Defence Science Journal, Vol. 55, No. 2, April 2005, pp. 117-123

SHORT COMMUNICATION

Dynamic Adsorptive Removal of Toxic Chemicals for Purification of Water

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ABSTRACT

To determine the efficiency of carbon column for the removal of toxic chemicals from water, the adsorption of phenol in concentration range from 0.600 g/l to 1.475 g/l was studied on active carbon of 80 CTC grade, 12 × 30 BSS particle size, 1280 m^2/g surface area, and of coconut shell origin, under dynamic conditions at space velocity from 0.318 min^{-1} to 4.24 min^{-1} at 25 °C. The carbon column of 100 cm length and 2 cm diameter was found to be removing phenol from the aqueous solution of concentration 1.475 g/l up to 84 min at 0.678 min^{-1} space velocity at 5.0 ppm phenol breakthrough concentration. However, no phenol was observed in carbon-treated water after 80 min. The service life of carbon column (100 cm length × 25 cm diameter) was assessed through the water purification system developed at the Defence Laboratory, Jodhpur and was determined to be 4.095 days with two as factor of safety for 10 ppm initial concentration of phenol at 0.678 min^{-1} space velocity (corresponding to water flow rate). Effects of carbon bed length, water flow rate, and the phenol concentration were also studied.

Keywords: Water purification, carbon-treated water, active carbon, carbon column, water contamination, potable water, adsorption, biological contaminants, chemical contaminants

1. INTRODUCTION

The purity of air and water is as important as their availability. Impure air and water can cause difficulties for sustaining life. Hence, it is necessary to purify both the water and air. However, ultra modernisation, the result of industrialisation and increased population have polluted both the air and the water which are the prime needs of life, alarmingly. As if it was not enough, there always exists the probability of contamination of air and water by over ambitious states and terrorist outfits. In the present scenario when most of the countries including USA are facing terrorism in one form or the other, it is essential to develop purification systems to meet eventuality, if any, that occurs.

One such indigenous system, the water purification system (pit) was developed by the Defence Laboratory, Jodhpur, for removing the biological and the chemical contaminants from the water. The system incorporates the membrane for reverse osmosis, and a carbon column to finally remove any traces of contaminants. This study was undertaken to determine the service life of carbon column and also check the efficiency of the system under dynamic conditions

Revised 18 May 2004

(at 0.678 min^{-1} space velocity corresponding to water flow rate through the water purification system developed). Phenol was used as a simulant of chemical agents of organic nature for dynamic adsorptive removal from the aqueous solution, as already reported[1].

The active carbon, due to its surface characteristics, removes the contaminants from polluted water streams by physically adsorbing these, and the surface characteristics vary from one carbon to another, this is the reason that this property of the carbon has been exploited by researchers continuously to use this for providing potable water by adsorptive removal of hazardous chemicals from the contaminated water. This method[2-4] has extensively been used due to high adsorption potential coupled with cost effectiveness. The removal of phenol by activated carbon was first reported by Honig[5], however, adsorptive removal was improvised by Rodrigeus[6], *et al.* for the adsorption of these compounds from industrial effluent in the 80-4000 mg/l concentration range over active carbon. Literature also reveals the use of phenol to simulate toxic chemicals[7]. The use of active carbon has been reported for the adsorption of soman (nerve agent) from aqueous solution by Eksanow[8], *et al.* However, the adsorptive removal of phenol from contaminated water under dynamic conditions has been reported to predict their service life against chemical warfare agents.

2. EXPERIMENTAL

2.1 Materials

Active carbon grade 80 CTC of surface area 1280 m^2/g, particle size 12×30 BSS of coconut shell origin was procured from M/S Active Carbon India Ltd, Hyderabad, India.

2.2 Chemicals

Phenol of 99 per cent purity, potassium bromate, potassium bromide, potassium iodide, starch, and sulphuric acid were procured from M/S E. Merck(I) Ltd.

2.3 Test Rig for Phenol Adsorption

The adsorptive removal of phenol was studied under dynamic conditions over carbon using test rig described in Fig. 1. The aqueous solution of phenol of known concentration was stored in a graduated reservoir and was passed through a carbon column of fixed diameter (2 cm) and varying bed lengths (30 cm to 100 cm) at a fixed flow rate attained under suction using vaccum pump, control valves (V_1 and V_2) and a rotameter. The float valve of rotameter was continuously monitored for its fixed position to ensure fixed flow rate (100–400 ml/min). To determine phenol breakthrough concentration and phenol breakthrough time, the carbon-treated water was collected in samplers S_1 and S_2 and using two-way valves at regular time intervals. The carbon-treated water collected in samplers S_1 and S_2 was analysed quantitatively for the phenol content. Each experiment was carried out in duplicate and the average values taken. The phenol in aqueous solution was estimated using bromate/bromide method[1].

The adsorptive removal of phenol was studied using the same test rig at different flow rates

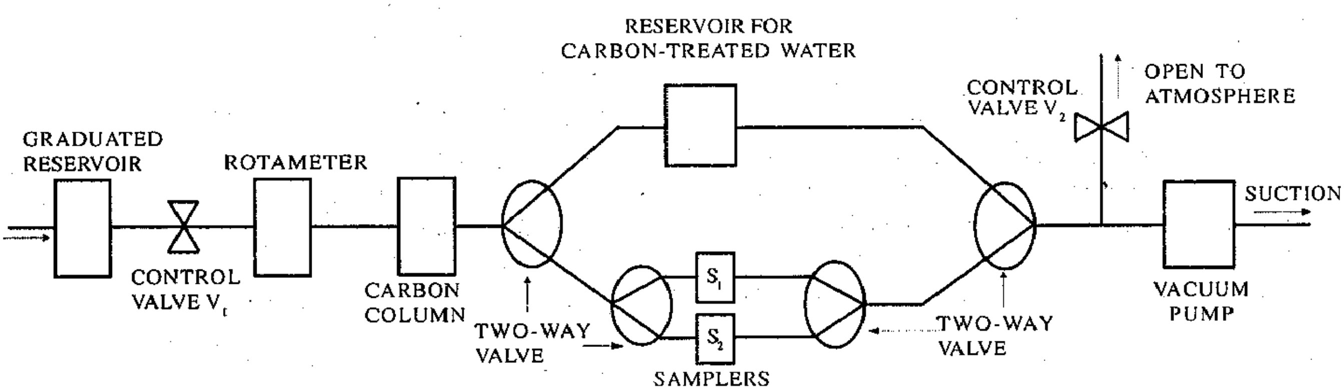

Figure 1. Schematic diagram of the test rig used for dynamic adsorption of phenol

Table 1. Phenol breakthrough time at 100 ml/min flow rate and initial concentration of 600 ppm to 1475 ppm

Bed length (cm)	Space velocity (min^{-1})	Phenol breakthrough time (min)			
		600 ppm conc	900 ppm conc	1200 ppm conc	1475 ppm conc
30	1.060	72	47	41.5	32
50	0.636	152	110	88.0	72
75	0.424	228	179	124.0	120
100	0.318	318	230	196.0	158

Table 2. Phenol breakthrough time at 200 ml/min flow rate and initial concentration of 600 ppm to 1475 ppm

Bed length (cm)	Space velocity (min^{-1})	Phenol breakthrough time (min)			
		600 ppm conc	900 ppm conc	1200 ppm conc	1475 ppm conc
30	2.12	35	19	16.0	13.0
50	1.273	86	58	45.0	34.5
75	0.848	142	104	76.5	65.0
100	0.636	195	143	116.0	91.5

(100–400 ml/min) and with the initial phenol concentrations (600–1475 ppm) in aqueous solution.

3. RESULTS & DISCUSSION

The adsorption of phenol on activated carbon grade 80 CTC was studied under dynamic conditions. The phenol breakthrough times for 5 ppm phenol breakthrough concentration were measured by monitoring phenol in the carbon-treated water at regular time intervals. The amount of phenol in the collected water was estimated using bromate/bromide method. The phenol breakthrough time was studied for carbon of different bed lengths at different flow rates for the initial concentration in the range 600–1475 ppm at 25 °C. The space velocity, ie, the volumetric feed-flow rate per unit of reactor, volume in chemical reactor was calculated for the studied reactor (carbon column) and the values presented in Tables 1 to 4. The results indicate that phenol breakthrough time decreased from 72 min to 8.5 min with an increase in the space velocity, from 1.06 min^{-1} to 4.24 min^{-1}at an initial phenol concentration of

Table 3. Phenol breakthrough time at 300 ml/min flow rate and initial concentration of 600 ppm to 1475 ppm

Bed length (cm)	Space velocity (min^{-1})	Phenol breakthrough time (min)			
		600 ppm conc	900 ppm conc	1200 ppm conc	1475 ppm conc
30	3.180	17	7.5	6.5	4.5
50	1.908	48	31.0	23.5	17.0
75	1.273	89	60.0	47.0	35.0
100	1.697	120	89.0	69.0	52.0

Table 4. Phenol breakthrough time at 400 ml/min flow rate and initial concentration of 600 ppm to 1475 ppm

Bed length (cm)	Space velocity (min^{-1})	Phenol breakthrough time (min)			
		600 ppm conc	900 ppm conc	1200 ppm conc	1475 ppm conc
30	4.240	8.5	2.5	2.0	2.0
50	2.546	27.5	16.5	12.5	8.0
75	1.697	55.0	35.5	29.5	18.5
100	1.273	72.5	56.0	41.0	29.5

600 ppm, which is quiet evident due to the fact that the higher flow rate (space velocity) allows less contact time between the adsorbate molecules and the adsorbent. However, for similar experimental conditions, the phenol breakthrough time got reduced from 318 min to 72.5 min for a higher-capacity carbon column (100 cm). This is quite obvious due to the role of dead layer of carbon column and more contact time in comparison to a smaller reactor. The data also indicate that phenol breaks through rapidly at higher concentration and space velocity.

To find the dead layer, bed length of carbon column was plotted against phenol breakthrough time (Figs 2 to 5). It can be inferred from these curves that for initial concentrations of phenol from 900 ppm to 1475 ppm, the dead layer of the carbon column became almost unchanged for a fixed flow rate except for 100 ml/min flow, but increased with the increased flow rates. The values were found to be 17.9 cm, 23.7 cm, and 28 cm at 200 ml/min, 300 ml/min, and 400 ml/min flow rates, respectively. Study indicated, however, varying dead layer of carbon column for 100 ml/min flow and 600 ppm concentration of phenol. Nevertheless, the dead layer was not more than 28 cm for any flow rate and phenol concentration. This data was used to design a carbon column for the water purification system and it was decided to have a carbon column of 100 cm (3.5 times more than 28 cm approx.)

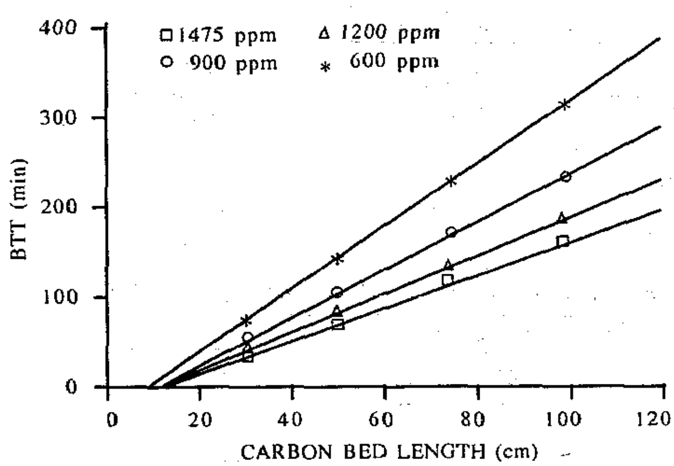

Figure 2. Effect of carbon bed length on phenol breakthrough time at 100 ml/min flow rate.

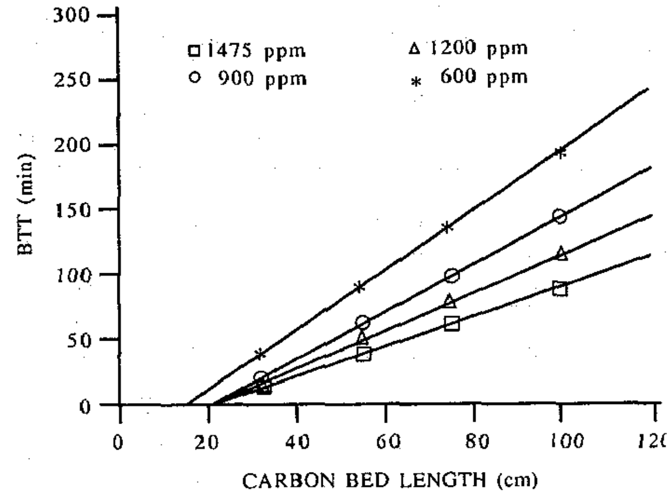

Figure 3. Effect of carbon bed length on phenol breakthrough time at 200 ml/min flow rate.

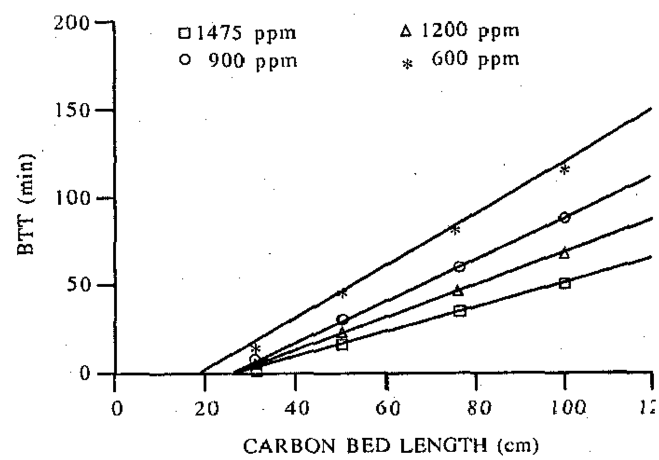

Figure 4. Effect of carbon bed length on phenol breakthroug time at 300 ml/min flow rate.

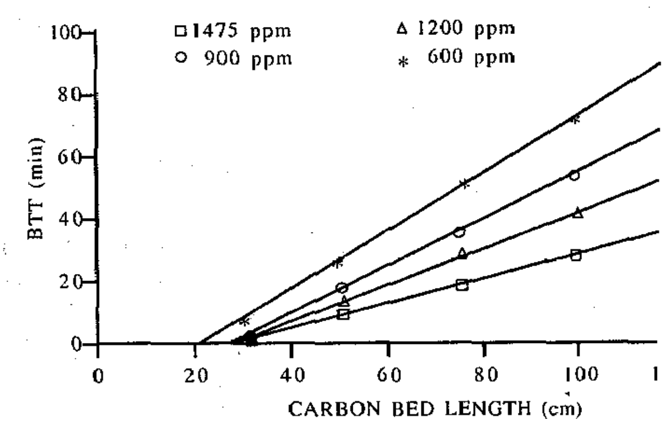

Figure 5. Effect of carbon bed length on phenol breakthrou time at 400 ml/min flow rate.

length and 25 cm diameter for better efficacy of the carbon column to remove the contaminants from the aqueous solutions. The phenol breakthrough time was determined for the corresponding flow rate (213 ml/min) for the carbon column (100 cm length×25 cm diameter) of water purification system using Fig. 6. It was found to be 84 min at space velocity of 0.678 min^{-1} for 1475 ppm initial concentration of phenol. Figure 7 shows the phenol breakthrough time for various initial concentrations of phenol, and it can be observed from the curves that at very low initial concentration, phenol breakthrough time values were very high. Figure 8 shows the phenol breakthrough profile, where at 1475 ppm initial concentration of phenol, no phenol breakthrough occurred up to 80 min at 213 ml/min (0.678 min^{-1} space velocity) flow rate. It can also be observed from Fig. 8 that phenol breakthrough concentration increases rapidly after the phenol breaks through (ie, 84 min), and attains almost maximum exit concentration within 1 h from the phenol breakthrough to become near-to-equal to the initial concentration of phenol.

To predict and calculate the service life of carbon column of the water purification system, contaminant concentration was found to be less than 10 ppm in the feed water, which could not be removed through reverse osmosis. Utilising this fact and the simple mathematical calculation, it can be predicted that the carbon column of water purification system can remove the pollutants (industrial or chemical warfare agents) up to 4.095 days with two as factor of safety , ie, the half of 8.19 days (80× 1475 / 10 min, assuming linear breakthrough behaviour, however, it is almost exponential (Fig. 7)

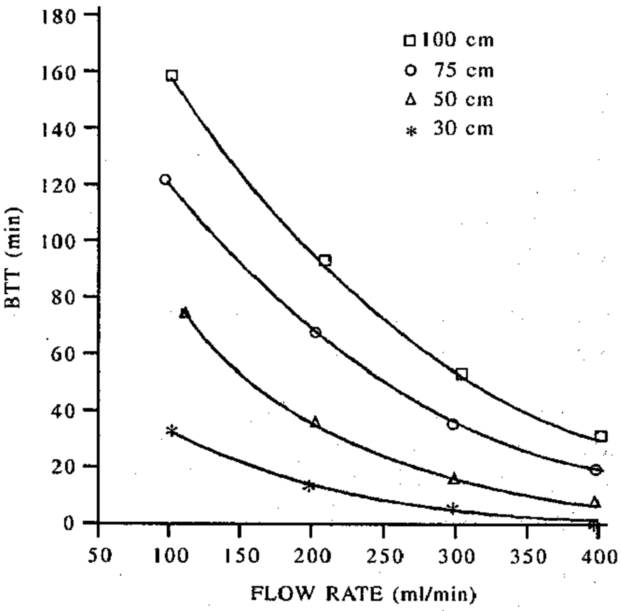

Figure 6. Effect of flow rates on breakthrough time at 1475 ppm phenol concentration.

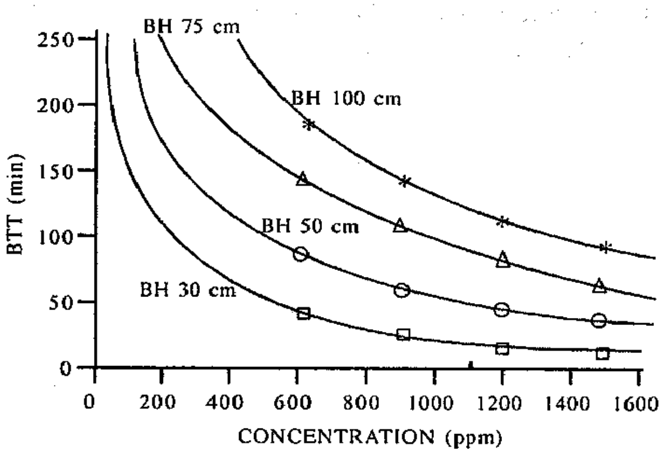

Figure 7. Effect of phenol concentration on breakthrough timeat 213 ml/min flow rate.

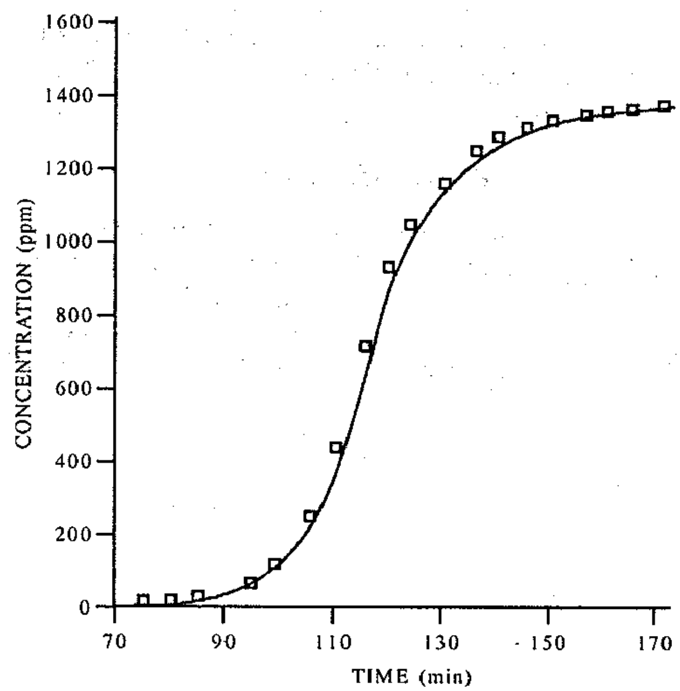

Figure 8. Phenol breakthrough profile at 1475 ppm concentration and 213 ml/min flow rate.

based on 80 min for no phenol breakthrough observed in carbon-treated water (Fig. 8). The service life of the carbon column of water purification system was calculated for contaminant concentration of 10 ppm, the service life, however, can be computed similarly for any initial concentration of the contaminant predetermined in the water obtained due to reverse osmosis for processing through a carbon column.

4. CONCLUSION

Adsorptive removal of phenol on activated carbon was studied in a binary mixture of adsorbate and water under dynamic conditions. Effect of carbon bed length, flow rate, and contaminant concentration was studied on phenol breakthrough time. At higher space velocity and contaminant concentration, phenol breakthrough time was found to be decreasing. A dead layer of the carbon column was found to be almost unchanged at higher concentrations of the contaminant, but was showing an increasing trend with the increase in flow rate except for 100 ml/min flow rate. Two as a factor of safety was considered for the prediction of service life of carbon column of the water purification system developed. The service life of the carbon column (100 cm length and 25 cm diameter) of water purification system was found to be 4.095 days for 10 ppm contaminants initial concentration at 0.678 min^{-1} space velocity.

ACKNOWLEDGEMENTS

The authors thank Shri K. Sekhar, Director, Defence Research and Development Establishment (DRDE), Gwalior for providing facilities to carry out this study and publish the results. Authors also thank Mr G.R. Khanwilkar for the preparation of the manuscript.

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