.02	79.60	1.3267	0.7688	0.0086	0.1228
	6.00	1.34	77.67	1.5533	0.8627	0.1271	0.1913
	7.00	1.72	75.43	1.7600	0.9773	0.2355	0.2455
	8.00	2.2	72.50	1.9333	1.1379	0.3424	0.2863
IBC	1.00	0.18	82.00	0.2733	0.6585	-0.7447	-0.5633
	2.00	0.44	78.00	0.5200	0.8462	-0.3565	-0.2840
	3.00	0.68	77.33	0.7733	0.8793	-0.1675	-0.1116
	4.00	0.98	75.50	1.0067	0.9735	-0.0088	0.0029
	5.00	1.26	74.80	1.2467	1.0107	0.1004	0.0958
	6.00	1.63	72.83	1.4567	1.1190	0.2122	0.1634
	7.00	2.12	69.71	1.6267	1.3033	0.3263	0.2113
	8.00	2.68	66.50	1.7733	1.5113	0.4281	0.2488
PFC	1.00	0.28	72.00	0.2400	1.1667	-0.5528	-0.6198
	2.00	0.58	71.00	0.4733	1.2254	-0.2366	-0.3248
	3.00	0.90	70.00	0.7000	1.2857	-0.0458	-0.1549
	4.00	1.24	69.00	0.9200	1.3478	0.0934	-0.0362
	5.00	1.60	68.00	1.1333	1.4118	0.2041	0.0544
	6.00	2.10	65.00	1.3000	1.6154	0.3222	0.1139
	7.00	2.50	64.29	1.5000	1.6667	0.3979	0.1761
	8.00	3.20	60.00	1.6000	2.0000	0.5051	0.2041

	1.00	0.68	32.00	0.1067	6.3750	-0.1675	-0.9720
	2.00	1.46	27.00	0.1800	8.1111	0.1644	-0.7447
	3.00	2.32	22.67	0.2267	10.2353	0.3655	-0.6446
	4.00	3.20	20.00	0.2667	12.0000	0.5051	-0.5740
CAC	5.00	4.07	18.60	0.3100	13.1290	0.6096	-0.5086
	6.00	5.02	16.33	0.3267	15.3673	0.7007	-0.4859
	7.00	6.12	12.57	0.2933	20.8636	0.7868	-0.5326
	8.00	7.20	10.00	0.2667	27.0000	0.8573	-0.5740

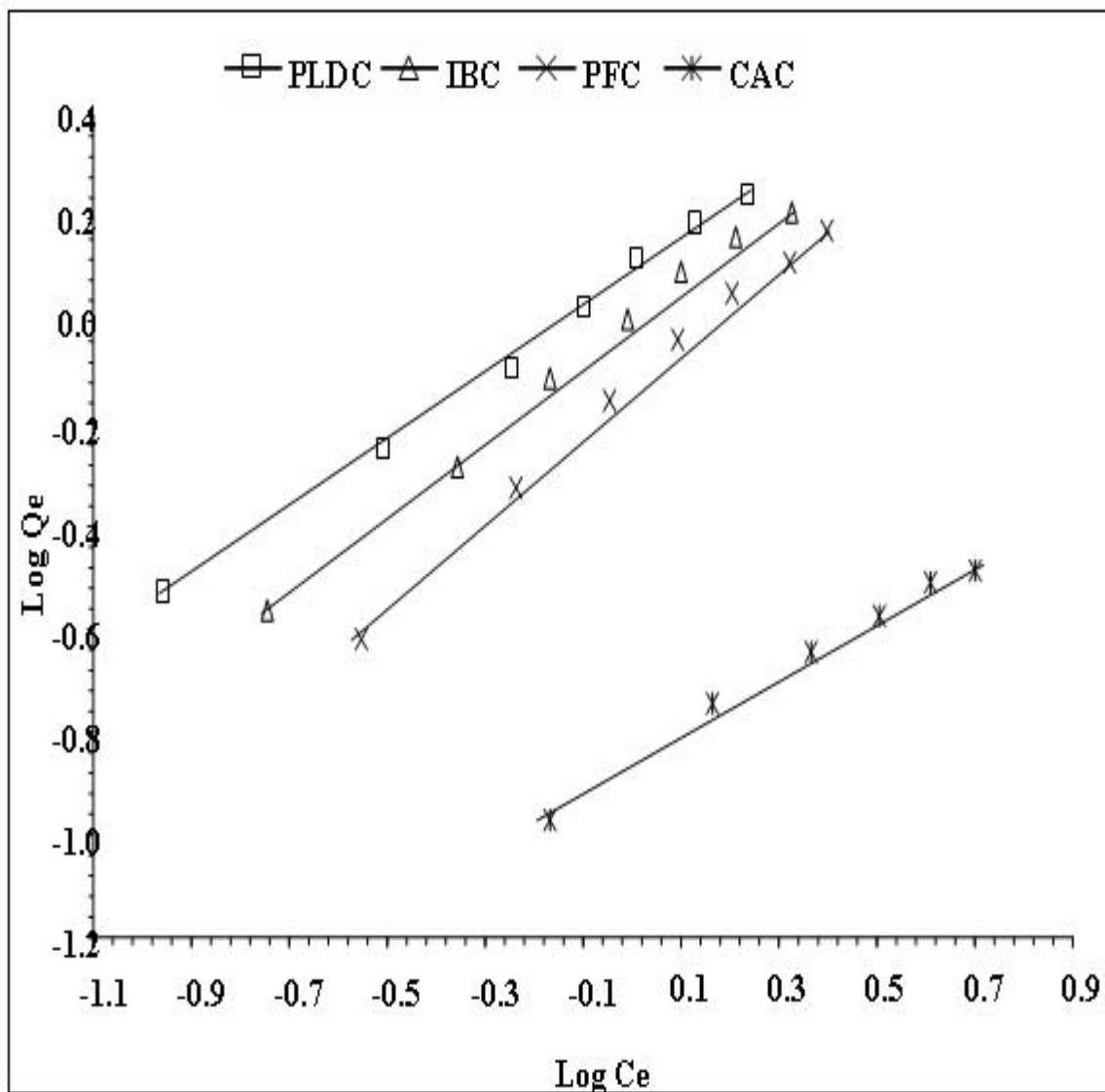


Figure 1: Calculation of Freundlich isotherm for the removal of fluoride, C_e = Equilibrium concentration of adsorbate in mg/L, Q_e = Amount of fluoride adsorbed by the adsorbent (mg/g).

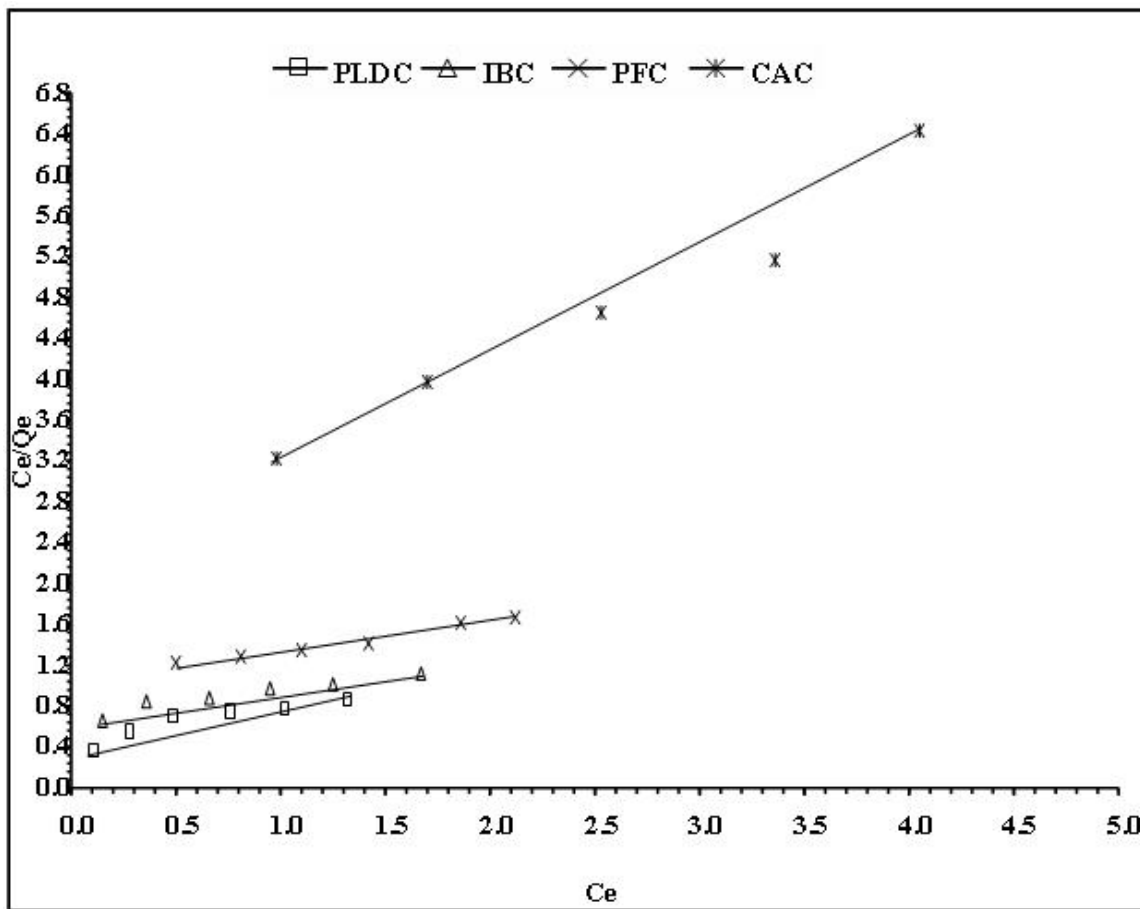


Figure 2: Calculation of Langmuir isotherm for the removal of fluoride, C_e = Equilibrium concentration of adsorbate in mg/L, Q_e = Amount of fluoride adsorbed by the adsorbent (mg/g).

Table-2: Adsorption isotherm parameters of the chosen adsorbents

Isotherm Parameter		PLDC	IBC	PFC	CAC
Freundlich isotherm	K_f	0.0204	0.0043	0.0421	0.6390
	$1/n$	0.6145	0.7478	0.7199	0.1620
	r	0.9984	0.9977	0.9973	0.9973
	R^2	0.9967	0.9953	0.9946	0.9946
Langmuir isotherm	a (mg/g)	0.0700	0.0710	0.0571	0.1105
	b (g/L)	0.2760	0.2460	0.2095	0.0335
	r	0.9993	0.9984	0.9987	0.9154
	R_L	0.4202	0.4485	0.4884	0.8567

Table 6: Effect of adsorbent concentration on the removal of fluoride from fluoridated water [(Ce = Equilibrium concentration of adsorbate (mg/l), Qe = Adsorbent concentration (mg/g.)].

Adsorbent	Dose (g/l)	Ce	% Rem.	Qe	Log Removal) (%)
PLDC	0.50	1.97	60.60	6.0600	1.78
	1.00	1.64	67.20	3.3600	1.82
	1.50	1.41	71.80	2.3933	1.85
	2.00	1.24	75.20	1.8800	1.87
	2.50	1.15	76.96	1.5392	1.88
	3.00	1.08	78.40	1.3067	1.89
	3.50	1.03	79.40	1.1343	1.89
	4.00	0.97	80.60	1.0075	1.90
	4.50	0.91	81.80	0.9089	1.91
	5.00	0.85	83.00	0.8300	1.91
	7.00	0.79	84.20	0.6014	1.92
	9.00	0.78	84.40	0.4689	1.92
IBC	0.50	2.48	50.40	5.0400	1.70
	1.00	2.19	56.20	2.8100	1.74
	1.50	1.83	63.40	2.1133	1.80
	2.00	1.53	69.40	1.7350	1.84
	2.50	1.35	73.00	1.4600	1.86
	3.00	1.24	75.20	1.2533	1.87
	3.50	1.17	76.60	1.0943	1.88
	4.00	1.12	77.60	0.9700	1.88
	4.50	1.08	78.40	0.8711	1.89
	5.00	1.05	79.00	0.7900	1.89
	7.00	0.98	80.24	0.5731	1.90
	9.00	0.98	80.32	0.4462	1.90
PFC	0.50	2.72	45.60	4.5600	1.65
	1.00	2.33	53.40	2.6700	1.72
	1.50	2.00	60.00	2.0000	1.77
	2.00	1.81	63.80	1.5950	1.80
	2.50	1.59	68.20	1.3640	1.83
	3.00	1.44	71.20	1.1867	1.85
	3.50	1.39	72.12	1.0303	1.85
	4.00	1.34	73.08	0.9135	1.86
	4.50	1.29	74.06	0.8229	1.86
	5.00	1.27	74.60	0.7460	1.87
	7.00	1.20	75.82	0.5416	1.87
	9.00	1.17	76.52	0.4251	1.88
CAC	0.50	4.60	8.00	0.8000	0.90
	1.00	4.06	18.80	0.9400	1.27
	1.50	3.60	28.00	0.9333	1.44
	2.00	3.33	33.40	0.8350	1.52
	2.50	3.12	37.60	0.7520	1.58

3.00	2.90	42.00	0.7000	1.62
3.50	2.80	44.00	0.6286	1.64
4.00	2.68	46.40	0.5800	1.67
4.50	2.60	48.00	0.5333	1.68
5.00	2.54	49.20	0.4920	1.69
7.00	2.54	49.20	0.3514	1.69
9.00	2.54	49.20	0.2733	1.69

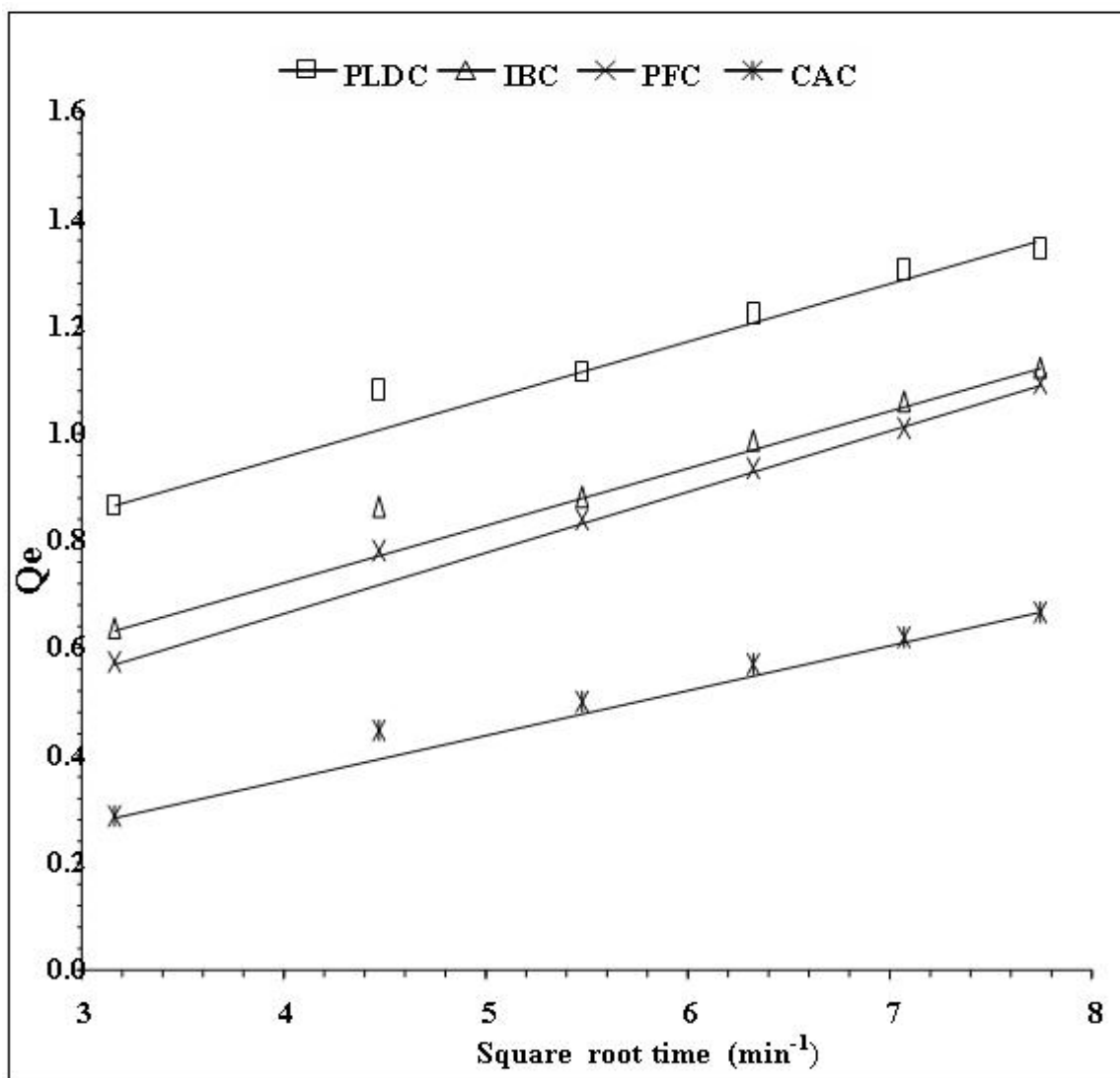


Figure.5: Intraparticle diffusion plots for the removal of fluoride by adsorption on various adsorbents

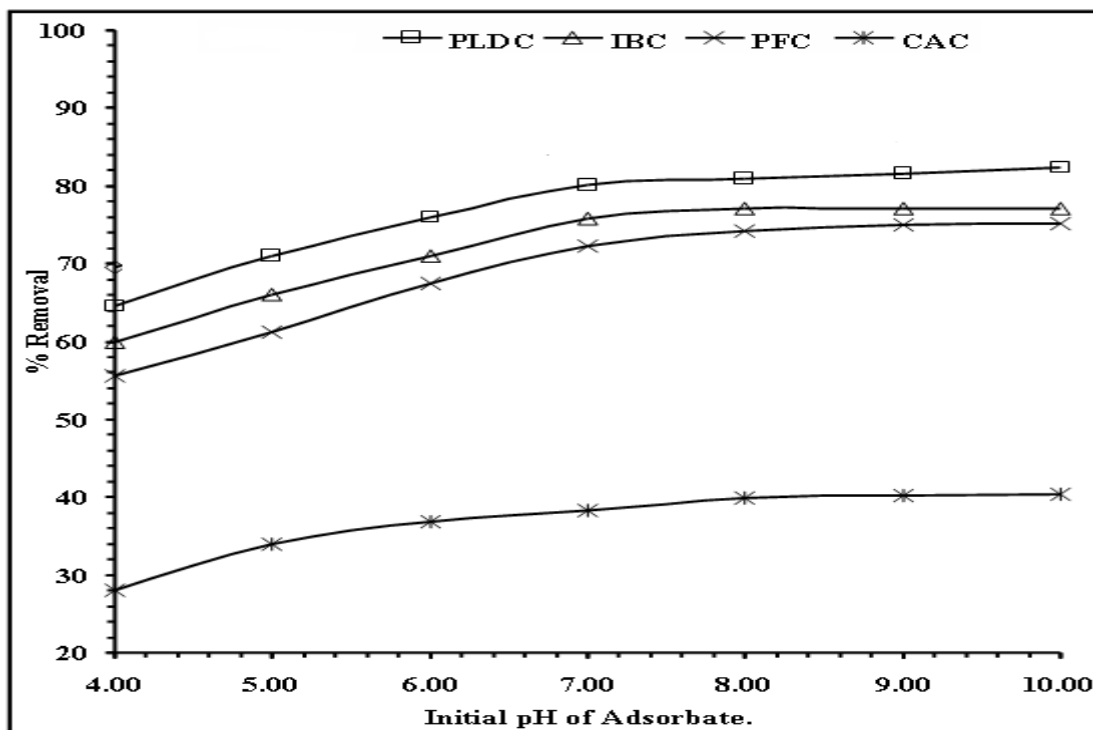


Figure 6. Plots showing the relationship between pH of initial fluoride by adsorbents.

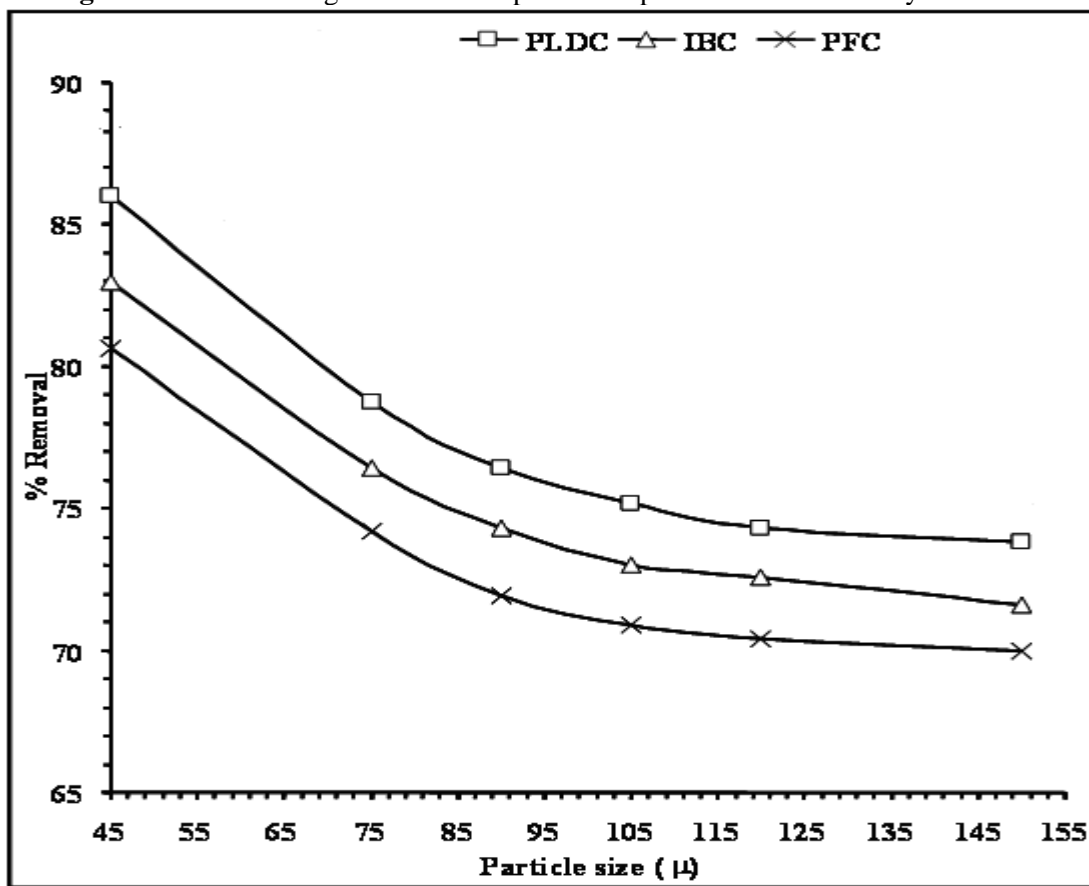


Figure 7: Effect of particle size on the percent removal of fluoride

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Table-4: Comparison of % removal of fluoride from all the parameters

Parameters	PLDC	IBC	PFC	CAC
pH 9	81.60	77.00	75.00	40.20
Dose 3gm/l	78.40	75.20	71.20	42.00
Contact time 40 min	76.52	73.70	71.76	35.00
Initial concentration of the adsorbate 5ppm	79.60	74.80	68.00	18.60
Particle size 45 μ	86.02	82.94	80.64	38.00

Table-3: Effect of contact time on the percent removal of fluoride by adsorption with prepared carbon

Time (Minutes.)	Ce				% Removal				Qe			
	PLDC	IBC	PFC	CAC	PLDC	IBC	PFC	CAC	PLDC	IBC	PFC	CAC
10	2.31	2.62	2.91	4.14	53.84	47.60	41.76	17.20	0.8973	0.7933	0.5966	0.2867
20	1.67	2.00	2.19	3.66	66.68	60.00	56.16	26.80	1.1113	1.0000	0.9360	0.4467
30	1.33	1.55	1.70	3.40	73.32	69.02	66.00	32.00	1.2220	1.1503	1.1000	0.5333
40	1.17	1.32	1.41	3.21	76.62	73.70	71.76	35.80	1.2770	1.2283	1.1960	0.5967
50	1.05	1.17	1.28	3.04	78.96	76.62	74.48	39.20	1.3160	1.2770	1.2413	0.6533
60	0.96	1.07	1.17	3.00	80.72	78.58	76.56	40.00	1.3453	1.3097	1.2760	0.6667
90	0.91	0.98	1.08	2.99	81.88	80.32	78.42	40.20	1.3647	1.3387	1.3070	0.6700
120	0.85	0.93	1.02	3.09	83.06	81.50	79.54	38.20	1.3843	1.3583	1.3257	0.6367

Table- 5: Statistical results of the application of the kinetic equations and models for the low cost adsorbents

Adsorbent	Helffrich equation	R ² Value	Helffrich Constant (K _f)	Lagergren equation	R ² Value	Lagergren constant (K)	Intraparticle diffusion model equation	(Kp)	R ² Value	log dos Vs logR ² (%Rem)	logR ² Value
PLDC	Y = -0.0084 X - 0.2881	0.9469	-0.0084	Y = -0.0104 X -0.3219	0.9973	-0.0104	Y = 0.0953 X + 0.6510	0.0953	0.9349	Y = 0.1178 X+ 1.8315	0.9652
IBC	Y = -0.0088 X - 0.2148	0.9728	-0.0088	Y = -0.0104 X -0.2315	0.9996	-0.0104	Y = 0.0973 X + 0.4102	0.0973	0.9588	Y = 0.1732 X+ 1.7725	0.9652
PFC	Y = -0.0091 X - 0.1684	0.9695	-0.0091	Y = -0.0108 X -0.6601	0.9990	-0.0108	Y = 0.1092 X + 0.2972	0.1092	0.9530	Y = 0.1833 X+ 1.7402	0.9338
CAC	Y = -0.0033 X - 0.0611	0.9670	-0.0033	Y = -0.0044 X -0.6601	0.9866	-0.0044	Y = 0.0837 X + 0.0528	0.0837	0.9685	Y = 0.5850 X+ 1.2662	0.8612