Adsorption Isotherm of O-cresol from Aqueous Solution by Granular Activated Carbon

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Abstract

Equilibrium adsorption isotherms of o-cresol from aqueous solution were investigated by a series of laboratory batch studies. Commercial Norit Granular Activated Carbon was used in order to evaluate the adsorption characteristic of o-cresol at different temperatures of 30, 38 and 48 °C. The effect of various initial concentrations (25-200 mg/l) and time of adsorption on o-cresol adsorption process were studied in details. The isotherm data were evaluated using Langmuir and Freundlich isotherms in order to estimate the monolayer capacity values of activated carbon used in the sorbate-sorbent system. The result reveals that the empirical Langmuir isotherm presents the observed data very well as compared to Freundlich isotherm. It was also found that the adsorption capacity of o-cresol was decreased with the increasing the adsorption temperature. The maximum adsorption capacity of 270 mg/g was obtained by o-cresol at temperature of 30 °C, 120 rpm and 24h of adsorption time.

Keywords:

Adsorption, O-cresol, Langmuir and Freundlich Isotherm Models, Activated Carbon

Introduction

Phenol and phenol derivatives are common organics contaminants in wastewater generated by refineries, paint industries, coking operation, coal processing and petrochemicals industries. The concentration of phenol and chlorinated phenols contains in the wastewater varies depends on the industries itself. It is around 750-1000 ppm phenol could be found in the wastewater stream of paint industry. There are many methods in removing phenolic substance from aqueous solution or wastewater namely photocatalytic degradation over ultraviolet irradiated TiO_2 [1], ozonation process [2], electro-catalytic oxidation [3], catalytic wet oxidation [4] and microbial degradation [5]. However, adsorption appears to be the most effective, especially for effluents with moderate and low concentration [6]. Various adsorbents have been used in adsorption process of phenolic compounds such as silicagel, zeolite molecular sieves, clays, polymeric adsorbent and many other agricultural based activated carbons [7-10]. All of these solid sorbents, activated carbons have been proved as one of the most effective adsorbent used in adsorption process. It has been employed to remove organics pollutant in water, wastewater and gaseous stream. The major advantage of activated carbon in adsorption process is that the solid adsorbent can easily separated from the treated liquid or gas streams [11]. Therefore this allows a flexible process operation for regeneration of adsorbent. Besides, activated carbons are complex and heterogeneous material with high adsorptive characteristics influenced by the porous structure, large surface area and chemical structure of the surface [12]. The adsorption capacity of activated carbon is also a function of porous structure, chemical nature of the surface and pH of aqueous solution [13].

The purpose of this present study was to investigate the adsorption behaviour of o-cresol from aqueous solution onto activated carbon. Laboratory batch studies were carried out experimentally to evaluate the adsorption capacity of activated carbon at temperatures of 30, 38 and 48 °C. Both Langmuir and Freundlich isotherm were put in trial to test their applicability for adsorption of o-cresol using activated carbon. The effects of adsorption time and initial concentration of adsorbate were studied in details.

Approach and Methods

The adsorbent used in this study was granular activated carbon 1240 manufactured by Norit (NAC 1240). This commercial activated carbon is produced by steam activation of selected grades of coal. Table 1 presents the important properties for NAC 1240 obtained by using autosorb.

Table 1 - Important properties of the NAC 1240

Property	Value
Multi-point BET, m^2/g	7.783×10^2
Langmuir surface area, m^2/g	1.503×10^3
Average pore diameter, nm	2.716

The activated carbon was washed several times with distilled water (DW) to remove carbon fines and dried at 110 °C for 24 hours. Then it was stored in a sealed bottle along with a silica gel to prevent the re-adsorption of moisture before use. O-cresol (>99%) was used as adsorbate and purchased from Merck, Germany.

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A concentration of 1000 mg/l stock solution of o-cresol was prepared in 1000 ml volumetric flask. Then the stock solution was dilute with deionized water without pH adjustment to yield various desired concentrations (25-200 mg/l) in 250 ml volumetric flask. Batch system laboratory test was conducted by adding a fixed amount of 0.20 g of adsorbent to a series of 250 ml glass-stoppered flasks filled with 200 ml diluted solutions. The glass-stoppered flasks were then placed in a thermostatic shaker bath and shaken at 120 rpm until it reached the equilibrium condition. The adsorption studies were carried out isothermally at different temperature of 30, 38 and 48 °C. The initial and equilibrium concentrations of all liquid samples were analyzed by means of Uv/Vis spectrophotometer (Shimadzu, UV-1601).

The amount of o-cresol adsorbed on activated carbon was calculated according to the following equation:

$$q_e = \frac{V(C_o - C_e)}{W} \qquad (1)$$

where C_o and C_e are initial and equilibrium liquid-concentration (mg/l), respectively, V is volume of solution (l) and W is weight of adsorbent (g).

Results and Discussion

Effect of Initial Concentrations

Figures 1-3 presents the adsorption data for the uptake of o-cresol on NAC 1240 versus time at equilibrium at temperatures of 30, 38 and 48 °C, respectively. It could be observed that lower initial concentrations of o-cresol (25 and 50 mg/l) have taken less time to reach the equilibrium stage as compared to the higher initial concentration of adsorbate. The equilibrium for NAC 1240 was attained within 15 hours for the initial solute concentration of 25 and 50 mg/l. The percentage of removal was up to 98.6%. Whereas for the higher initial concentrations, the adsorption time taken was almost 24 hours to approach an equilibrium condition. It could be seen that an increase in initial o-cresol concentration results in increased of o-cresol uptakes. The initial solute concentration provides an importance driving force to overcome all mass transfer resistance of o-cresol between aqueous and solid phase. The trend occurred because the resistance to the uptake of solute from the solution decreases with the increasing of solute concentration [14]. Hence, higher initial concentration of adsorbate enhances adsorption process with the result of higher interaction between o-cresol and the activated carbon.

Previous studies on adsorption process using activated carbon in removing phenolic compound have been carried out for wide range of initial concentration, time of adsorption by various types of adsorbents. Thus, it is quite difficult to compare the adsorption capacity in this present study to the others because of the differences in the working experimental condition. For example, in adsorption process of o-cresol, phenol and 3-chlorophenol from aqueous solutions on pinewoods based activated carbons at 30 °C, it

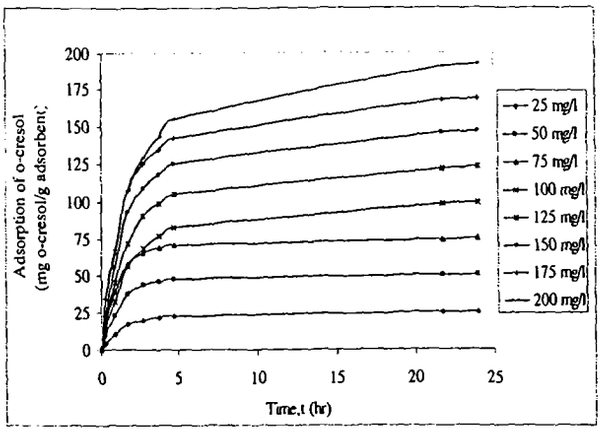

Figure 1 - Effect of initial concentrations on the adsorption of o-cresol on NAC 1240 at 30 °C

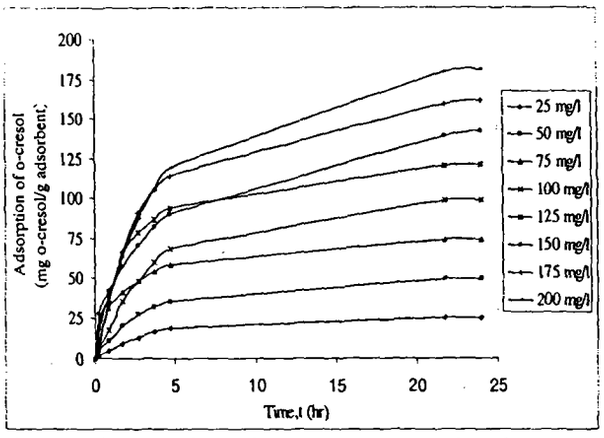

Figure 2 - Effect of initial concentrations on the adsorption of o-cresol on NAC 1240 at 38 °C.

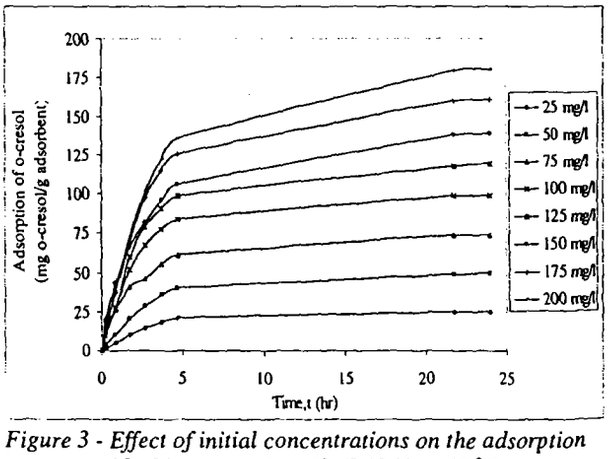

Figure 3 - Effect of initial concentrations on the adsorption of 3-chlorophenol on NAC 1240 at 48 °C

has been examined that the process attained equilibrium condition after 4 days [15]. The adsorption data of phenols were well described by the Freundlich model. However less adsorption time was required in removing of chlorophenols from aqueous solution using dye-affinity microbeads. It was observed that the equilibrium levels of chlorinated phenol

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were reached within 20 minutes [16]. Other finding found that the results obtained from a batch adsorption studied on commercial activated carbons without further treatment was fitted to the Freundlich equation after 1 hour of adsorption time of phenol and chlorophenols on granular activated carbons (GAC) [12].

Adsorption Isotherm

Correlation of isotherm data by theoretical or empirical equations reveals as common method to describe how solutes interact with adsorbents and very useful in optimizing the use of adsorbents. Figure 4 shows adsorption isotherm of o-cresol on activated carbon at temperatures of 30, 38 and 48 °C.

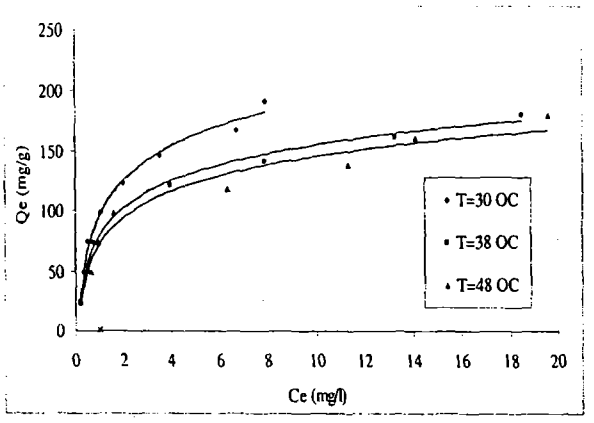

Figure 4 - Adsorption isotherm of o-cresol by NAC 1240 at different temperatures.

Langmuir Isotherm

Langmuir isotherm is presented by the following linear form of correlation:

$$\frac{1}{q_e} = \frac{1}{Q} + \frac{1}{bQ}\frac{1}{C_e} \qquad (2)$$

where, q_e is the isotherm amount adsorbed at equilibrium (mg/g), C_e is the equilibrium concentration of the adsorbate (mg/l), and Q (mg/g) and b (l/mg) are the Langmuir constants related to the maximum adsorption capacity and the energy of adsorption, respectively. These constants can be evaluated from the intercept and the slope of the linear plot of experimental data of $1/q_e$ versus $1/C_e$ as shown in Figure 5.

The essential characteristics of the Langmuir equation can be expressed in terms of a dimensionless separation factor, R_L, defined as [17]:

$$R_L = \frac{1}{(1+bC_o)} \qquad (3)$$

where, C_o is the highest initial solute concentration and b is the Langmuir's adsorption constant (l/mg).

The R_L value implies the adsorption to be unfavorable ($R_L>1$), linear ($R_L = 1$), favorable ($0 < R_L < 1$), or irreversible ($R_L = 0$). Values of R_L for NAC 1240 were found to be 0.009, 0.006 and 0.005 for temperatures of 30, 38 and 48 °C, respectively. Therefore, the present adsorption systems reveal favorable for the initial concentrations studied.

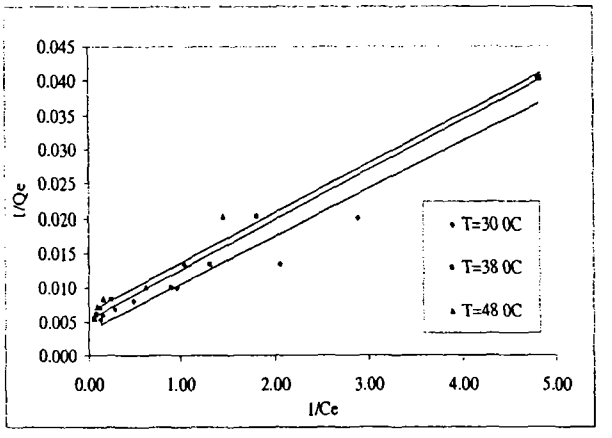

Figure 5 - Langmuir adsorption isotherm for o-cresol adsorption on NAC 1240 at different temperatures

Freundlich Isotherm Model

The linear form of the Freundlich isotherm model is given by the following equation:

$$\log q_e = \log K_F + \frac{1}{n}\log C_e \qquad (4)$$

where K_F, $(mg/g)(l/mg)^{1/n}$ and 1/n are Freundlich constants related to adsorption capacity and adsorption intensity of the sorbent respectively. The values of K_F and 1/n can be obtained from the intercept and slope, respectively, of the linear plot of experimental data of log q_e versus log C_e as shown in Figure 6.

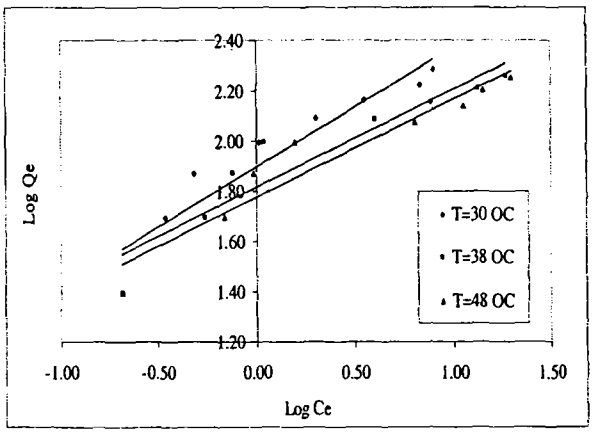

Figure 6 - Freundlich adsorption isotherm for o-cresol adsorption on NAC 1240 at different temperatures.

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Table 2 - Langmuir and Freundlich constants for the adsorption of phenol on different activated carbons

Temperature (°C)	Langmuir Isotherm Model			Freundlich Isotherm Model		
	Q	b	R^2	K_F	n	R^2
30	270.27	0.536	0.95	6.667	2.096	0.90
38	185.19	0.750	0.99	6.159	2.575	0.89
48	153.85	0.902	0.98	5.910	2.570	0.82

The adsorption data for all the temperatures studied are well described by both Langmuir and Freundlich models. However, Langmuir isotherm is found to represent the adsorption behaviour of o-cresol more closely than the Freundlich model. This could be observed by comparing the linear regression of both linear plots. It could be stated that the values of maximum adsorption capacity, Q decrease as the temperature increases. Greater adsorption of o-cresol is apparent for lower temperature. Thus, the adsorption process of o-cresol by NAC 1240 is found to be favorable at lower temperature.

Conclusion

The present study proved that NAC 1240 was capable to remove o-cresol from an aqueous solution up to 98 % of the initial solute concentration 25-100 mg/l for all the temperatures studied. The results showed that the time taken by the o-cresol to reach its equilibrium conditions was 15 hours for initial concentration of 25 and 50 mg/l while about 24 hours for initial concentration of 75-200 mg/l. The maximum adsorption capacity of o-cresol onto granular activated carbon was 270 mg/g at the temperature of 30 °C. The adsorption process was apparent at lower temperature. Langmuir isotherm model represents the adsorption data very well for the whole range of initial solute concentrations and temperatures studied.

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