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PACKED BED ADSORPTION OF PHENOL ON MODIFIED COAL FLY ASH (MCFA)

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Keywords: Modified coal fly ash, Phenol, packed bed column, adsorption, Mass transfer zone and Fractional bed utilization.

ABSTRACT
Coal based thermal power plants generates huge amount of fly ash as waste worldwide. This coal fly ash was modified by alkaline hydrothermal treatment and termed as modified coal fly ash (MCFA), which was then used as an adsorbent for phenol removal from aqueous solution using packed bed adsorption column. The effect of bed height (7.5, 13.5, 27.5 cm), flow rate (0.375, 0.75, 1.0 ml/min) and initial phenol concentration (70.0, 292.7, 651.2, 1039.9 mg/l) on the breakthrough curve and adsorption performance was investigated. The various process parameters such as breakthrough capacity (qb), volume of effluent treated (Veff), mass transfer zone (MTZ) and fractional bed utilization (FBU) were investigated to evaluate the column performance. The results showed that for the flow rate of 1.00 ml/min, initial phenol concentration of 1039.9 mg/l and bed height of 13.5 cm, the maximum column capacity (at 80% breakthrough) was obtained to be 67.724, 17.472 and 62.150 mg/g during the column study for effect of different bed height, flow rate and phenol concentration respectively. It was observed that, the column performance was affected by flow rate, bed height and initial phenol concentration.

INTRODUCTION
Coal based thermal power plants, contributing to the 61.5 percent of total installed power capacity, are the major source of electricity generation in India [1]. Most of industries are using pulverized coal as the fuel, producing enormous quantities of coal fly ash every year. India has 211 billion tonnes of coal reserves. The power generation in India was about 200,000 MW in 2012 and it is expected to increase up to 300,000 MW by 2017. In developing countries like India power generation is most important requirement for economic and social development. At the time of independence in 1947, the installed capacity was 1,361 MW, which has increased to 1, 87, 732 MW on 31 March, 2012. Out of it, 1, 10, 232 MW is thermal (Coal/Lignite) based and is responsible to co-generate nearly 200 million tons of fly ash per year. Various approaches have been made for the utilisation of fly ash either to reduce the cost of disposal or to minimise its impact on the environment. Coal fly ash has found uses in the various fields like cement and concrete industry as an additive, treatment of acid mine drainage as well as in land reclamation and restoration [2-3]. On the other hand, coal fly ash can be converted into zeolite which is one of the approaches to reduce the pollution created by thermal power plants [4]. The need to find a suitable means of managing this huge amount of coal fly ash generated from thermal power plants in India has lead to present study to convert this coal fly ash by hydrothermal alkali treatment as Modified Coal Fly Ash (MCFA) and its utilization as an adsorbent for removal of phenol.

The wastewater released from the various chemical industries contains some organic and inorganic chemicals which creates environmental pollution. Phenolic wastewater is a serious environmental problem and this water cannot release into the environment without treatment [5]. Environmental Protection Agency (USA) has been classified phenolic compounds as high-priority pollutants [6]. The plastic, pharmaceutical, petrochemical, paint, paper & pulp, solvent, coal conversion etc. are some industries which generate phenolic waste water. Phenolic compounds are known one of the priority pollutants in wastewater, because they are harmful to organisms even at low concentrations [7, 8, 9].

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 time and can be scaled up from a laboratory step [10].
The column studies were undertaken in order to improve the adsorption capacity aiming at industrial applications. In present study, an organized column investigation of the phenol adsorption on MCFA was reported. The study tested the effect of different operating parameters on adsorption, such as variation of packed

bed height, flow rate and initial phenol concentration. The prediction of the breakthrough curves and estimations of the adsorption parameters are reported.

Estimation of adsorption parameters

The various process parameters such as breakthrough capacity (q_b), volume of effluent treated (V_{eff}), mass transfer zone (MTZ) and fractional bed utilization (FBU) were investigated to evaluate the column performance. These parameters will provide the information on the column performance which will be useful in the design of the column [11].

The breakthrough curves are drawn by plotting the relative concentration of phenol, which is the ratio of the phenol concentration in the effluent to the concentration in the feed solution with respect to time.

The fixed bed column experimental parameters are calculated by using the equation 1 to 4 [11-12].

The adsorption uptake (q_b) at breakthrough time (t_b) was obtained by following equation.

$$q_b = (t_b \ F C_b) / m \qquad (1)$$

Where q_b is the breakthrough adsorption capacity (mg/g), t_b is the time needed for the breakthrough (min), F is the flow rate of influent (L/min), C_b is the effluent concentration of solute at time t_b (mg/L) and m is the mass of adsorbent.

The volume of effluent treated was determined using the following equation

$$V_{eff} = t_b F \qquad (2)$$

Where V_{eff} is the volume of effluent treated (L).

The mass transfer zone (MTZ) was calculated from following equation.

$$MTZ = Z \text{ x } [1- (t_b / t_s)] \qquad (3)$$

Where Z is the bed height (cm).

The fractional bed utilization (FBU) parameter shows the fraction of packed column used for the adsorption process. It is given by the following equation.

$$FBU = q_b / q_s \qquad (4)$$

MATERIALS AND METHODS

Materials

The material used for this study includes:
(i) Adsorbate: Phenol
(ii) Adsorbent: Modified coal Fly Ash.

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.

Adsorbent

Modified coal fly ash was prepared as given in our earlier research paper [13]. It was dried at 100^0C for an hour before using for experimentations.

Experimental Method

MCFA was packed in the glass column having 45 cm length and 10 mm internal diameter with the support of glass bed and cotton wool at the bottom of the column. The column was operated under down flow condition which allows the influent to be gravity fed and also ensured that the bed remains packed and steady during the entire operation, which results in the maximum contact between the MCFA and the influent. The experiments were conducted for the effect of bed height (7.5, 13.5, 27.5 cm), flow rate (0.375, 0.750, 1.0 ml/ min) and initial

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phenol concentration (70.0, 292.7, 651.2, 1039.9 mg/l) 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 for phenol concentration which was determined by UV spectrophotometer.

Effect of Bed Height

To study the effect of bed height, 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 MCFA respectively. The process was performed at the constant flow rate of 1.0 ml/min and phenol concentration was 1039.9 mg/litre. The breakthrough curves and breakpoint has been drawn for each column.

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. The breakthrough curves and breakpoint has been drawn for each column.

Effect of phenol 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. The breakthrough curves and breakpoint has been drawn for each column.

RESULTS AND DISCUSSIONS

Effect of bed height

Figure 1 presents the performance of breakthrough curves at bed heights of 7.5, 13.5 and 27.5 cm
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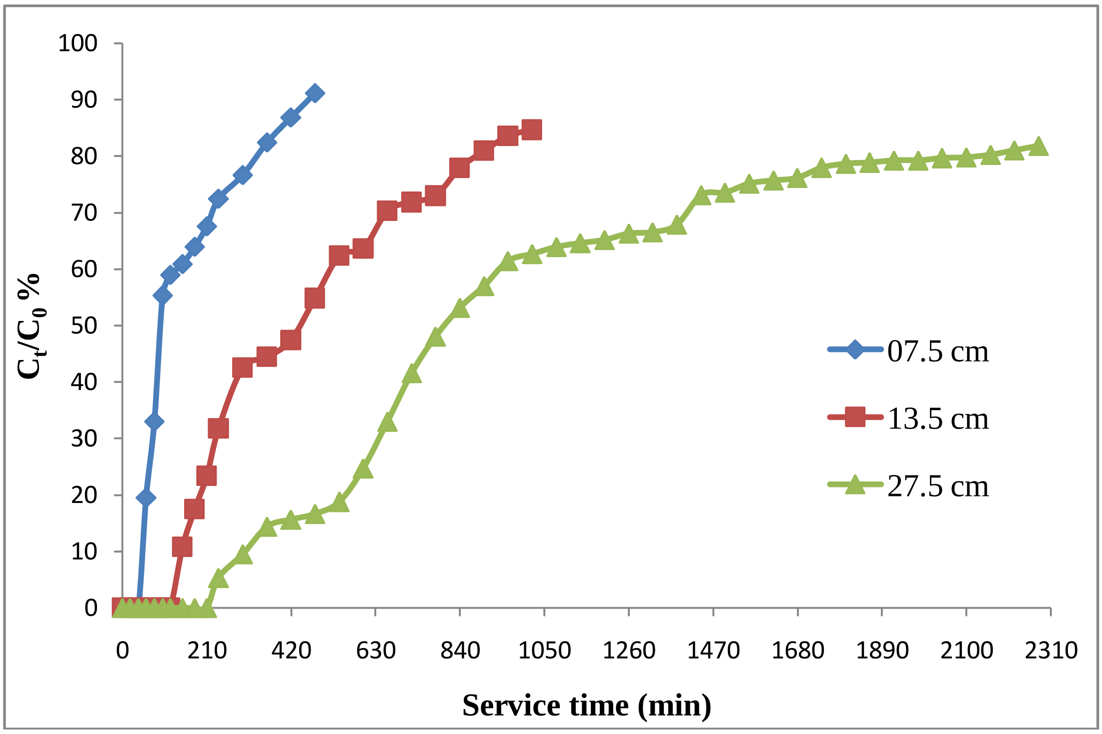

Fig. 1. Effect of bed height on breakthrough curve. (Conditions:- pH=6, Amount of MCFA= 5, 10 and 20 grams respectively, Influent flow rate = 1.0 ml/ min, Initial phenol concentration (C0) = 1039.9 mg/L)

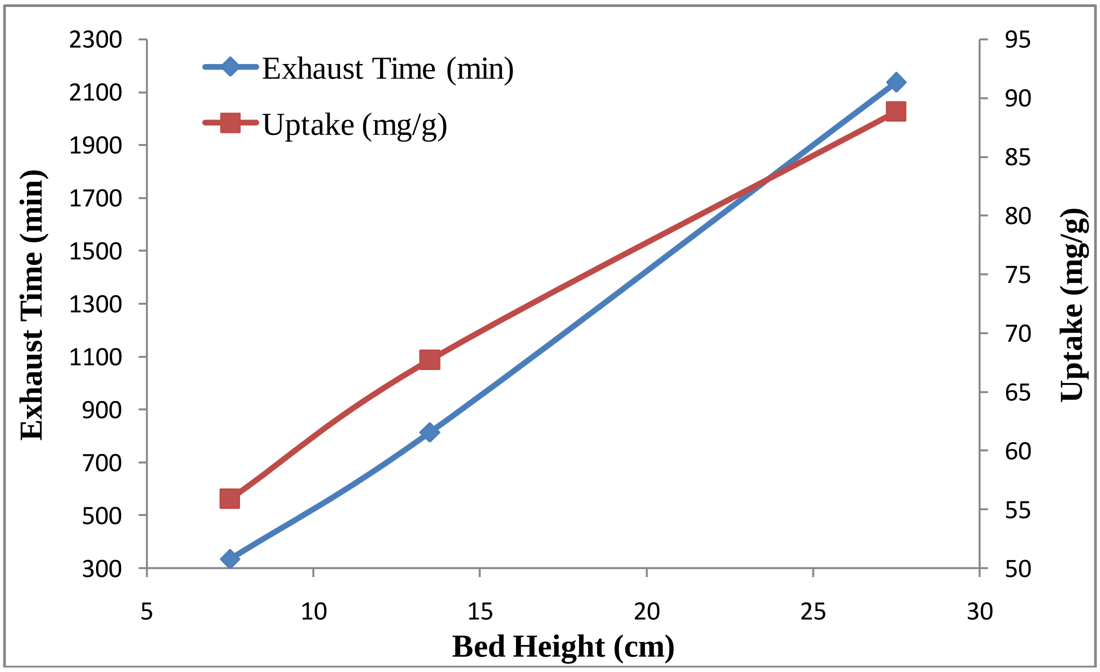

Fig. 2. Effect of bed height on uptake and exhaust time. (Conditions:- pH=6, Amount of MCFA= 5, 10 and 20 grams respectively, Influent flow rate = 1.0 ml/ min, Initial concentration (C0) = 1039.9 mg/L)

It was apparent from Figure 1and 2 that the breakthrough time and bed exhaust time increases with increase in bed height. The 30% breakthrough time for phenol concentration of 1039.9 mg/L was found as 65, 235 and 645 minutes while exhaust time (70% breakthrough) was found to be 220, 658 and 1435 minutes for the bed height 7.5, 13.5 and 27.5 cm respectively (Table 1). It was also noticed that the slope of breakthrough curve decreased with increasing bed height, confirming extended mass transfer zone. Similar results are observed by Girish C. R. and Murty V. R. [11] for phenol adsorption on Lantana camara, Forest waste. Baral S. S. [14] quoted that as the breakthrough time in shorter bed is generally lower and complete utilization of the bed may not be possible. Hence considering the adsorption capacity and different bed heights, 13.5 cm bed height was selected for further experiments.

Table 1: Column data and parameters obtained at different bed height.

Operating parameters (Height, Flow rate, Phenol conc.)			**Breakthrough points (b.p.)**								
			0.2			**0.3**			**0.4**		
Z (cm)	F (ml/min)	C_0 (mg/L)	t_b (min)	V_{eff} (ml)	q_b (mg/g)	t_b (min)	V_{eff} (ml)	q_b (mg/g)	t_b (min)	V_{eff} (ml)	q_b (mg/g)
7.5	1.000	1039.9	61	61	2.537	65	65	4.056	87	87	7.2384
13.5	1.000	1039.9	191	191	3.972	235	235	7.332	346	346	14.393
27.5	1.000	1039.9	555	555	5.772	645	645	10.06	710	710	14.768
Operating parameters (Height, Flow rate, Phenol conc.)			**Breakthrough points (b.p.)**								
			0.5			**0.7**			**0.8**		
Z (cm)	F (ml/min)	C_0 (mg/L)	t_b (min)	V_{eff} (ml)	q_b (mg/g)	t_b (min)	V_{eff} (ml)	q_b (mg/g)	t_b (min)	V_{eff} (ml)	q_b (mg/g)
7.5	1.000	1039.9	95	95	9.88	220	220	32.032	336	336	55.910
13.5	1.000	1039.9	399	399	20.74	658	658	47.902	814	814	67.724
27.5	1.000	1039.9	804	804	20.90	1435	1435	52.234	2136	2136	88.857

Table 1 shows that at any breakthrough point the corresponding breakthrough time, capacity and treated volume increases with increase in bed height. It can also be observed from the table that larger the breakthrough time higher the breakthrough capacity of the column. This could be a result of the fact that an increase in bed height provides the phenol molecule with more time to get adsorbed into the increased mass transfer zone and this also result in treating more volume of effluent [12]. Therefore a reduction in the phenol concentration of the effluent can be achieved in a column design approach by increasing the bed height at the same time [12]. Hence higher bed height favours better column performance.

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The other adsorption parameters like mass transfer zone (MTZ) and fractional bed utilization (FBU) at 20 and 80 % breakthrough; 30 and 70 % breakthrough are also estimated and tabulated in Table 2.

Table 2: Mass transfer zone (MTZ) and fractional bed utilization (FBU) obtained at different bed height.

Operating parameters (Height, Flow rate, Phenol conc.)			Breakthrough points (b.p.)						Calculated parameters		
			0.2			0.8					
Z (cm)	F (ml/min)	C_0 (mg/L)	t_b (min)	V_{eff} (ml)	q_b (mg/g)	t_b (min)	V_{eff} (ml)	q_b (mg/g)	MTZ (cm)	FBU	% BU
7.5	1.000	1039.9	61	61	2.537	336	336	55.910	6.1383	0.0453	4.53
13.5	1.000	1039.9	191	191	3.972	814	814	67.724	10.332	0.0586	5.86
27.5	1.000	1039.9	555	555	5.772	2136	2136	88.857	20.354	0.0649	6.49
Operating parameters (Height, Flow rate, Phenol conc.)			Breakthrough points (b.p.)						Calculated parameters		
			0.3			0.7					
Z (cm)	F (ml/min)	C_0 (mg/L)	t_b (min)	V_{eff} (ml)	q_b (mg/g)	t_b (min)	V_{eff} (ml)	q_b (mg/g)	MTZ (cm)	FBU	% BU
7.5	1.000	1039.9	65	65	4.056	220	220	32.032	5.2840	0.1266	12.66
13.5	1.000	1039.9	235	235	7.332	658	658	47.902	8.6785	0.1530	15.30
27.5	1.000	1039.9	645	645	10.06	1435	1435	52.234	15.139	0.1926	19.26

From Table 2 it can be noticed that the mass transfer zone (MTZ) and fractional bed utilization (FBU) increases as the bed height increases. From this it can be inferred that at higher bed height, high MTZ and FBU could be obtained. Hence it can be concluded that for better column performance longer packed bed height is favoured.

Effect of flow rate

The breakthrough curves obtained by plotting effluent phenol concentration versus time at different flow rates are represented in Figure 3 and 4.

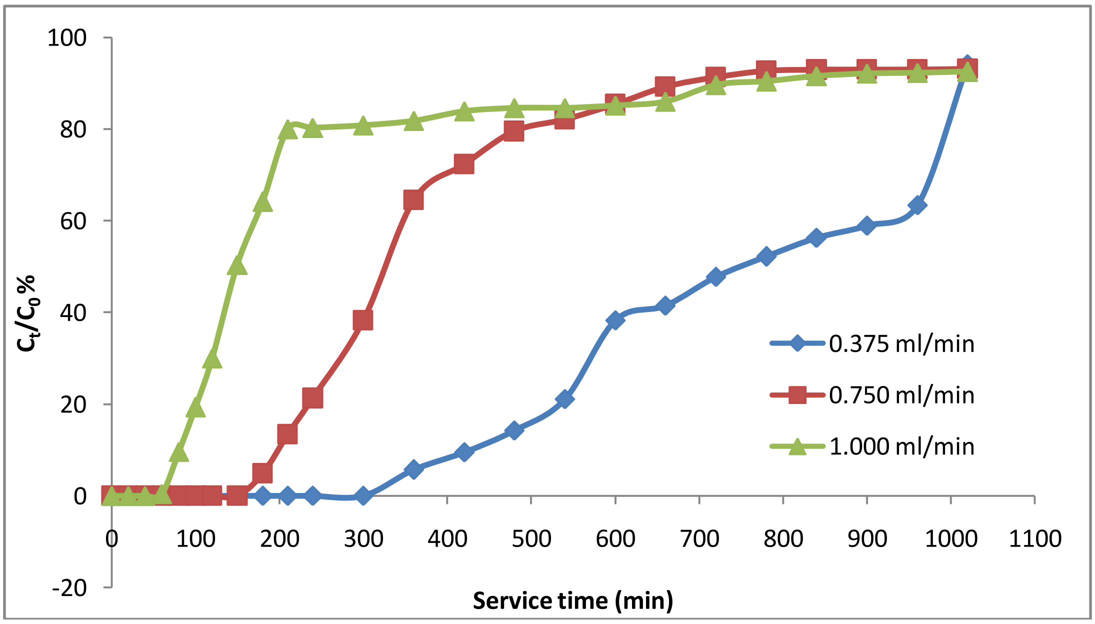

Fig. 3. Effect of flow rate on breakthrough curve. (Conditions:- pH=6, Amount of MCFA= 10 grams, Bed Height = 13.5 cm, Initial concentration C0 = 1039.9 mg/L)

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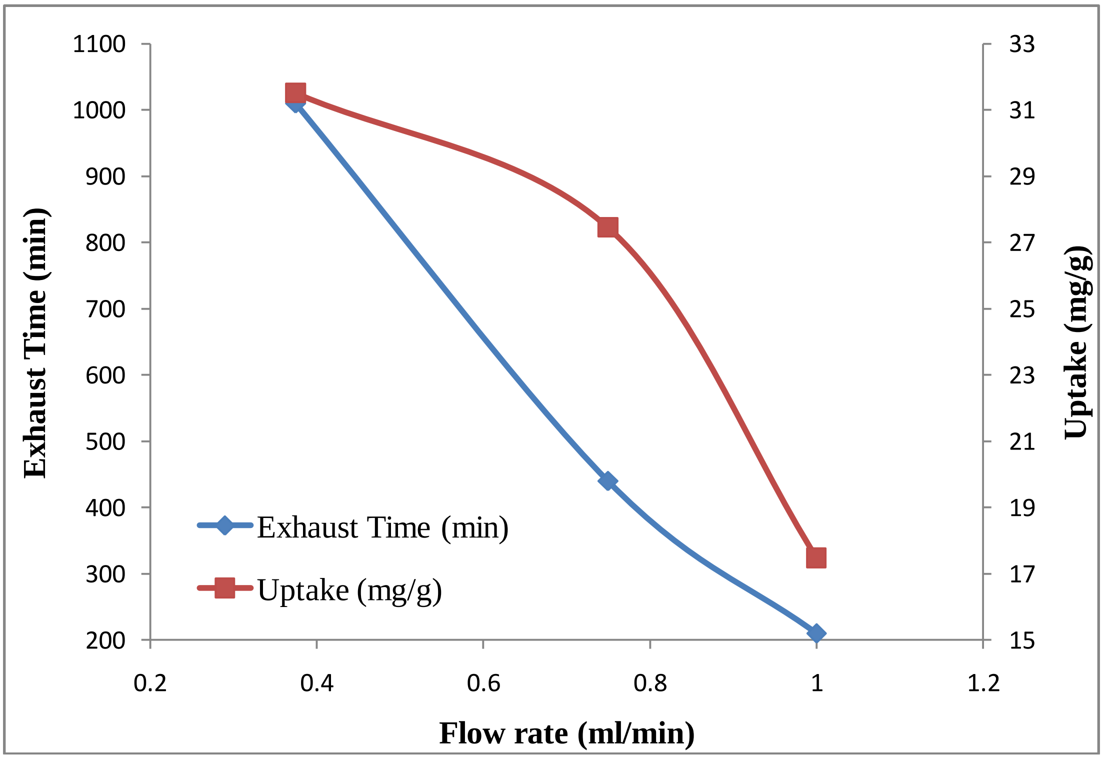

Fig. 4. Effect of flow rate on uptake and exhaust time. (Conditions:- pH=6, Amount of MCFA= 10 grams, Bed Height = 13.5 cm, Initial concentration C0 = 1039.9 mg/L)

It was observed that (Fig. 4) the adsorption efficiency was higher at lower flow rate. This might be due to the fact that at lower flow rate the diffusion of phenol in the pores of MCFA becomes slow and hence the MCFA needs more time to bind the phenol molecule. However if residence time of the phenol in the column is not large enough for adsorption equilibrium to be reached at that flow rate the phenol solution leaves the column before equilibrium occurs. It was also observed that the decrease in both the volume treated and the breakthrough time as the flow rate was increased (Table 3). The faster breakthrough occurred at higher flow rates and thus the shortened bed service time was required for saturation of the bed (Fig. 3). The breakthrough curve became steeper when the flow rate was increased which implicates the mass transfer zone was shortened indicating more effective intraparticle diffusion effects [15]. Other studies on fixed bed adsorption have reported that as flow rate increases beyond the certain value it results in decrease in adsorption rate because of the decrease in the residence time of the adsorbate in the column [16].

Table 3: Column data and parameters obtained at different flow rate.

Operating parameters (Height, Flow rate, Phenol conc.)			**Breakthrough points (b.p.)**								
			0.2			**0.3**			**0.4**		
Z (cm)	F (ml/min)	C_0 (mg/L)	t_b (min)	V_{eff} (ml)	q_b (mg/g)	t_b (min)	V_{eff} (ml)	q_b (mg/g)	t_b (min)	V_{eff} (ml)	q_b (mg/g)
13.5	0.375	1039.9	536	201	4.180	571	214.12	6.6807	656	246	10.233
13.5	0.750	1039.9	235	176	3.666	276	155.25	6.4584	304	228	9.4848
13.5	1.000	1039.9	114	114	2.371	120	120	3.744	136	136	5.6576
Operating parameters (Height, Flow rate, Phenol conc.)			**Breakthrough points (b.p.)**								
			0.5			**0.7**			**0.8**		
Z (cm)	F (ml/min)	C_0 (mg/L)	t_b (min)	V_{eff} (ml)	q_b (mg/g)	t_b (min)	V_{eff} (ml)	q_b (mg/g)	t_b (min)	V_{eff} (ml)	q_b (mg/g)
13.5	0.375	1039.9	752	282	14.66	973	364.87	26.562	1010	378.7	31.512
13.5	0.750	1039.9	326	244	12.71	406	304.50	22.167	440	330	27.456
13.5	1.000	1039.9	145	145	7.54	191	191	13.904	210	210	17.472

The column parameters obtained from effect of flow rate are tabulated in Table 3. The table shows that relative breakthrough time and effective volume at any breakthrough point decreases as the flow rate increases. The

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optimum uptake capacity for flow rate of 0.375, 0.750 and 1.000 ml/min was found to be 31.512, 27.456 and 17.472 mg/g respectively (Fig. 4) at 80% saturation of the column. This is because as the flow rate is increased, more volume of the phenol solution is made to pass through the adsorption zone thereby providing insufficient residence time for the phenol molecule to adsorb on the MCFA pores [12]. This leads to the exit of solute in the phenol solution from the column before the formation of equilibrium which results in shorter breakthrough time. Hence lower flow rate favours better column performance which implicates at the lowest flow rate of 0.375 ml/min.

Table 4: Mass transfer zone (MTZ) and fractional bed utilization (FBU) obtained at different flow rate.

Operating parameters (Height, Flow rate, Phenol conc.)			**Breakthrough points (b.p.)**						Calculated parameters		
			0.2			**0.8**					
Z (cm)	F (ml/min)	C_0 (mg/L)	t_b (min)	V_{eff} (ml)	q_b (mg/g)	t_b (min)	V_{eff} (ml)	q_b (mg/g)	MTZ (cm)	FBU	% BU
13.5	0.375	1039.9	536	201	4.180	1010	378.7	31.512	6.335	0.132	13.26
13.5	0.750	1039.9	235	176	3.666	440	330	27.456	6.289	0.133	13.35
13.5	1.000	1039.9	114	114	2.371	210	210	17.472	6.171	0.135	13.57
Operating parameters (Height, Flow rate, Phenol conc.)			**Breakthrough points (b.p.)**						Calculated parameters		
			0.3			**0.7**					
Z (cm)	F (ml/min)	C_0 (mg/L)	t_b (min)	V_{eff} (ml)	q_b (mg/g)	t_b (min)	V_{eff} (ml)	q_b (mg/g)	MTZ (cm)	FBU	% BU
13.5	0.375	1039.9	571	214.12	6.680	973	365	26.562	5.577	0.251	25.15
13.5	0.750	1039.9	276	155.25	6.458	406	304	22.167	4.322	0.291	29.13
13.5	1.000	1039.9	120	120	3.744	191	191	13.904	5.018	0.269	26.92

From Table 4 it can be noticed that the mass transfer zone (MTZ) and fractional bed utilization (FBU) decreases as the flow rate increases. From this it can be inferred that at lower flow rate high MTZ and FBU could be obtained. Hence it can be concluded that for better column performance lower flow rate has favoured.

Effect of phenol concentration

The breakthrough curves for different initial phenol concentrations are shown in Figure 5 and 6.

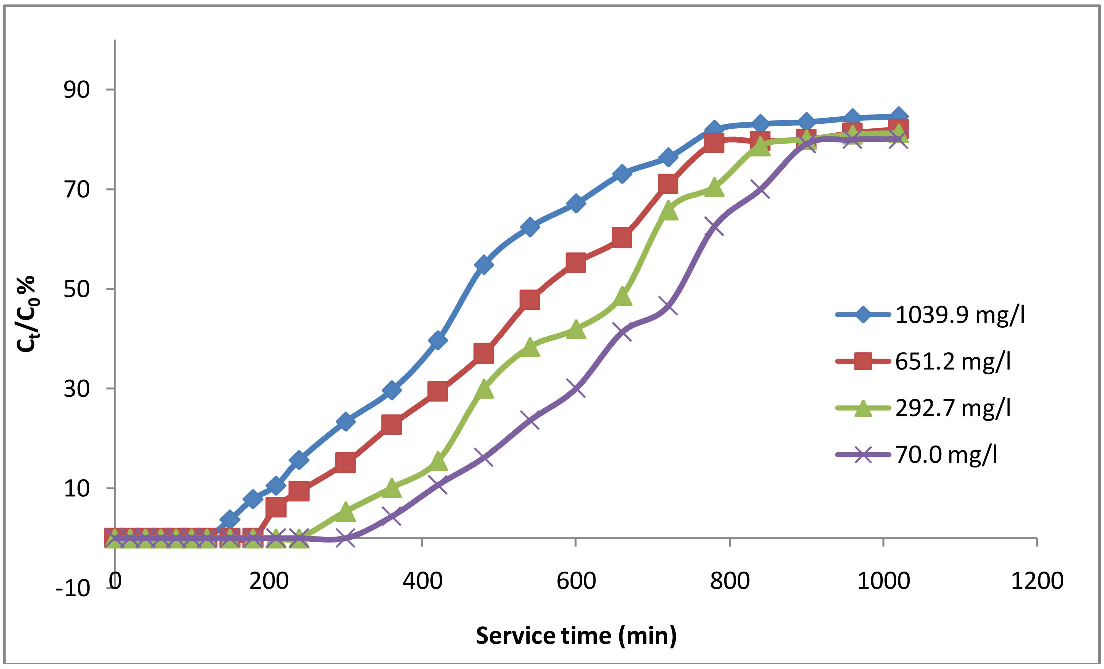

Fig. 5. Effect of phenol concentration on breakthrough curve. . (Amount of MCFA= 10 grams, Bed Height = 13.5 cm, Influent flow rate = 1.0 ml/min, Initial concentration C_0 = 70.0, 292.7, 651.2 and 1039.9 mg/L)

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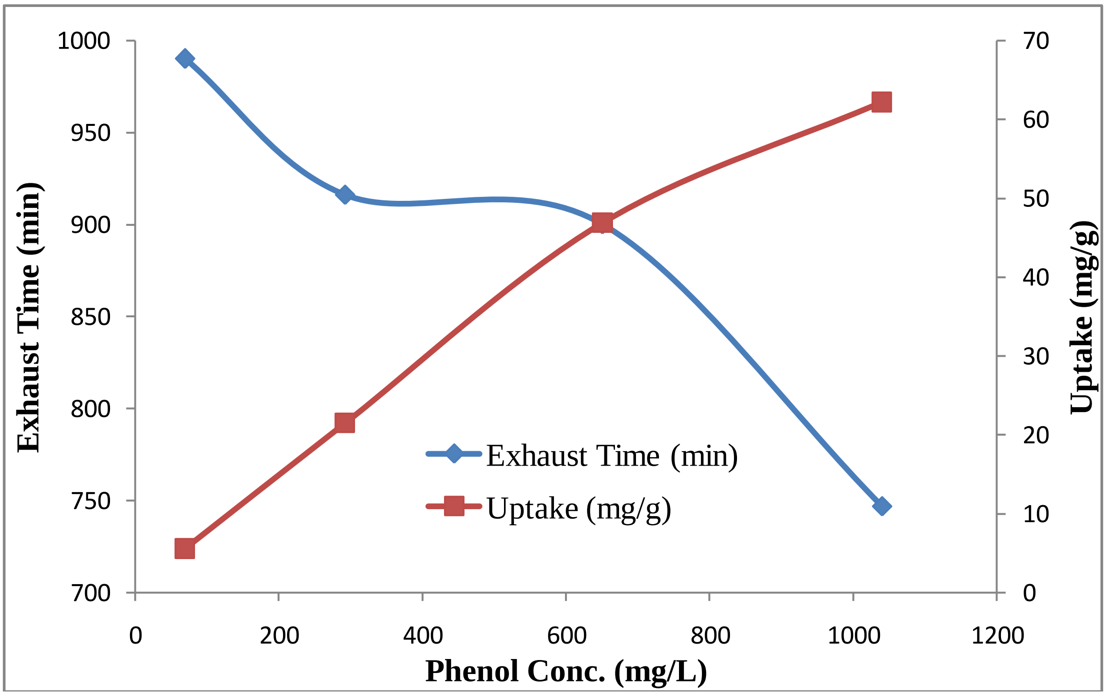

Fig. 6. Effect of phenol concentration on uptake and exhaust time. (Amount of MCFA= 10 grams, Bed Height = 13.5 cm, Influent flow rate = 1.0 ml/ min, Initial concentration C_0 = 70.0, 292.7, 651.2 and 1039.9 mg/L)

It was noticed from Figure 5 and 6 that the breakthrough time decreased with increasing concentration. It was observed form Table 5 that as concentration increases from 70.0 to 1039.9 mg/L, the breakthrough time decreases from 515 to 274 minutes for 20% breakthrough. This means that higher phenol inlet concentration saturates the MCFA particles more rapidly. As the concentration increased the breakthrough curves became steeper while the broader curves were obtained at lower concentration values. The slope of the curves increased at higher initial phenol concentration. This was due to the fact that the mass transfer driving force increases with increase in phenol concentration [11]. From these results it can be inferred that the change of concentration gradient influences the saturation rate and breakthrough time [11]. The steepness of curves determines the column efficiency to reach saturation. The steeper curves have longer mass transfer zone which is necessary for the better column performance. Hence it concludes that increase in phenol concentration increases the phenol uptake but decreases the exhaust time (Fig. 6).

Table 5: Column data and parameters obtained at different phenol concentration.

Operating parameters (Height, Flow rate, Phenol conc.)			Breakthrough points (b.p.)								
			0.2			**0.3**			**0.4**		
Z (cm)	F (ml/min)	C_0 (mg/L)	t_b (min)	V_{eff} (ml)	q_b (mg/g)	t_b (min)	V_{eff} (ml)	q_b (mg/g)	t_b (min)	V_{eff} (ml)	q_b (mg/g)
13.5	1.000	70.0	515	515	0.721	600	600	1.26	653	653	1.8284
13.5	1.000	292.7	439	439	2.569	480	480	4.214	570	570	6.6735
13.5	1.000	651.2	339	339	4.415	425	425	8.302	496	496	12.919
13.5	1.000	1039.9	274	274	5.698	365	365	11.38	422	422	17.553
Operating parameters (Height, Flow rate, Phenol conc.)			Breakthrough points (b.p.)								
			0.5			**0.7**			**0.8**		
Z (cm)	F (ml/min)	C_0 (mg/L)	t_b (min)	V_{eff} (ml)	q_b (mg/g)	t_b (min)	V_{eff} (ml)	q_b (mg/g)	t_b (min)	V_{eff} (ml)	q_b (mg/g)
13.5	1.000	70.0	733	733	2.565	840	840	4.704	990	990	5.5440
13.5	1.000	292.7	665	665	9.732	780	780	15.98	916	916	21.449
13.5	1.000	651.2	558	558	18.16	712	712	32.45	900	900	46.886
13.5	1.000	1039.9	430	430	22.35	569	569	41.41	747	747	62.150

The column data and parameters obtained at different initial phenol concentration are summarised in Table 5. As the initial phenol concentration increases breakthrough time and effective volume treated decreases but

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breakthrough adsorption capacity increases. This shows that at higher phenol concentration the driving force between adsorbate and adsorbent are less as compared to the lower phenol concentration. It can also be inferred that because of the concentration difference formed the adsorption capacity increases with increase in phenol concentration.

Table 6: Mass transfer zone (MTZ) and fractional bed utilization (FBU) obtained at different phenol concentration.

Operating parameters (Height, Flow rate, Phenol conc.)			**Breakthrough points (b.p.)**						Calculated parameters		
			0.2			**0.8**					
Z (cm)	F (ml/min)	C_0 (mg/L)	t_b (min)	V_{eff} (ml)	q_b (mg/g)	t_b (min)	V_{eff} (ml)	q_b (mg/g)	MTZ (cm)	FBU	% BU
13.5	1.000	70.0	515	515	0.721	990	990	5.544	6.4772	0.1300	13.00
13.5	1.000	292.7	439	439	2.569	916	916	21.449	7.0300	0.1198	11.98
13.5	1.000	651.2	339	339	4.415	900	900	46.886	8.415	0.0941	9.416
13.5	1.000	1039.9	274	274	5.698	747	747	62.150	8.5481	0.0916	9.169
Operating parameters (Height, Flow rate, Phenol conc.)			**Breakthrough points (b.p.)**						Calculated parameters		
			0.3			**0.7**					
Z (cm)	F (ml/min)	C_0 (mg/L)	t_b (min)	V_{eff} (ml)	q_b (mg/g)	t_b (min)	V_{eff} (ml)	q_b (mg/g)	MTZ (cm)	FBU	% BU
13.5	1.000	70.0	600	600	1.26	840	840	4.704	3.8571	0.267	26.78
13.5	1.000	292.7	480	480	4.214	780	780	15.981	5.1923	0.263	26.37
13.5	1.000	651.2	425	425	8.302	712	712	32.455	5.4417	0.255	25.58
13.5	1.000	1039.9	215	215	11.38	569	569	41.419	4.8400	0.274	27.48

From Table 6 it can be noticed that the mass transfer zone (MTZ) increases as the initial phenol concentration increases while fractional bed utilization (FBU) decreases. From this it can be inferred that at higher phenol concentration, high MTZ can be obtained but reduction in FBU was observed. Hence it can be concluded that for better column performance lower concentration is favoured to get the maximum utilisation of the packed bed.

CONCLUSION

Column experiments exhibits that at 13.5 cm bed height, 1.0 ml/min flow rate and 1039.9 mg/l phenol concentration at breakthrough point of 0.8, the bed attained maximum adsorption capacity of 67.724 mg/g. It was also observed that as the bed height increases, breakthrough time and bed exhaust time increases with the bed height but the slope of breakthrough curve decreased with increasing bed height; thus, it results in an extended mass transfer zone. The breakthrough curves became steeper and the slope of the breakthrough curve increase as the flow rate increases, hence better results are obtained at lower flow rate. The breakthrough time decreased with increasing initial phenol concentration. It was also observed that the breakthrough adsorption capacity increased as well as removal efficiency also increased with increase in initial phenol concentration.

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