Available online at www.elixirpublishers.com (Elixir International Journal)

Chemical Engineering

Elixir Chem. Engg. 97 (2016) 42131-42136

ISSN: 2229-712X

# Performance Evaluation of Column Dynamics for Phenol Adsorption by Coal Fly Ash

Y.P.Chauhan* and Mohd. Talib

University Institute of Chemical Technology, North Maharashtra University, Jalgaon, Maharashtra State, India.

ARTICLE INFO

Article history:

Received: 22 June 2016;

Received in revised form: 5 August 2016;

Accepted: 10 August 2016;

Keywords

Coal fly ash,
Phenol,
Packed bed column,
Adsorption,
Thomas and Yoon Nelson model.

ABSTRACT

In this study coal fly ash (CFA) which is the waste product of coal fired power plant is used as an adsorbent for adsorption of phenol from aqueous solution in packed bed column. The effect of bed height (7.5, 13.5, 27.5 cm), effect of flow rate (0.375, 0.75 and 1.0 ml/min) and initial phenol concentration (70.0, 292.7, 651.2, 1039.9 mgL$^{-1}$) on the adsorption were studied by assessing the breakthrough curve. Thomas and Yoon-Nelson models were used to evaluate the column performance. The result shows that with increase in flow rate, break point time decreases while the values of maximum adsorption capacity ($q_0$) decreased and the Thomas constant ($K_{Th}$) increased. As the bed height and initial concentration increases, break point time increases with bed height but decreases with initial concentration but $q_0$ increased while $K_{Th}$ decreased. The maximum adsorption capacity was found to be 5.90 mg/g at 1.0 ml/min flow rate and 27.5 cm bed height with phenol concentration of 1039.9 mg/L.



## 1.Introduction

Phenolic wastewater is a serious environmental problem and this water cannot release into the environment without treatment [1]. The nature of phenol and their derivatives for hazards and toxicity have been well documented [2, 3, 4] and can cause several health problems. Phenolic compounds have been classified as high-priority pollutants by the USA EPA, 1984 [5]. Phenolic waste water are generated from the plastic, pharmaceutical, petrochemical, paint, paper & pulp, solvent, coal conversion industries. They are known one of the priority pollutants in wastewater, because they are harmful to organisms even at low concentrations [6, 7, 8].

CFA is considered as a waste for power generation plants, but from coal utilization point, it is a resource yet to be fully utilised and exploited. Currently, the cement industry might use them as a raw material to produce concrete. The coal fly ash generated in power plants are designated as a by-product and it is used as a recycling materials in the various fields like agriculture and engineering is widely attempted [9, 10]. As one of the effective use of coal fly ash, its conversion into zeolites has also been widely attempted [11].

Many researchers are studied the batch adsorption of phenol on to coal fly ash, but limited of them worked on the column dynamics of phenol with CFA. Packed bed columns are the continuous contacting apparatus which includes the continuous flow of the influent from the top of the column on the adsorbent bed and continuous withdrawal of the effluent from bottom resulting in the removal of adsorbate on the surface of the adsorbent. Column adsorption is preferred over batch adsorption because of its ease of operation, high yields, and high liquid residence times and can be scaled up from a laboratory step [12].

## 2. Materials and Methods

### 2.1. Materials

The material used for this research work includes:

(i) Adsorbate: Phenol

(ii) Adsorbent: Coal Fly Ash.

#### 2.1.1. Adsorbate

The phenol composition of the aqueous solutions prepared for experimentation was similar to that generated by the various industries which produces the phenol containing wastewater. The stock solution was prepared by diluting the required quantities of phenol, in the distilled water to obtain adsorbate solutions of various initial concentrations ($C_o$ ). Fresh solutions were prepared on a time of experiment for phenol concentration.

#### 2.1.2. Adsorbent

Fly ash is the fine powdery residue obtained from the coal fired power station after combustion of the coal. The fly ash utilized in this study was a low grade Coal Fly Ash (CFA) obtained from the Paras Thermal Power Station at Paras village in Akola district of Maharashtra State, India. It is washed several times with distilled water to remove any contaminants like dirt, soil etc. and dried at 100$^0$C for an hour before using for experimentations.

### 2.2 Experimental Methods

#### 2.2.1. Dynamic column study

CFA was packed in the glass column having 45 cm in length and 10 mm internal diameter with the support of glass bed and cotton at the bottom of the column. The column was operated under down flow condition which allows the influent to be gravity fed and also ensure that the bed remains packed and steady during the entire operation, which results in the maximum contact between the fly ash and the influent. The experiments are conducted for the effect of bed height (7.5, 13.5, 27.5 cm), the effect of flow rate (0.375, 0.750, 1.0 ml min.$^{-1}$) and initial phenol concentration (70.0, 292.7, 651.2, 1039.9 mgL$^{-1}$) on the adsorption by assessing the breakthrough curve. The pH of the influent was kept at 6.0 for all the experiments. Effluent from the bottom of the column was collected with fixed interval of time and phenol concentration was determined by UV spectrophotometer.

Tele: +919960590195

E-mail address: yp_chauhan@yahoo.co.in

Adsorption parameters are calculated by using the following equations 1 to 5 [13]. Thomas and Yoon-Nelson models have been studied for getting the maximum adsorption capacity and rate constant as well as the time required for 50 % adsorbate breakthrough.

The effluent volume was calculated by using the following equation [15].

$V_{eff} = Q.t_{total}$ ………………………………………..(1)

Where, $V_{eff}$ is volume of effluent collected in ml, Q is volumetric flow rate in ml/min, and $t_{total}$ is total flow time in minutes.

Maximum bed capacity for given flow rate and influent phenol concentration was calculated by using the following equation.

$q_{total} = Q \int C_{ad}\, dt / 1000$ ………..………………………(2)

Where, $q_{total}$ is maximum bed capacity in mg and $C_{ad}$ is adsorbed phenol concentration in mg/liter. The value of integral is obtained from the area under the curve of adsorbed phenol concentration versus time.

The total amount of phenol fed to the column was calculated by using the following equation.

$M_{total} = C_0\, Q\, t_{total} / 1000$ ................................................(3)

Where, $M_{total}$ is the total amount of phenol fed to the column in gm and $C_0$ is the initial phenol concentration in mg/lit.

The percentage of phenol removal was calculated by using the following equation.

% Removal = $(q_{total} / M_{total})$ x 100 ................................(4)

Equilibrium phenol uptake was calculated by using the following equation.

$q_{eq(exp)} = q_{total} / m$ ..........................................................(5)

Where $q_{eq(exp)}$ is the equilibrium phenol uptake in mg/gm and m is the amount of fly ash present in the column.

**2.2.2. Effect of Bed Height**

The column was packed with glass bed and the cotton wool at the bottom as the support for the fly ash bed. Then the different weight of the fly ash has been poured into the column to form the bed of different height. In this study fly ash having 5, 10 and 20 grams are taken which results in the 7.5, 13.5 and 27.5 cm bed height of the CFA respectively. Cotton was used as the supporting layer to keep the glass bed and cotton wool in position and to support the fly ash. The process was performed at the constant flow rate of 0.0375 ml/min and phenol concentration was 1039.9 mg/liter. Effluent concentrations were measured as a function of time for each column and analyzed by UV spectrophotometer. The breakthrough curves and breakpoint has been drawn for each column. Thomas and Yoon Nelson model have been used to explain the dynamic adsorption process.

**2.2.3. Effect of Flow rate**

The same column as described above is used to study the effect of flow rate on adsorption process. Different flow rate of 0.375, 0.750 and 1.0 ml/min are used for different bed height of 7.5, 13.5 and 27.5 cm. separately. Effluent concentrations were measured as a function of time for each column and analyzed by UV spectrophotometer. The breakthrough curves and breakpoint has been drawn for each column. Thomas and Yoon-Nelson model have been used to explain the dynamic adsorption process.

**2.2.4. Effect of initial concentration**

The same column as described above is used to study the effect of initial phenol concentration on adsorption process. Different initial concentration of 70, 292.7, 651.2 and 1039.9 mg/L are used for different bed height of 7.5, 13.5 and 27.5 cm. with a constant flow rate of 1.0 ml/min separately. Effluent concentrations were measured as a function of time for each column and analyzed by UV spectrophotometer. The breakthrough curves and breakpoint has been drawn for each column. Thomas and Yoon-Nelson model have been used to explain the dynamic adsorption process.

**2.2.5. Modeling of Fixed bed column**

Experimental data can be used as the basis for the design of fixed bed column operations. Many models have been proposed for the evaluation of efficiency and applicability of the models for industrial operations. To design a dynamic column adsorption operation, break through curve and adsorbent capacity prediction for the required adsorbate under given set of operating conditions is necessary. In the present study, adsorption data from fixed bed dynamic column were analyzed using Thomas model and Yoon-Nelson model.

**2.2.6. Thomas Model**

The Thomas model is frequently applied to calculate the adsorption capacity of adsorbent and predict break through curve assuming the second order reversible reaction kinetics and the Langmuir isotherm [14, 15]. Linear form of Thomas model is given as under

$\ln [(C_0 / C_t) - 1] = K_{TH}\, q_0 M / Q - K_{TH}\, C_0\, t$ ..................(6)

Where, Co is initial phenol concentration, mg/lit; $C_t$ is effluent phenol concentration at time t, ppm; $K_{TH}$ is Thomas model constant, L/min.mg; $q_0$ is prediction adsorption capacity, mg/gm. M is mass of adsorbent, gm; Q is inlet flow concentration, ml/min. The value of $K_{TH}$ and $q_0$ are determined from slope and intercept of a plot of ln (C0/Ct -1) versus t.

**2.2.7. Yoon - Nelson Model**

The main aim of Yoon-Nelson model is to predict the time of column run before regeneration of column becomes necessary. The model is a very simple way to represent the break through curve. According to this model, the amount of phenol adsorbed in a fixed bed is half of the total phenol entering the adsorbent bed within time period 2 Ʈ, where Ʈ is the time required for 50 % break through. Linear form of Yoon-Nelson model is given below [16].

$\ln [C_t / (C_0 - C_t)] = K_{YN}\, t - \tau K_{YN}$ ................................(7)

Where, $C_0$ is initial phenol concentration, mg/lit; $C_t$ is phenol concentration at time t, mg/lit; t is flow time, min.; Ʈ is time required for 50 % breakthrough, min; $K_{YN}$ is Yoon-Nelson rate constant, 1/min. The values of $K_{YN}$ and Ʈ are determined from the slope and intercept of ln $[C_t / (C_0 - C_t)]$ versus t.

The adsorption capacity in mg/gm can be calculated by the following equation [17].

$q_0 = C_0\, Q\, \tau / m$ ......................................................(8)

Where, $C_0$ is initial phenol concentration, mg/lit; Q is inlet flow concentration, ml/min; Ʈ is time required for 50 % breakthrough, min; and m is the mass of adsorbents, gm.

**3. Results and Discussions**

**3.1 Effect of operating Conditions**

**3.1.1 Effect of bed height**

The effect of bed height on fixed bed adsorption at different bed height of 7.5, 13.5 and 27.5 cm is shown in following figure

It is observed that as the bed height increases, breakpoint time also increases. This shows that at the smaller bed height the effluent phenol concentration ratio increases more rapidly than for a higher bed height.

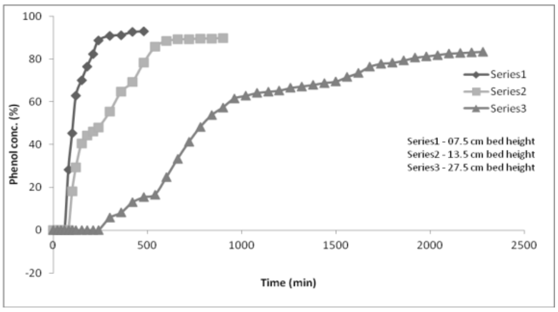


**Fig 1. Effect of bed height on breakthrough curve for phenol adsorption. (Amount of CFA= 5, 10 and 20 grams, Bed Height = 7.5, 13.5 and 27.5 cm, Influent flow rate = 0.375 ml/ min, Initial concentration ($C_0$) = 1039.9 mg/lit).**

Additionally the bed is saturated in less time for smaller bed height than the bigger one. Smaller bed height corresponds to less amount of adsorbent..As a result, a smaller capacity of the bed to adsorb phenol from solution and a faster increase in the rate of adsorption is expected [18]. For the bed height of 7.5, 13.5 and 27.5 cm, the break point time was observed as 68, 124 and 246 minutes respectively. This shows that as the bed height increases the velocity variation effect on breakthrough curve increases. The column parameters obtained from effect of bed height are listed in following table 1.

**Table 1. Effect of bed height on adsorption**

| Bed Height (cm) | $q_{total}$ (mg) | $M_{total}$ (gm) | % Phenol Removal | $q_{eq(exp)}$ (mg/gm) |
|---|---|---|---|---|
| 7.5 | 12.43 | 187.18 | 6.64 | 2.48 |
| 13.5 | 30.91 | 397.76 | 7.77 | 3.09 |
| 27.5 | 82.58 | 889.11 | 9.04 | 4.02 |

As shown in table 1, the total adsorption capacity of the bed increased with increase in bed height. At higher bed depth, more sites were available for adsorption and this resulted in higher phenol removal.

### 3.1.2 Effect of Flow rate

The effect of varying flow rate as 0.375, 0.750 and 1.0 ml/min on adsorption column for different bed height of 7.5, 13.5 and 27.5 cm are shown in following figures.

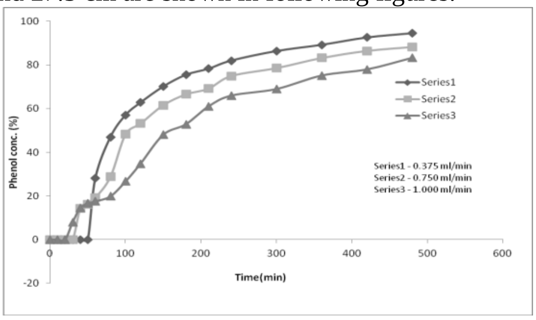


**Fig 2. Effect of flow rate on breakthrough curve for phenol adsorption. (Bed Height = 7.5 cm, Amount of CFA= 5 gm, Initial concentration ($C_0$) = 1039.9 mg/lit).**

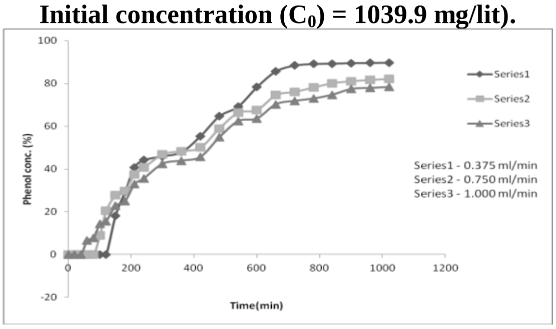


**Fig.3. Effect of flow rate on breakthrough curve for phenol adsorption. (Bed Height = 13.5 cm, Amount of CFA= 10 gm, Initial concentration ($C_0$) = 1039.9 mg/lit).**

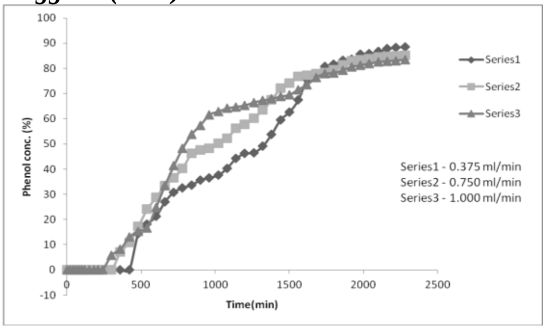


**Fig 4. Effect of flow rate on breakthrough curve for phenol adsorption. (Bed Height = 27.5 cm, Amount of CFA= 20 gm, Initial concentration ($C_0$) = 1039.9 mg/lit).**

It was observed from the figures 2, 3 and 4 that as the flow rate increases, the break point time decreases and the breakthrough curves become steeper. This occurs due to short residence time of phenol in the column for equilibrium adsorption is to be reached at high flow rate. So at high flow rate the phenol solution leaves the column before equilibrium occurs. Phenol adsorption on CFA at lower flow rate is more. At higher flow rate column gets saturated soon.

**Table 2. Effect of flow rate on adsorption**

| Flow rate (ml/min) | Bed Height (cm) | $q_{total}$ (mg) | $M_{total}$ (gm) | % Phenol Removal | $q_{eq(exp)}$ (mg/gm) |
|---|---|---|---|---|---|
| 0.375 | 7.5 | 12.5241 | 187.18 | 6.69090 | 2.50483 |
| 0.75 | | 22.7211 | 374.36 | 6.06925 | 4.54422 |
| 1.00 | | 26.0803 | 499.15 | 5.22493 | 5.21607 |
| 0.375 | 13.5 | 22.8370 | 397.76 | 5.7414 | 2.28370 |
| 0.75 | | 42.2909 | 795.52 | 5.31611 | 4.22909 |
| 1.00 | | 52.7767 | 1060.6 | 4.97566 | 5.27767 |
| 0.375 | 27.5 | 38.6897 | 889.11 | 4.35149 | 1.93448 |
| 0.75 | | 86.0946 | 1778.2 | 4.84159 | 4.30473 |
| 1.00 | | 118.007 | 2370.9 | 4.97718 | 5.90003 |

As shown in table 2, as the flow rate increases, percent removal of phenol decreases for bed height 7.5 and 13.5 cm but increases for bed height 27.5 cm. The equilibrium phenol uptake increases for all the bed heights. This may happen because of more volume of phenol solution is in contact with the more adsorbents sites.

### 3.1.3 Effect of initial concentration

The effect of varying initial concentration 1039.9, 651.2, 292.7 and 70.0 mg/l on adsorption column for different bed height of 7.5, 13.5 and 27.5 cm are shown in following figures 5, 6 and 7.

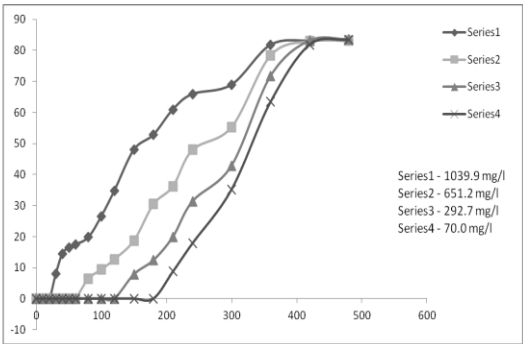


**Fig 5. Combined breakthrough curve for phenol adsorption. (Bed Height = 7.5 cm, amount of CFA= 5 grams, Influent flow rate = 60.0 ml/ hr, Initial concentration ($C_0$) = 1039.9, 651.2, 292.7 & 70.0 mg/l).**

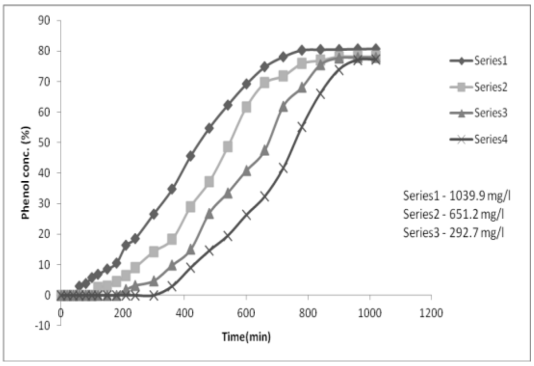


**Fig 6. Combined breakthrough curve for phenol adsorption. (Bed Height = 13.5 cm, Amount of CFA= 10 grams, Influent flow rate = 60.0 ml/ hr, Initial concentration ($C_0$) = 1039.9, 651.2, 292.7 & 70.0 mg/l).**

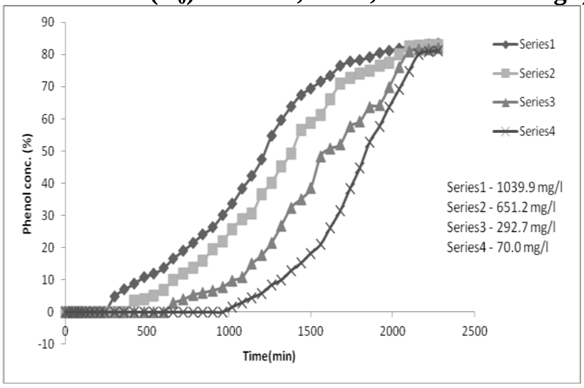


**Fig 7. Combined breakthrough curve for phenol adsorption. (Bed Height = 27.5 cm, Amount of CFA= 20 grams, Influent flow rate = 60.0 ml/ hr, Initial concentration ($C_0$) = 1039.9, 651.2, 292.7 & 70.0 mg/l).**

It was observed from the figures 5, 6 and 7 that as the initial phenol concentration increases, the break point time decreases. For large phenol concentration, steeper breakthrough curves are found, because of the lower mass-transfer difference from the phenol solution to the particle surface due to the weaker driving force. In addition at higher concentration, the isotherm gradient is lower, resulting in higher driving force along the adsorbent pores.

**Table 3. Effect of initial phenol concentration on adsorption**

| Phenol Conc. (ml/lit) | Bed Height (cm) | $q_{total}$ (mg) | $M_{total}$ (gm) | % Phenol Removal | $q_{eq(exp)}$ (mg/gm) |
|---|---|---|---|---|---|
| 70.0 | 7.5 | 14.3918 | 33.6 | 42.8329 | 2.87837 |
| 292.7 | | 16.9936 | 140.496 | 12.0954 | 3.39872 |
| 651.2 | | 20.8607 | 312.576 | 6.6738 | 4.17213 |
| 1039.9 | | 26.7897 | 499.152 | 5.36704 | 5.35793 |
| 70.0 | 13.5 | 27.4135 | 71.4 | 38.3943 | 2.74135 |
| 292.7 | | 34.8933 | 298.554 | 11.6874 | 3.48933 |
| 651.2 | | 42.7972 | 664.224 | 6.44319 | 4.27972 |
| 1039.9 | | 50.8495 | 1060.69 | 4.79396 | 5.08495 |
| 70.0 | 27.5 | 45.6222 | 159.6 | 28.5853 | 2.28111 |
| 292.7 | | 64.0108 | 667.356 | 9.59170 | 3.20054 |
| 651.2 | | 85.6434 | 1484.73 | 5.76825 | 4.28217 |
| 1039.9 | | 99.7392 | 2370.972 | 4.206682 | 4.986963 |

The above table 3 indicates that with increase in initial phenol concentration, the adsorption capacity of the bed increased for all bed heights, but percentage phenol removal decreased with increase in concentration. This may happen because of the required driving force for adsorption increases with increase in concentration.

### 3.2 Modelling of the Breakthrough Curves

In this study, Thomas and Yoon-Nelson models were used for the prediction of dynamic behavior of the column.

#### 3.2.1 Thomas and Yoon-Nelson Model Parameters for Effect of Bed Height

**Table 4. Column kinetic parameters for Thomas model and Yoon-Nelson model obtained at different experimental conditions**

| Model | Parameters | Bed Height | | |
|---|---|---|---|---|
| | | **7.5 cm** | **13.5 cm** | **27.5 cm** |
| Thomas | $K_{th}$ (ml/min.mg) | 6.92374E-06 | 3.94269E-06 | 1.8271E-06 |
| | $q_0$ (mg/gm) | 3652.649 | 13692.44 | 21132.89 |
| | $R^2$ | 0.8395 | 0.9256 | 0.8338 |
| Yoon-Nelson | $K_{YN}$ ($min^{-1}$) | 0.0072 | 0.0041 | 0.0019 |
| | $\tau$ (min) | 46.75 | 351.12 | 1083.84 |
| | $q_0$ (mg/gm) | 3.652648 | 13.69244 | 21.13289 |
| | $R^2$ | 0.8398 | 0.9256 | 0.8338 |

As shown in table 4, for Thomas model, the value of $q_0$ increased and the value of $K_{th}$ decreased with the increase in bed height. Similarly for Yoon-Nelson model, it was found that by increasing the bed height the value of $K_{YN}$ decrease and the $\tau$ and $q_0$ increases. The value of $q_0$ for Yoon-Nelson model is nearer to experimental $q_0$ as compared to Thomas Model. These results are in good agreement with [13].

#### 3.2.2 Thomas and Yoon-Nelson Model Parameters for Effect of Flow Rate

**Table 5. Column kinetic parameters for Thomas model and Yoon-Nelson model obtained at different experimental conditions**

| MODEL | BED Height - 7.5 cm | | | |
|---|---|---|---|---|
| | **Flow Rate (ml/min)** | **0.375** | **0.750** | **1.000** |
| Thomas | $K_{th}$ (ml/min.mg) | 0.020 | 0.0112 | 0.0084 |
| | $q_0$ (mg/gm) | 2.100 | 18.36 | 44.58 |
| | $R^2$ | 0.915 | 0.843 | 0.892 |
| Yoon-Nelson | $K_{YN}$ ($min^{-1}$) | 0.0077 | 0.0084 | 0.0084 |
| | $\tau$ (min) | 74.68 | 163.28 | 222.92 |
| | $q_0$ (mg/gm) | 5.82 | 25.47 | 46.36 |
| | $R^2$ | 0.91 | 0.84 | 0.89 |
| | BED Height - 13.5 cm | | | |
| Thomas | $K_{th}$ (ml/min.mg) | 0.0109 | 0.0045 | 0.0037 |
| | $q_0$ (mg/gm) | 4.937 | 24.67 | 51.67 |
| | $R^2$ | 0.925 | 0.890 | 0.885 |
| Yoon-Nelson | $K_{YN}$ ($min^{-1}$) | 0.0041 | 0.0034 | 0.0037 |
| | $\tau$ (min) | 351.12 | 438.67 | 516.78 |
| | $q_0$ (mg/gm) | 13.69 | 34.21 | 53.74 |
| | $R^2$ | 0.92 | 0.89 | 0.88 |
| | BED Height – 27.5.5 cm | | | |
| Thomas | $K_{th}$ (ml/min.mg) | 0.0058 | 0.0025 | 0.0019 |
| | $q_0$ (mg/gm) | 8.304 | 31.75 | 54.19 |
| | $R^2$ | 0.979 | 0.920 | 0.833 |
| Yoon-Nelson | $K_{YN}$ ($min^{-1}$) | 0.0022 | 0.0019 | 0.0019 |
| | $\tau$ (min) | 1181.1 | 1128.89 | 1083.8 |
| | $q_0$ (mg/gm) | 23.02 | 44.02 | 56.35 |
| | $R^2$ | 0.97 | 0.92 | 0.83 |

As shown in table 5, with increase in flow rate for Thomas model, the value of $q_0$ increased and the value of $K_{th}$ decreased. Similarly for Yoon-Nelson model, it was found that by increasing the flow rate the value of $K_{YN}$ increases for the bed height 7.5 cm while it decreases for 13.5 and 27.5 cm bed height. The $\tau$ and $q_0$ values are increases with increase in flow rate.

#### 3.2.3 Thomas and Yoon-Nelson Model Parameters for Effect of Initial Phenol Concentration

As shown in table 6, with increase in initial phenol concentration for Thomas model, the value of $q_0$ increased and

**Table 6. Column kinetic parameters for Thomas model and Yoon-Nelson model obtained at different experimental conditions**

| **MODEL** | **BED Height - 7.5 cm** | | | | |
|---|---|---|---|---|---|
| | **Phenol conc. (mg/lit)** | **70.0** | **292.7** | **651.2** | **1039.9** |
| Thomas | $K_{th}$ (ml/min.mg) | 0.000218571 | 4.50974E-05 | 1.7199E-05 | 8.46235E-06 |
| | $q_0$ (mg/gm) | 4804.28 | 18600.2 | 36523.0 | 45316.01 |
| | $R^2$ | 0.9609 | 0.9653 | 0.9531 | 0.906 |
| Yoon-Nelson | $K_{YN}$ ($min^{-1}$) | 0.0153 | 0.0132 | 0.0112 | 0.008 |
| | $\tau$ (min) | 343.163 | 317.734 | 280.42 | 217.8 |
| | $q_0$ (mg/gm) | 4.804288 | 18.60020 | 36.5202 | 45.31601 |
| | $R^2$ | 0.9609 | 0.9653 | 0.9531 | 0.9066 |
| | BED Height - 13.5 cm | | | | |
| Thomas | $K_{th}$ (ml/min.mg) | 9.71429E-05 | 2.28903E-05 | 9.0602E-06 | 5.09664E-06 |
| | $q_0$ (mg/gm) | 5444.456 | 20558.46 | 41430.67 | 58204.970 |
| | $R^2$ | 0.9647 | 0.9457 | 0.9244 | 0.9122 |
| Yoon-Nelson | $K_{YN}$ ($min^{-1}$) | 0.0068 | 0.0067 | 0.0059 | 0.0053 |
| | $\tau$ (min) | 777.77 | 702.37 | 636.22 | 559.717 |
| | $q_0$ (mg/gm) | 5.444456 | 20.55846 | 41.43067 | 58.204970 |
| | $R^2$ | 0.9647 | 0.9457 | 0.9244 | 0.9122 |
| | BED Height - 27.5 cm | | | | |
| Thomas | $K_{th}$ (ml/min.mg) | 6.14286E-05 | 1.09327E-05 | 4.29975E-06 | 2.30791E-06 |
| | $q_0$ (mg/gm) | 6530.267 | 24782.09 | 47214.33 | 67866.47 |
| | $R^2$ | 0.9910 | 0.9891 | 0.9749 | 0.9595 |
| Yoon-Nelson | $K_{YN}$ ($min^{-1}$) | 0.0043 | 0.0032 | 0.0028 | 0.0024 |
| | $\tau$ (min) | 1865.791 | 1693.344 | 1450.071 | 1305.2500 |
| | $q_0$ (mg/gm) | 6.530269 | 24.78209 | 47.21431 | 67.866470 |
| | $R^2$ | 0.9910 | 0.9891 | 0.9749 | 0.9595 |

the value of $K_{th}$ decreased. Similarly for Yoon-Nelson model, it was found that by increasing the initial phenol concentration the value of $K_{YN}$ and $\tau$ decreases while the value of $q_0$ increases.

## 4. Conclusion

The disposal problem of coal fly ash (CFA) has been resolved by using it as an adsorbent for removal of phenol from aqueous solution to some extent. The CFA as an adsorbent showed maximum adsorption capacity of 5.90 mg/gm. The effect of operating parameters such as bed height, flow rate and initial phenol concentration were investigated. The adsorption capacity increases with increase in bed height, flow rate and initial phenol concentration. The Thomas and Yoon-Nelson model was used for experimental data to predict the breakthrough curve and to determine the adsorption capacity of the column. The Yoon-Nelson model found the good agreement with the experimental data rather than Thomas model.

## References

[1] Chauhan Y.P., Talib M., “Coal Fly Ash Characterization and its use as an adsorbent for removal of phenol from aqueous solution”, International Journal for Science and Advance Research in Technology, Vol. 1. (10), pp 179 -188, 2015.

[2] Brandt S., Zeng A. and Deckwer D.W., “Adsorption and desorption of pentachlorophenol on cells of Mycobacterium chlorophenolicum PCP-1”, Biotechnol. Bioeng., Vol.55, pp. 480 – 489, 1997.

[3] Denizli A., Cihanger N., Taner A., Taner M. and Alsancak G., “Removal of chlorophenols from synthetic solutions using Phanerochaete chrysosporium”, Process Biochem., Vol. 39, pp. 2025 – 2030, 2004.

[4] Greminger D.C., Burns G.P., Lynn S., Hanson D.J. and King C.J., “Solvent-extraction of phenols from water”, Ind. Eng. Chem., Vol. 21, pp. 51-54, 1982.

[5] Environmental Protection Agency (EPA) (1984) Methods 604, Phenols in Federal Register. October 26, Part VIII, 40, CFR, 58, USA.

[6] M. T. Uddin , M. S. Islam , and M. Z. Abedin, “Adsorption of Phenol from Aqueous Solution by Water Hyacinth Ash”, ARPN Journal of Engineering and Applied Sciences, Vol. 2 (2), pp 11-17, 2007.

[7] O. A. Ekpete , M. Horsfall Jnr and T. Tarawou, “Potential of Fluted Pumpkin and Commercial Activated Carbons for Phenol Removal in Aqueous Systems”, ARPN Journal of Engineering and Applied Sciences, Vol. 5 (6), pp 39-47, 2010.

[8] S. B. Divate, R. V. Hinge, S.R. Kadam, “Removal of heavy metal (phenol) by using various adsorbents”, International Journal of Scientific & Engineering Research, Vol. 5 (7), pp 673-678, 2014.

[9] Kikuchi R., “Application of coal ash to environmental improvement—transformation into zeolite, potassium fertilizer, and FGD absorbent”, Resour. Conserv. Recy., Vol. 27, pp. 333–346, 1999.

[10] Iyer R.S., Scott J.A., “Power station fly ash—a review of value-added utilization outside of the construction industry”, Resour. Conserv. Recy., Vol. 31, pp. 217–228, 2001.

[11] X. Querol X., Moreno N., Umana J.C., Alastuey A., Hernandez E, Lopez-Soler A., Plana F., “Synthesis of zeolites from coal fly ash: an overview”, Int. J. Coal Geol., Vol. 50, pp. 413–423, 2002.

[12] Vazquez G, Alonso R, Freire S, Alvarez J.G and Antorrena G., “Uptake of phenol from aqueous solutions by adsorption in a Pinus pinaster bark packed bed”, J. Hazard. Mater, Vol. B133, pp 61 – 67, 2006.

[13] Girish C. R., Murty V. R., “Adsorption of Phenol from Aqueous Solution Using Lantana camara, Forest Waste: Packed Bed Studies and Prediction of Breakthrough Curves”, Environ. Process, Vol. 2, pp 773-796, 2015.

[14] Han, R., Ding, D., Xu, Y., Zou, W., Wang, Y., Li, Y., Zou, L. (2008). Use of rice husk for the adsorption of congo

red from aqueous solution in column mode. Bioresource Technology, Vol. 99(8), pp 2938 - 2946.
[15] Ghasemi, M., Keshtkar, A.R., Dabbagh, R., Jaber Safdari, S. (2011). Biosorption of uranium (VI) from aqueous solutions by Ca-pretreated Cystoseira indicaalga: breakthrough curves studies and modeling. Journal of Hazardous Materials, Vol. 189(1-2), pp 141 – 149.
[16] Shadeera R., Nagapadma M. (2015) Modelling of fixed bed column studies for adsorption of azo dye on chitosan impregnated with a cationic surfactant, International Journal of Scientific & Engineering Research, Vol. 6(2), pp 538 – 545.
[17] Pablo D. R., Adriana S. F., Leandro S. O. (2015). Batch and Column Studies of Phenol Adsorption by an Activated Carbon Based on Acid Treatment of Corn Cobs. International Journal of Engineering and Technology, Vol. 7(6), pp 459 – 464.
[18] B.V. Babu and Suresh Gupta Modeling and Simulation of Fixed Bed Adsorption Column: Effect of Operating Variables. http://discovery.bits-pilani.ac.in/discipline/chemical/BVb/index.html; pp 1 – 15.