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Packed Bed Adsorption Column Modeling for Cadmium Removal

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Abstract

Packed bed adsorption of various pollutants from effluents is efficient and cost effects method. Various factors affecting the removal percentage are initial concentration, flow rate, pH and bed height. Various models can be used to explain the packed bed adsorption. In the current work, the experimental data obtained for packed bed is fitted in the two model equations. Thomas model and Yoon Nelson model were used and the kinetic parameters were computed. Also effect of the factors like initial concentration, flow rate, pH and bed height on these kinetic parameters was studied. It was observed that these factors moderately influence the kinetic parameters. The experimental data was well described by these two models.

Keywords: *kinetic model, parameters, capacity, concentration, saturation.*

1. Introduction

Heavy metal treatment is one of the major environmental concerns in the fast moving industrial growth. Many industries like metallurgical, fertilizer, pigment, dyes, electroplating, battery, steel, mining, chemical, pharmaceutical, smelting etc. emit heavy metal through their effluent. Heavy metal can cause long term and short term diseases in human being. It is very necessary to minimize the heavy metal pollution in wastewater. Cadmium is one of the heavy metal present in the effluent which can cause renal damage, anemia, hyper tension and liver damage. Cadmium can be removed from the wastewater by various biological, non biological, physical and chemical treatment methods. Adsorption is one of the major technique used for cadmium removal. Packed bed removal of heavy metal is widely studied area of research. Removal of the cadmium in batch and continuous operation has been reported by various investigators[1].Use of various low cost adsorbents like sugarcane bagasse, oil cake, maize corncob, rice husk ash, wheat straw, cashew nut shell was reported to be very effective for cadmium removal[2,3,4,5,6].Packed bed contactors are used for removal of various pollutants in continuous operations. The studies on batch and packed bed removal of heavy metal include the research on isotherm, kinetics and modeling[7,8,9,10]. The studies on fixed bed operation for removal of various pollutants like phenol, cadmium, chromium, lead, zinc, organic matter has been reported by various investigators [11,12,13,14]. Nwabanne and Igbokwe reported the modeling for lead removal in fixed bed [15].The experimental data was well described by Thomas and Yoon and Nelson kinetic models. An investigation was carried out for modeling and fixed bed column adsorption of chromium (VI) onto orthophosphoric acid-activated lignin by Albadarin et.al. [16]. Thomas model, The modified Dose model and the Bed Depth Service Time (BDST) model were verified for the micro column experiments. They observed that experimental data of individual runs were well represented by the Thomas and Modified dose-response model for variable influent initial pH, ionic strength, initial Cr (VI) concentration, flow rate and mass of the adsorbent. Bed depth service time model (BDST) was used to analyze the experimental data by Zulfadhly et.al. [17]. In their experiments Pycnoporus sanguineus was used for biosorption of lead, copper and cadmium. BDST model was able to satisfactory explain the experimental data. Modeling of fixed bed removal of lead using nanostructure γ-alumina was carried out by Sadi et.al.[18]. In their studies they compared Thomas, Yoon-Nelson, and Adams-Bohart models with experimental results. They evaluated the model parameters by

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linear regression analysis for lead adsorption at different bed heights, initial concentrations, and flow rates. Thomas and Yoon-Nelson models were followed by the processes. In the case of Adams-Bohart model, low correlation coefficient was observed. In our earlier studies packed bed removal of cadmium is carried by using rice husk as an adsorbent was reported[19]. The parameters affecting the fixed bed adsorption like initial concentration, flow rate, initial concentration, and pH and bed height were analyzed and their effect on solute uptake kinetics was reported. In the current work the data obtained for fixed bed experiments is fitted in two fixed bed models namely Thomas Model and Yoon and Nelson model.

2. Models

2.1 Thomas Model

An expression for adsorption column by Thomas is given by following equation[20].

$$\frac{C}{Co} = \frac{1}{1+\exp[\frac{Kt}{Q(q_0 M - CoV)}]} \quad (1)$$

In this equation, C is out let concentration at any time t and Co is inlet concentration. V is throughput volume, Q volumetric flow rate, K_t is Thomas constant and q_0 is maximum adsorption capacity.

The linear form of this equation is written as

$$\ln(\frac{C_0}{C} - 1) = \frac{K_t q_0 \ M}{Q} - \frac{K_T C_0}{Q} V \quad (2)$$

The plot of $\ln(C_0/C-1)$ against t is a straight-line. The values of the parameters KT, and q_0 are estimated from this plot.

2.2 Yoon and Nelson model

This model is expressed by following equation [15,19,21].

$$\frac{C}{C0} = \frac{1}{1+\exp[(K(T-t)]} \quad (3)$$

$$\ln\frac{C}{C0-C} = k\,t - T\,k \quad (4)$$

Here, k is the rate constant and T is time required for 50 percent adsorbate breakthrough and t is sampling time. The plot of $\ln\frac{C}{C0-C}$ against time is plotted. The parameters, T and k are obtained from the plot.

3. Methodology

Packed bed experiments were carried out by using rice husk adsorbent in a column having 5.3 cm diameter and total 100 cm height. The effluent was allowed to flow by gravity through the column. The influent sample was synthetically prepared. The analysis was carried out using U.V . spectrophotometer (Elico 159). The data of time verses out let concentration was obtained by varying the parameters like inlet concentration, flow rate, pH and bed height.

4. Results and Discussion

Experiments were carried out in fixed bed with rice husk adsorbent. The effluent was collected after 30 minutes interval and analyzed for cadmium concentration. The samples were collected till the exhaustion of the bed. This was indicated by two to three constant readings at the end of the run. Experiments were carried out by changing initial concentration and keeping all other parameters constant. Similar experiments were carried out for studying the effect of flow rate, pH and bed height on the Thomas and Yoon Nelson model parameters. For Thomas model, $\ln(\frac{C0}{C}-1)$ against time was plotted and for Yoon and Nelson model, $\ln\frac{C}{C0-C}$ against time was plotted.

4.1 Effect of initial concentration

The effect of initial concentration at fixed flow rate, pH and bed height is shown in fig.1(a,b,c). As shown in fig. the maximum adsorption capacity $q_{0,}$ increased with initial concentration. Value of K_t obtained is in agreement with similar work carried out for various metal ion removal experiments. For concentrations of 10 mg/l and 30 mg/l, the R^2 values were 0.97 and 0.98 respectively, indicating near perfect fit. For 50 mg/l , the deviation is more with R^2 value of 0.9. Yoon and Nelson model is represented by fig.5(a,b,c). The data is well represented by this model with R^2 values in the range of 0.93-0.96. The time required for 50 percent breakthrough (T) decreased with initial concentration.

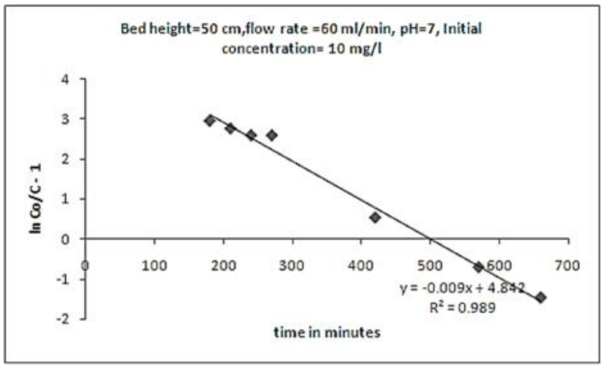

Fig.1a: Thomas Model at initial concentrations of 10 mg/l

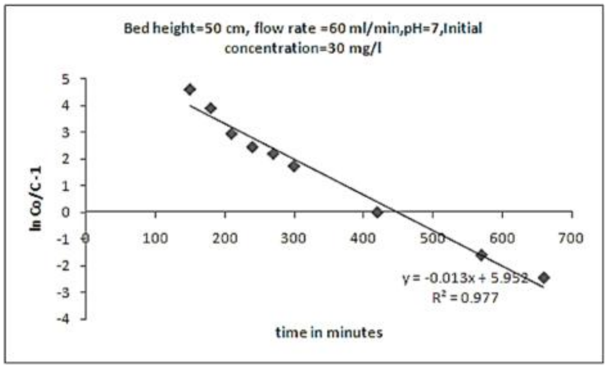

Fig.1b: Thomas Model at initial concentrations of 30 mg/l

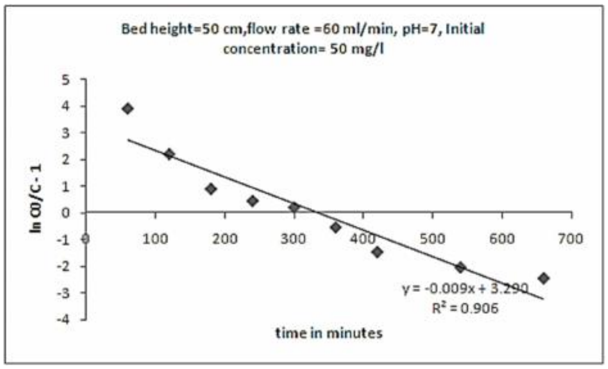

Fig.1c: Thomas Model at initial concentration of 50 mg/l

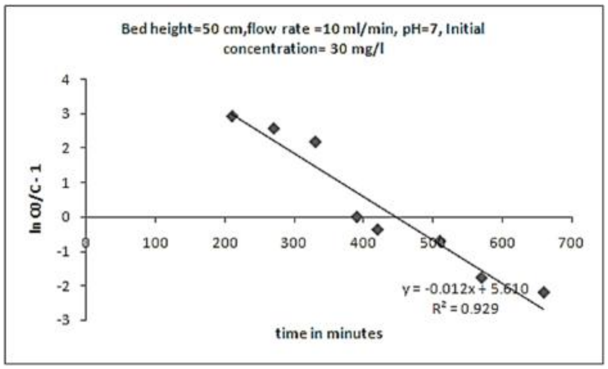

Fig.2a: Thomas Model at flow rate of 10 ml/min

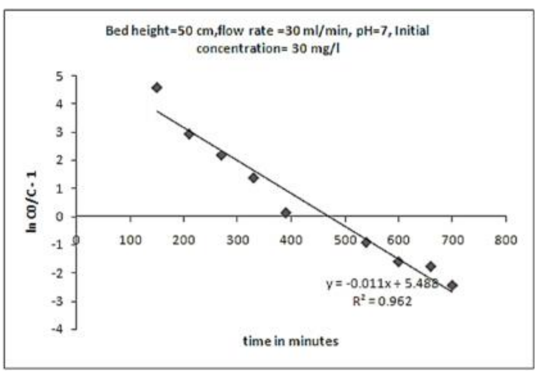

Fig.2b: Thomas Model at flow rate of 30 ml/min

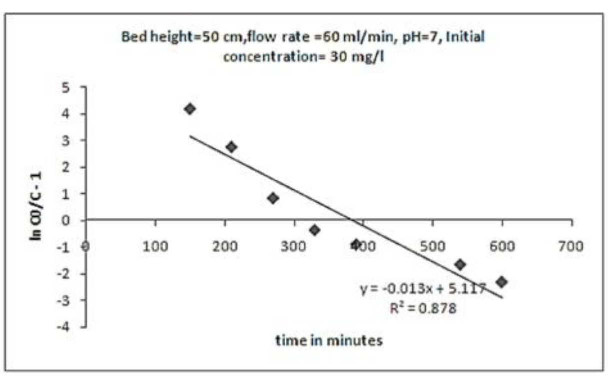

Fig.2c: Thomas Model at flow rate of 60 ml/min

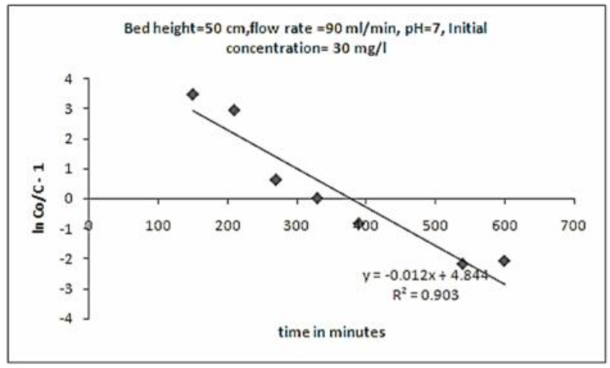

Fig.2d: Thomas Model at flow rate of 90 ml/min

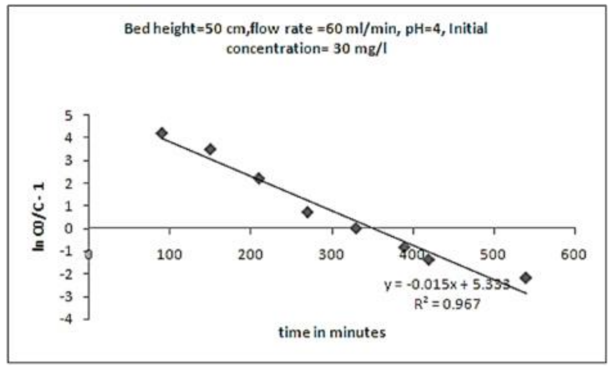

Fig.3 a: Thomas Model at pH value of 4

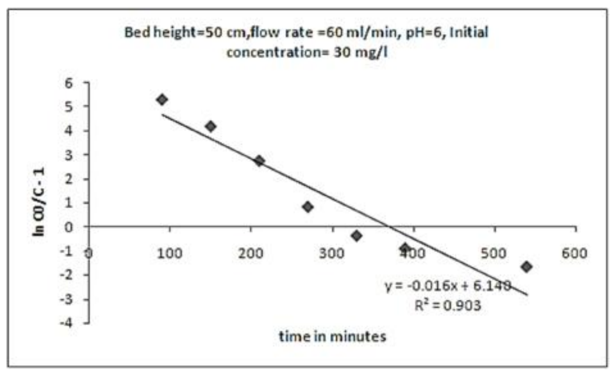

Fig.3 b: Thomas Model at pH value of 6

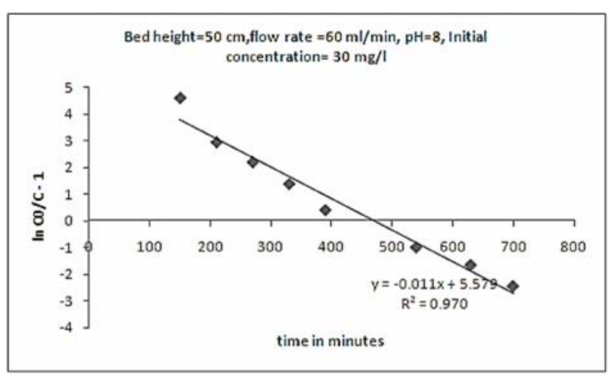

Fig.3 c: Thomas Model at pH value of 8

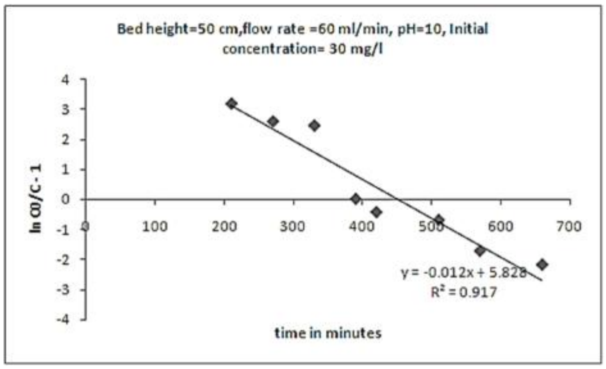

Fig.3 d: Thomas Model at pH value of 10

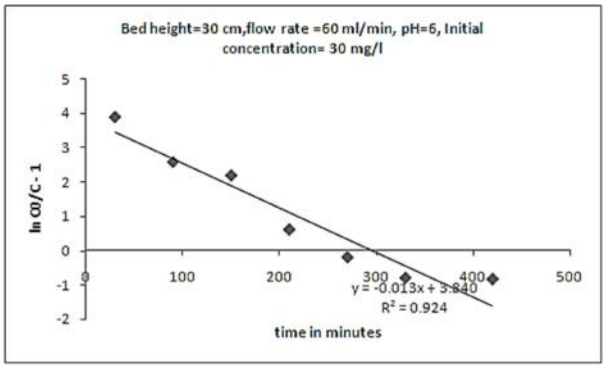

Fig.4 a: Thomas Model for bed height of 30 cm

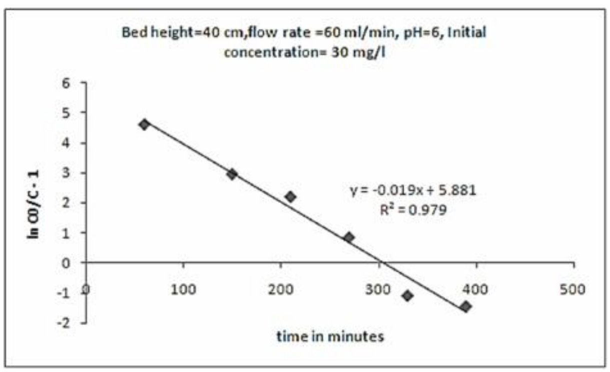

Fig.4 b: Thomas Model for bed height of 40 cm

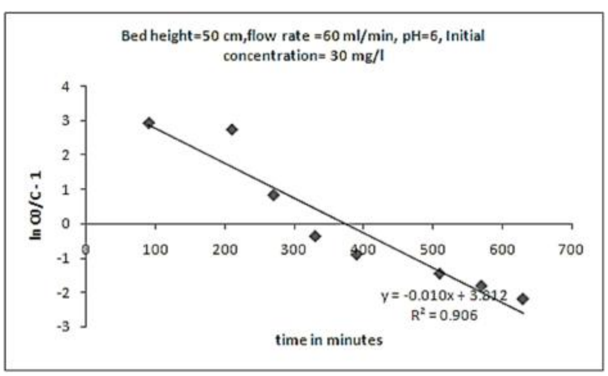

Fig.4 c: Thomas Model for bed height of 50 cm

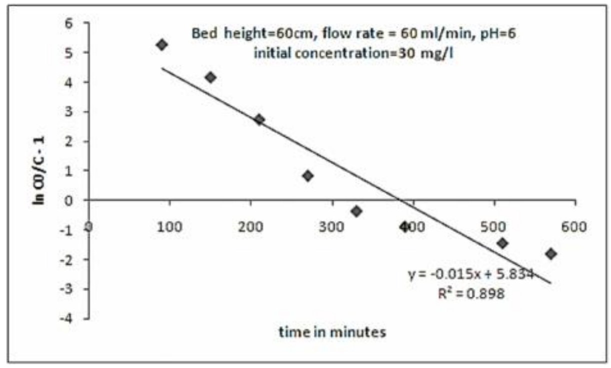

Fig.4 d: Thomas Model for bed height of 60 cm

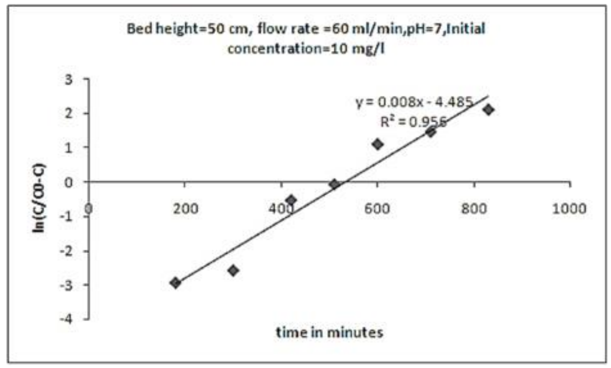

Fig 5 a: Yoon & Nelson at initial concentration of 10 mg/l

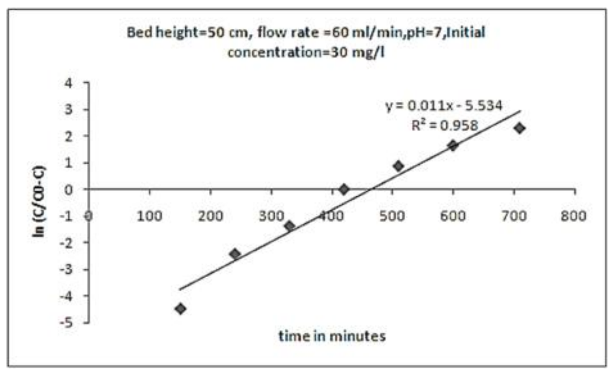

Fig 5 b: Yoon & Nelson at initial concentration of 30 mg/l

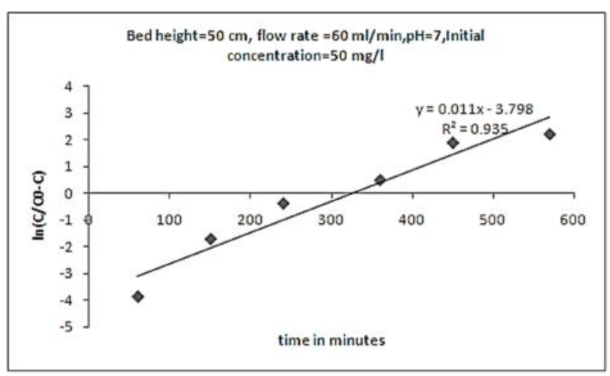

Fig 5 c: Yoon & Nelson at initial concentration of 50 mg/l

4.2 Effect of flow rate

In case of Thomas model, as shown in fig.2(a,b,c,d), with increase in flow rate q_0 increased. There was very small increase in K_t value. In case of Yoon and Nelson model , as shown in fig.6(a,b,c,d), for flow rate increase from 30 ml/min to 90 ml/min, there was decrease in T, time required for 50 percent breakthrough. For these data R^2 values were in the range of 0.93 to 0.96, indicating perfect fit. For higher flow rate(90 mg/l) the deviation was more (R^2= 0.89). According to the observations, flow rate has significant effect on the Thomas and Yoon Nelson parameters.

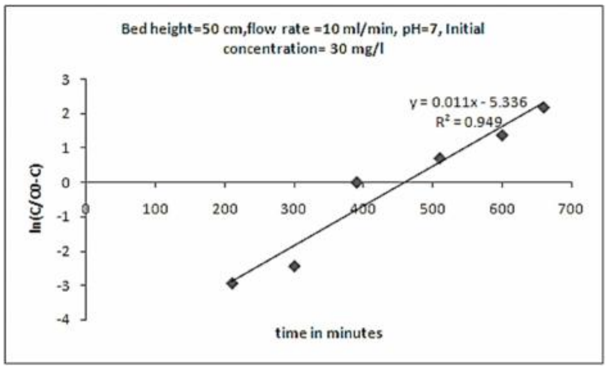

Fig 6 a: Yoon & Nelson at flow rate of 10 ml/min

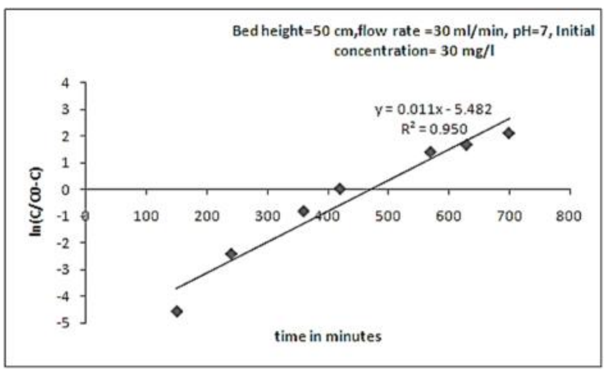

Fig 6 b: Yoon & Nelson at flow rate of 30 ml/min

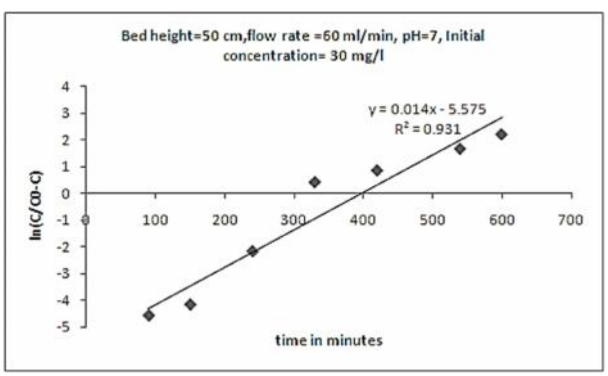

Fig 6 c: Yoon & Nelson at flow rate of 60 ml/min

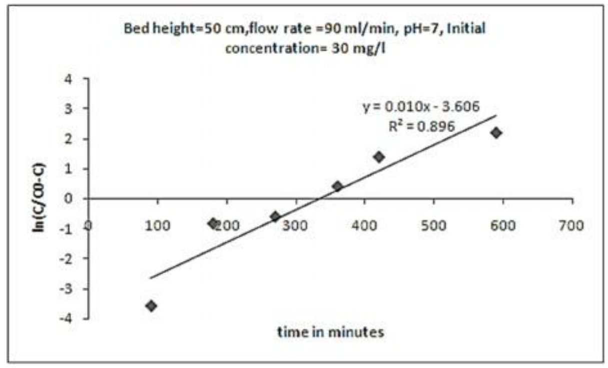

Fig 6 d : Yoon & Nelson at flow rate of 90 ml/min

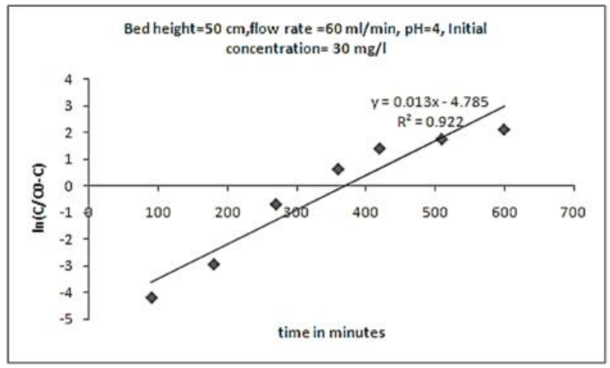

Fig 7 a : Yoon & Nelson at pH value of 4

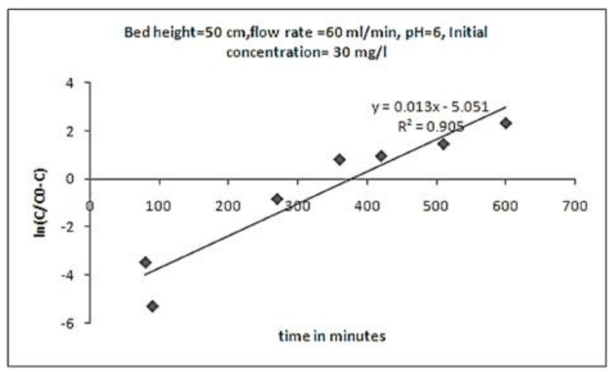

Fig 7 b : Yoon & Nelson at pH value of 6

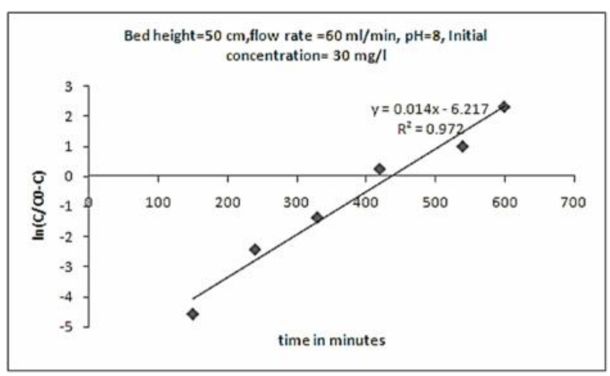

Fig 7 c : Yoon & Nelson at pH value of 8

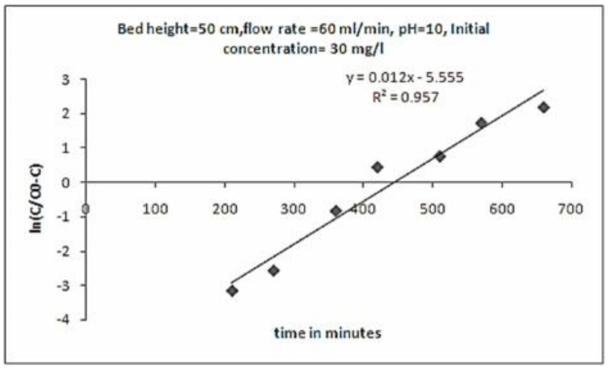

Fig 7 d : Yoon & Nelson at pH value of 10

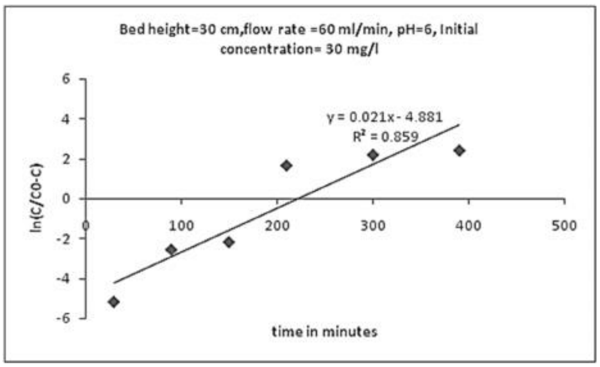

Fig 8 a : Yoon & Nelson for bed height of 30 cm

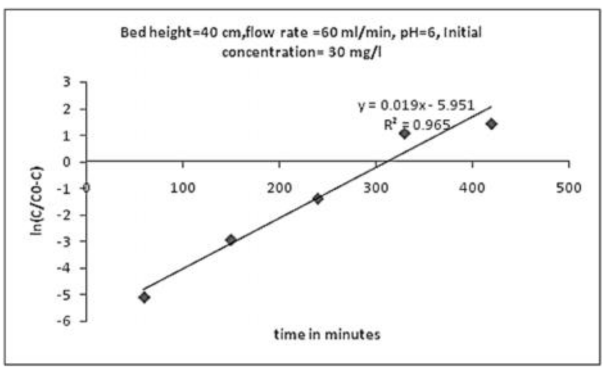

Fig 8 b: Yoon & Nelson for bed height of 40 cm

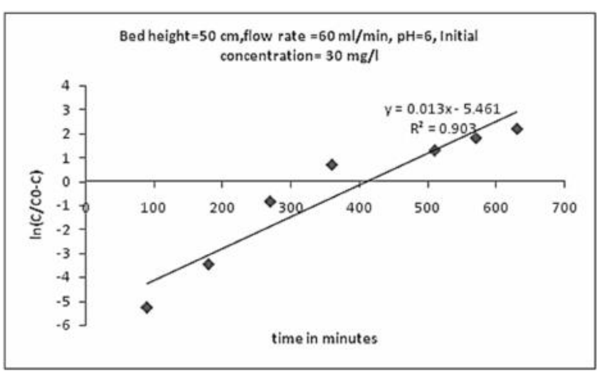

Fig 8 c: Yoon & Nelson for bed height of 50 cm

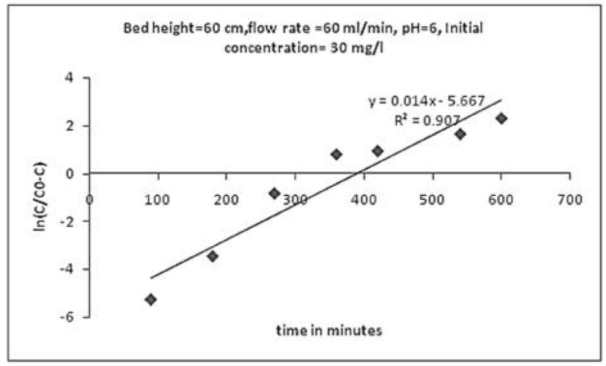

Fig. 8 d : Yoon & Nelson for bed height of 60 cm

4.3 Effect of pH

Thomas model for pH values is plotted in fig.3(a,b,c,d). The value of q_0 increased in pH range of 6 to 8. As shown in fig 7(a,b,c,d), for Yoon-Nelson model, constant K is not much affected by the pH. The value of T, time for 50 percent breakthrough is minimum for pH values of 4 to 6. This value increased significantly for further increase in pH value.

4.4 Effect of Bed Height

Bed height has significant effect on kinetic parameters. Thomas Model parameters at various bed heights are plotted in fig. 4(a,b,c,d). With increase in bed height, the adsorption capacity (q_0) decreased. The Yoon and Nelson model is satisfactory for bed height between 40 cm to 50 cm. The Yoon Nelson model is represented in fig. 8(a,b,c,d).

Table 1:Effect of Initial Concentration for Thomas Model

Parameters	Initial Concentration at fixed bed height, pH and flow rate (mg/l)		
	10	30	50
K_t(ml/min/mg)	0.9	0.43	0.18
q_0(mg/g)	1.42	3.77	4.98
R^2	0.98	0.97	0.90

Table 2: Effect of Flow Rate for Thomas Model

Parameters	Flow rate at fixed bed height, pH and initial concentration (ml/min)			
	10	30	60	90
K_t(ml/min/mg)	0.4	0.36	0.43	0.4
q_0(mg/g)	0.67	2.04	3.24	4.95
R^2	0.92	0.96	0.87	0.90

Table3:Effect of pH for Thomas Model

Parameters	pH at fixed bed height, initial concentration and flow rate			
	4	6	8	10
K_t(ml/min/mg)	0.5	0.53	0.36	0.4
q_0(mg/g)	2.91	2.72	4.15	3.97
R^2	0.96	0.90	0.97	0.91

Table 4: effect of Bed Height for Thomas Model

Parameters	Bed height at fixed initial concentration, flow rate and pH(cm)			
	30	40	50	60
K (ml/min/mg)	0.43	0.63	0.33	0.5
q_0(mg/g)	4.06	3.18	3.14	2.65
R^2	0.92	0.97	0.90	0.89

5. Conclusion

Thomas and Yoon & Nelson model parameters are shown in tables 1 to 8. It is observed that the parameters like initial concentration, flow rate, bed height and pH affect the model parameters significantly. The values of model parameters are in agreement with similar work carried out for various metal ions and adsorbents [18,20). The experimental data also fits well in both the models with exception of three experimental runs out of total 30 runs. The time required for 50 percent break through decreased with flow rate and initial concentration with only one exception. The adsorption capacity decreased with bed height and increased with initial concentration and flow rate.

Table 5:Effect of Initial Concentration for Yoon Nelson Model

Parameters	Initial Concentration at fixed bed height, pH and flow rate (mg/l)		
	10	30	50
K(/min^{-1})	0.008	0.011	0.011
T (min)	185.6	498	345.27
R^2	0.956	0.958	0.935

Table 6: Effect of Flow rate for Yoon Nelson Model

Parameters	Flow rate at fixed bed height, pH and initial concentration (ml/min)			
	10	30	60	90
K(/min^{-1})	0.011	0.011	0.014	0.01
T (min)	485	498.3	398.2	368
R^2	0.94	0.95	0.93	0.89

Table 7:Effect of pH for Yoon Nelson Model

Parameters	pH at fixed bed height, initial concentration and flow rate			
	4	6	8	10
K(/min^{-1})	0.013	0.012	0.014	0.012
T (min)	368	388	444	463
R^2	0.922	0.905	0.972	0.957

Table 8:Effect of Bed Height for Yoon Nelson Model

Parameters	Bed height at fixed initial concentration, flow rate and pH(cm)			
	30	40	50	60
K(/min^{-1})	0.021	0.019	0.013	0.014
T (min)	232	313	420	404
R^2	0.859	0.965	0.903	0.907

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