

Fixed Bed Modelling Column Adsorption Studies by Activated Carbon for Removal of Fluoride

Keerthi B. Gurani¹ and S.R. Mise²

¹*Department of Civil Engineering, KCT Engineering College, Gulbarga, India*

²*Department of Civil Engineering, PDA College of Engineering, Gulbarga, India*

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ABSTRACT

The fluoride removal from aqueous solution was investigated utilising Copper Pod adsorption in a fixed bed column. The effects of flow rate, bed height, and fluoride concentration at the start were studied. Breakthrough curves were plotted after determining maximum bed capacity, % fluoride elimination, and equilibrium fluoride uptake. With a lower flow velocity and a higher bed height, the percentage of fluoride removed increased. At a flow rate of 5 ml/min, a bed height of 10 cm, and an initial fluoride concentration of 5 ppm, a maximum bed capacity of 6.5 mg was achieved. The Three well-known models were used to fit data from column studies known column models. The Yoon-Nelson model, the Thomas model, and the Adams-Bohart model. The experimental data and theoretical results remained in good accord. The study discovered that activated carbon can be used in a fixed bed column to remove fluoride.

Key words : Fluoride, Activated Carbon(AC), Copper Pod Seeds, Models Thomas, Adams-Bohart, and Yoon Nelson, Fixed Bed Column Studies

Introduction

Water is essential for life, but we are still unable to supply everyone with safe, affordable drinking water. For all living things, water is a necessary component of life. Only a small percentage of the population, however, has access to safe drinking water. Others drink varied degrees of polluted water. The issue of supplying safe drinking water is causing widespread anxiety around the world, particularly in developing and developing countries. Because India is a developing country with a large population living in villages with limited infrastructure, a high prevalence of the notion of safe drinking water is inhibited by illiteracy as well as a lack of sanitation and hygiene knowledge. On the other hand, the bulk of the rural population drinks contaminated ground water, which contains a wide spectrum of

minerals and salts. An excessive level of fluoride in the water is one of them, and it is damaging to people's health. Fluoride is a toxin that accumulates in the body and is less damaging than arsenic but more lethal than lead. Drinking unclean water on a frequent basis causes dental and skeletal fluorosis, as well as a variety of other health problems including gastrointestinal problems. Because "Fluorosis" is regarded as an incurable disease, the only approach to deal with it is to prevent it. As a result, research into the defluoridation of water using a variability of adsorbents has gotten a lot of attention in recent years. Reverse osmosis, electro dialysis, and ion exchange are all methods for defluoridation. The Nalgonda de-fluoridation procedure developed by NEERI has recently acquired popularity, however it has its own set of drawbacks. A number of adsorbents are used to test de-fluoridation activity.

¹Asst Professor, ²Professor

Materials and Methods

Materials

Adsorbent: The fruit of copper pod seeds were utilised to make carbon.

Preparation of Physical Activated carbon

The spores of copper pod were cleaned and broken into little pieces, then washed in distilled water 8 to 9 times. The powder was previously wilted in a 105 °C oven for 24 hours. To avoid powder weight loss, the oven dried powder was compacted in three layers in a small container with no air space between each layer; otherwise, the material would burn rapidly, leaving only ash. The small the container was formerly placed into a larger ampule with the lid of the larger container tightly closed, encircling the little container completely in sand. The setup was then heated at a continuous rate in a muffle furnace until it reached 800 °C. After reaching the furnace was set to a temperature of 800 °C. allowable to cool for around 10 hours before the ampule was removed. The activated carbon was sieved to a size of 300 microns, packed in polythene bags, and maintained in a dessicator.

Studies on Fixed Bed Columns

A beaker column was filled with activated carbon (Borosil). The column's inside diameter was 1 cm and its height was 60 cm. An above tank was used to store the fluoride solution to be treated. The solution was designed to flow naturally. The movement rate was measured by control valves at the input and outlet. The effects of flow rate, bed height, and fluoride attentiveness at the start were studied. The column was crammed with AC to a height of 7.5 cm (5.46 g). m to examine the influence of incoming flow rate. Experiments were 3 distinct flow rates were used: 5 ml/min, 10 ml/min, and 15 ml/min, with a starting fluoride concentration of 5 ppm. The 3 distinct flow rates were used: 5 ml/min, 10 ml/min, and 15 ml/min, with 5 cm (4.5 g), 7.5 cm (5.46 gm), and 10 cm (6.96 g) to evaluate the influence of bed height (6.96 g). With the use of a control valve, the inlet flow rate was set to 5 ml/min, and the inlet fluoride concentration was set to 5 ppm. The column was packed with AC to a height of 7.5 cm (5.46 g) and fluoride solution of appropriate attentiveness (5 ppm, 10 ppm, and 15 ppm) was complete to movement done the column at an amount of 5 ml/min to

evaluate the effect of original fluoride attentiveness. The pH of the fluoride solution was kept constant throughout all of the trials. After every 10 minutes, the fluoride solution was collected and the attentiveness of fluoride was evaluated using a UV spectrophotometer. The following equation was used to compute the effluent volume:

$$V_{\text{eff}} = Qt_{\text{total}}$$

Where V_{eff} is the seepage volume collected in millilitres; Q is the volumetric movement amount in millilitres per minute; and t_{total} is the total movement time in minutes. The following equation gives the extreme bed volume for a given flow amount and feed concentration:

$$q_{\text{total}} = Q + \int C_{\text{ad}} dt / 1000$$

Where q_{total} is the supreme bed capacity in milligrammes; Q is the inflow movement rate in millilitres per minute; and C_{ad} is the adsorbed fluoride concentration in parts per million. The area below the arch of adsorbed fluoride concentration vs time yields the integral value. The following equation gives the whole amount of fluoride transferred to the column:

$$\% \text{ Removal} = \frac{q_{\text{total}}}{M_{\text{total}}} \cdot 100$$

Where q_{total} is the total quantity of fluoride sent to the column in milligrammes, and M_{total} is the total quantity of fluoride sent to the column in milligrammes. The equation for equilibrium fluoride uptake in the column is as follows:

$$q_{\text{eq}(\text{exp})} = \frac{q_{\text{total}}}{x}$$

Where, $q_{\text{eq}(\text{exp})}$ is symmetry fluoride uptake, mg/gm; x is quantity of adsorbent in the column, gm.

Studies on Fixed Bed Columns Modeling

The results of laboratory research can be used to develop full-scale column operations. Many approaches for evaluating the efficiency and usability of column models for industrial activities have been presented. It is vital to forecast the required adsorbate, the break through curve and adsorbent capacity must be determined. a specific set of operating parameters in order to design a column adsorption operation. The models Thomas, Adams-Bohart, and Yoon-Nelson were employed to assess adsorption data from fixed bed column investigations in this

study. The mass transmission model posits that fluoride travels from the solution to the particle's coating, then diffuses through the fluid film to the surface adsorbent surface. Intraparticle dispersion then adsorption on the active site follows. The following is the linear form of the Thomas adsorption model:

$$\ln\left(\frac{C_0}{C_t} - 1\right) = \frac{K_{TH}q_e x}{Q} - K_{TH}C_0 t$$

Where C_0 is the starting fluoride concentration in parts per million (ppm); C_t is the seepage fluoride concentration at time t in parts per million (ppm); K_{TH} is the Thomas model constant in L/min.mg; and q_e is the predicted adsorption volume in mg/g. x is the adsorbent mass in grams; Q is the inlet stream concentration in millilitres per minute. The slope and intercept of a plot of $\ln(C_0/C_t - 1)$ vs t are used to calculate K_{TH} and q_e . Adsorption rate is proportional to remaining adsorbent, according to the Adams-Bohart model concentration and adsorbing species concentration. The first phase of the breakthrough curve is described using this concept. The subsequent equation gives the linear version of the Adams-Bohart model.

$$\ln\left(\frac{C_t}{C_0}\right) = K_{AB}C_0 t - \frac{K_{AB}N_0 Z}{U_0}$$

Where C_0 is the original fluoride concentration, ppm; C_t is the effluent concentration at time t , ppm; Z is the bed depth, cm; N_0 is the supreme fluoride uptake volume per unit volume of the adsorbent column, mg/l; U_0 is the linear velocity of the influent fluoride solution, cm/min; and K_{AB} is the Adams-Bohart rate constant, l/mg.min. The slope and intercept of $\ln(C_t/C_0)$ vs t are used to get the values of K_{AB} and N_0 . The Yoon-Nelson model's main goal is to forecast how long a column will run before it needs to be regenerated or replaced. The model provides a straightforward representation of the breakthrough curve. The main benefit of utilizing this model is that it does not necessitate any particular information on the type of adsorbent, adsorbate appearance, or the physical assets of the adsorbent bed. The likelihood for each adsorbate molecule, Adsorption occurs at a proportionate rate to the chance. According to this model, the amount of adsorbate and the likelihood on the adsorbent of adsorbate breakthrough. This model suggests that,

semi of the whole fluoride incoming the adsorbent bed is adsorbed in a fixed bed in a timely manner. Where does the time for 50 percent breakthrough. The linear method of the Yoon-Nelson model is as follows:

$$\ln\left(\frac{C_t}{C_0 - C_t}\right) = K_{YN}t - K_{YN}\tau$$

$$\ln(C_t/C_0 - C_t) = K_{YN}t - k_{YN}\hat{\delta}$$

Where C_0 represents the starting fluoride concentration in ppm, C_t represents the fluoride concentration at time t in ppm, t represents the flow duration in minutes, and τ is the time necessary for 50 percent breakthrough in minutes. The Yoon-Nelson rate constant, K_{YN} , is 1/min. The slope and intercept of $\ln(C_t/(C_0 - C_t))$ vs t are used to calculate K_{YN} .

Results and Discussion

Adsorption and the Inlet Flow Rate

On the breakthrough curve, the following trend was seen when the inlet movement rate was varied from 5 ml/min to 15 ml/min.

The graph overhead illustrates that increased flow rates resulted in faster breakthrough. The fluoride solution had enough time to adsorb on the adsorbent at the lower flow rate. For both fluoride, higher fluoride removal occurred at lower flow rates. At increasing flow rates, the breakthrough curve became steeper and shifted back to origin. The bed will take longer to become saturated at a higher movement rate. In the table below, the parameters derived from the influence of inlet flow rate are provided. The overall adsorption capacity of the bed, q_{total} , dropped as the flow rate increased, as seen in

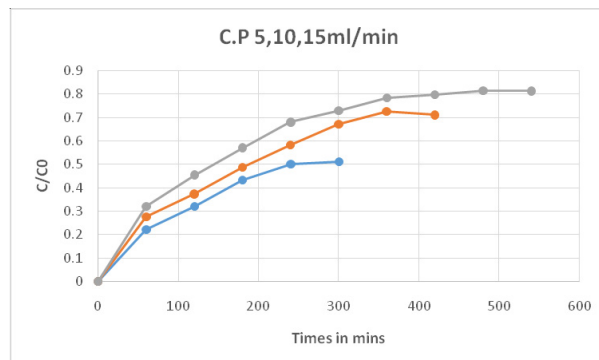


Fig. 1. Outcome on the breakthrough curve of inlet flow rate

the table above. The residence period of the solute in the bed was shorter at higher flow rates. Before equilibrium was attained, the solute exited the column. The percentage of fluoride removed reduced when the volume of the flow rose. At lower flow rates, there was more adsorption.

Adsorption and the Height of the Bed

The following graphic depicts the influence of bed height on adsorption by adjusting the bed height from 5 cm to 10 cm.

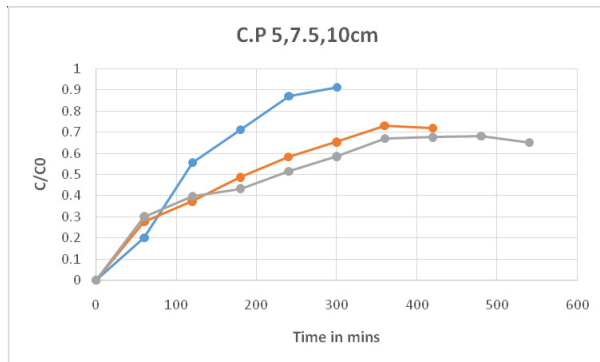


Fig. 2. Outcome of bed height on break through curve

Fluoride solution had greater time to contact the adsorbent as the bed height climbed. As a result, more fluoride was removed. As a result, the fluoride concentration in the effluent was reduced. As can be seen in the diagram above, the slant of the innovation arch reduced as bed height increased, resulting in a larger mass handover zone. At lower bed heights, the break through curve was steeper. The table below shows the column characteristics derived from the influence of bed height. The total adsorption volume of the bed rose when the bed height was increased. More adsorption sites were accessible at deeper bed depths, resulting in higher fluoride elimination.

The Influence of Fluoride Concentration at the Start on Adsorption

The effect of initial fluoride concentration was investigated using three different levels of fluoride: 5 ppm, 10 ppm, and 15 ppm. With an increase in fluoride concentration, the following trend was found.

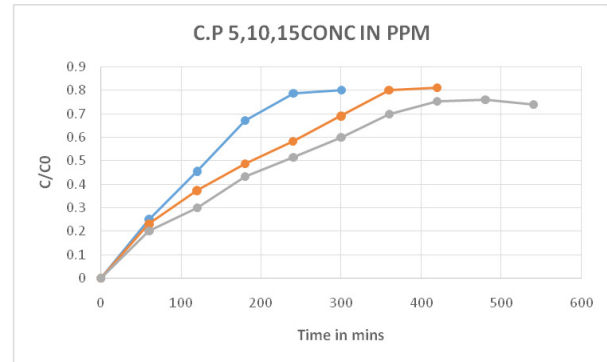


Fig. 3. Outcome of initial fluoride focus on the break through curve

The break through curves are spread at lower fluoride concentrations, as can be shown. Break-through curves grew sharper as fluoride concentrations increased. Changes in concentration gradient affect saturation rate and minimise break concluded time, as shown in the graph above. This can be clarified by the fact that as the fluoride concentration rises, more adsorption sites are covered. The break through curve becomes steeper as the fluoride concentration increases. The pushing force for mass transfer will increase as fluoride concentration rises. As a result, the adsorption zone shrank. The table below shows the column characteristics derived from the effect of starting fluoride attentiveness. The adsorption capacity of the bed rose as the starting fluoride concentration increased, as seen in the table above. However, as the attentiveness of fluoride amplified, the percentage of fluoride removed

Table 1. Linear Regression Analysis Parameters for the Thomas Model

Q(ml/min)	H(cm)	Co(ppm)	q _{e(max)} (mg/gm)	K _{TH} L/min. mg	q _{eq(exp)} (mg/g)	r ²
10	5	5	0.48	3.9x10-4	0.40	0.994
10	5	10	0.26	4.8x10-4	0.35	0.984
10	5	15	0.22	6.8x10-4	0.28	0.972
5	5	20	0.13	4.8x10-4	0.37	0.995
15	5	5	1.57	1.3x10-4	0.45	0.952
10	7.5	5	0.79	1.4x10-4	0.89	0.933
10	10	5	0.81	8.3x10-5	1.24	0.992

dropped. The Thomas, Adams, and Bohart models, as well as the Yoon-Nelson model, were used examine fixed bed adsorption data.

Model Thomas

Experimental data were trim to equations to obtain the supreme adsorption volume $q_e(\max)$ and the kinetic coefficient K_{TH} . Table 2 summarises the matching model limits calculated from the lined plot.

The experimental adsorption capacities obtained using the Thomas model are nearly identical, as seen in Table 1. As a result, the experimental data and theoretical results are in good accord. It can be seen that when the flow rate increased, the extreme adsorption capacity and constant K_{TH} both declined. This is due to the fact that the solute's residence duration in the bed was shorter. With an increase in bed height, the value of $q_e(\max)$ increased, whereas the K_{TH} values declined. This is because there were more reactive sites accessible at greater bed heights. $q_e(\max)$ increased as fluoride concentration increased, while K_{TH} decreased. This is due to the fact that when my income grows, so does my ability to help others. This is because the driving vigor for adsorption increased as attentiveness increased.

Adams-Bohart model

Table 2 shows the values of the adsorbent's adsorp-

tion capacity, N_0 , and the model's kinetic constant, K_{AB} , as obtained by linear regression analysis. The results reveal that as the flow rate amplified, the adsorption capacity N_0 dropped. The related coefficients K_{AB} rose in value. The reduced residence time of the solute in the column causes a decrease in adsorption capacity. The adsorption capacity increased as the bed height increased. K_{AB} values have dropped. The adsorption volume increased as the fluoride concentration increased.

Model Yoon-Nelson

The Yoon-Nelson approach was castoff to calculate the time required for a 50% break through. Table 3 summarises the values of τ and K_{YN} obtained by suitable the investigational data to equation (8).

The time essential for 50 percent breakdownover reduced as the flow rate amplified, as shown in the above findings. This was attributed to the solute's shorter residence period in the column. The Yoon-Nelson rate continual rose as the flow rate increased for both fluorides. With increasing bed height, The amount of time required to achieve a 50% break through has increased. More adsorption spots were accessible at higher bed depths, and break through time was reduced. The time necessary for 50 percent break through reduced as the initial fluoride concentration amplified. The driving force for adsorption

Table 2. Constraints of the Adams-Bohart Model Using Linear Regression Analysis

Flow Rate (ml/min)	Bed Height (cm)	Fluoride Conc (ppm)	N_0 (mg/g)	K_{AB} (L/min.mg)	R^2
10	5	5	1.51	1.29×10^{-4}	0.91
10	5	10	1.37	1.61×10^{-4}	0.968
10	5	15	1.27	1.68×10^{-4}	0.97
5	5	20	1.46	1.27×10^{-4}	0.97
15	5	5	2.83	8.1×10^{-5}	0.978
10	7.5	5	3.23	4.2×10^{-5}	0.98
10	10	5	5.16	2.7×10^{-5}	0.91

Table 3. Parameters of the Yoon-Nelson Model Using Direct Regression Analysis

Flow Rate (ml/min)	Bed Height (cm)	Fluoride Conc (ppm)	τ (min)	K_{YN} (min^{-1})	R^2
10	5	5	123.5	0.0046	0.96
10	5	10	40.52	0.0067	0.95
10	5	15	31.23	0.0232	0.932
5	5	20	37.00	0.0088	0.96
15	5	5	727668	0.0034	0.981
10	7.5	5	478.00	0.0026	0.98
10	10	5	375.53	0.0028	0.92

amplified as the fluoride concentration amplified. As a result, it took longer for the bed to become saturated.

Conclusion

The elimination of fluoride in a secure bed column was examined in this study. The adsorbent remained activated carbon obtained from Copper Pod Seeds. The research was accepted out in a fixed bed column with an interior diameter of 1 cm and a length of 60 cm. On the break through curve, the effect of inflow flow rate, bed height, and initial fluoride content was examined. Adsorption was shown to be higher when the flow rate was lower, the bed depth was greater, and the initial fluoride concentration was lower. The Thomas, Adams-Bohart, and Yoon Nelson models were used to model the fixed bed column. The experimental data and theoretical results were in good accord. According to the findings, activated carbon bursting in a column can be employed as an active adsorbent for fluoride removal.

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References

- Crini, G. 2006. Non-conventional low cost adsorbents for fluoride removal: a review. *Bio resource Technology*. 97 : 1061-1085.
- Ekpete, O.A., Horsfall Jnr, M. and Spiff, A.I. 2011. Fixed bed adsorption of chlorophenol on to fluted pumpkin and commercial activated carbon. *Australian Journal of Basic and Applied Sciences*. 5 : 1149-1155.
- Falah H. Hussein¹, Ahmed F. Halbus¹, Abbas J. Lafta¹, and Zahraa H. Athab², 2015. Preparation and Characterization of Activated Carbon from Iraqi Khestawy Date palm. *Journal of Chemistry*. Article ID 295748, 8 Pages.
- Kofa, G.P., Gomdje, V.H., Telegang, C. and Ndi Koungou, S. 2017. Removal of fluoride from water by adsorption onto fired clay pots: kinetics and equilibrium studies. *Journal of Applied Chemistry*. ID 6254686, 7 pages.
- Monal Dutta, Tanumoy Ray and Jayanta Kumar Basu, 2012. Batch adsorption of fluoride ions onto microwave assisted activated carbon derived from Acacia Auriculiformis scrap wood. *Archives of Applied Science Research*. 4 (1) : 536-550
- Monika Kharub, 2012. Use of various technologies, methods and adsorbents for the removal of fluoride. *Journal of Environmental Research and Development*. 879-883.
- Nasehir Khan, E. M. Yahayaa, Ismail Abustana, Muhamad Faizal Pak, 2011. Fixed-bed column study for Cu (II) removal from aqueous solutions using rice husk based activated carbon. *International Journal of Engineering and Technology*. 11 : 186-190.
- Pranjali Saikia, Ranjan Kumar Bharali and Hemanta Kumar Baruah, 2017. Kinetic and thermodynamic studies for fluoride removal using a novel bio-adsorption from possotia (vitex negundo) leaf. *Journal of Analytical Science and Technology*.
- Riskiono Slamet and Erdawati, 2013. Adsorption of congo red using chitosan montmorillonite in batch and column method. *International Journal of Chemical and Petrochemical Technology*. 3 : 13-23.
- Salwa, A. Ahmed, Ahmed, A. Abdel Gaber and Asmaa, M. Abdel Rahim, 2015. Removal of calmagitefluoride from aqueous media using nanoparticles of mango seeds kernel impregnated Fe(III). *International Journal of Advanced Research*. 3(2): 621-632.
- Sanjay. P Kamble, Sneha Jagtap, Nitin, K. Labhsetwar, Dilip Thakare and Samuel Godfrey, 2007. Defluoridation of drinking water using chitin, chitosan and lanthanum-modified chitosan. *Chemical Engineering Journal* 12: 173-180.
- Sivakumar, P. and Palanisami, P.N. 2009. Packed bed column studies for the removal of Acid Blue 92 and Basic Red 29 using non-conventional adsorbent. *Indian Journal of Chemical Technology*. 16 : 301-307 .
- Suresh Gupta, and Babu, B. V. 2011. Experimental investigations and theoretical modeling aspects in column studies for removal of Cr(VI) from aqueous solutions using activated tamarind seeds. *Journal of Water Resource and Protection*. 2 : 706-716.
- Wan Ngah, W.S., Kamari, A. and Koay, Y. 2004. Equilibrium and kinetic studies of adsorption of copper(II) on chitosan and chitosan/PVA beads. *International Journal of Biological Macro Molecules*. 34.
- Weber, E. J. and Adams, R. L. 1995. Chemical and sediment mediated reduction of the azo fluoride Disperse Blue 79. *Environmental Science & Technology*. 29 : 1163-1170.
- Zolinger, H. 1987. *Colour Chemistry-Synthesis, Properties of Organic Fluorides and Pigments*. VCH publishers, New York. 92.