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A Study of the Adsorption of Phenol by Activated Carbon from Aqueous Solutions

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A commercial active carbon was tested as an adsorbent for the removal of phenol from aqueous solutions. The optimum conditions for maximum adsorption in terms of shaking time, amount of the adsorbent, and concentration of the adsorbate were identified. The adsorption data fitted the Langmuir isotherm equation in the whole range of concentrations studied. The adsorption of picric acid, pyrogallol and salicylic acid at selected conditions for phenol was also studied. Elution studies to recover the adsorbed phenol from active carbon were performed with distilled water, NaOH and HCl solutions.

Key Words: Phenol, active carbon, adsorption and aqueous solutions

Introduction

Several techniques are currently under development for the production of synthetic fuel from coal. The waste solution generated from such coal conversion processes contains substantial amounts of phenol, i.e. 200-600 mg/l¹, which is discharged into natural water streams, contaminating the ground water. Phenol is considered to have toxic effects on human health even when present in small concentrations². The ingestion of such contaminated water in the human body causes protein degeneration, tissue erosion, and paralysis of the central nervous system and also damages the kidney, liver and pancreas². The threshold value of phenol in water is 4000 µg/l. Therefore, it is considered necessary to remove the phenol from industrial effluents before discharging into the water stream. The treatment of waste with active carbon is considered to be an effective method for the removal of phenol from waste solution because of its large surface area, micro-porous nature, high adsorption capacity, high purity and easy availability. Several investigators have studied the adsorption of phenol on active carbon³⁻⁸. In this communication, the efficiency of a commercial active carbon to remove the phenol from solutions was determined.

Experimental

A commercial active carbon (Riedel-de Haën, item No. 18001) was used as the adsorbent. Values of different parameters of this material have been determined previously using various physical methods⁹ and are given in Table 1.

Table 1. Measured values of different parameters of active carbon.

Parameter	Technique used	Measured value
pH	pH meter	6.8
Carbon content	Carbon analyzer	87.60%
Specific surface area (BET)	N ₂ gas adsorption	750 m ² /g
Porosity	Hg intrusion	60.30%
Pore volume	N ₂ adsorption	1.50 cm ³ /g
Bulk density	Powder density meter	0.23 g/cm ³
Tap density	Powder density meter	0.46 g/cm ³
True density	N ₂ adsorption	0.99 g/cm ³
Average particle size	Sub-sieve sizer	5 microns

The adsorption of phenol on active carbon was carried out using batch technique at room temperature ($22 \pm 1^\circ\text{C}$). Details of the adsorption procedure employed were similar to those described elsewhere¹⁰. The concentration of phenol in aqueous solution was measured by UV-visible spectrophotometer (Double beam, Shimadzu UV-160A) at wavelength 269 nm, except where otherwise specified. The percentage adsorption of phenol was computed in the usual way.

Results and Discussion

The dependence of phenol adsorption on shaking time was examined in the initial study. The study was performed by shaking 10 ml phenol solution of 0.01 g/l (pH 3.4) with 0.1 g of active carbon for different intervals of time ranging from 2 to 120 minutes. It was observed that the adsorption process is instantaneous and attained equilibrium within five minutes. Therefore, a shaking time of 10 minutes was selected for all further studies. The quick establishment of equilibrium indicates the high adsorption capacity of the active carbon for phenol.

Another parameter that controls adsorption is the amount of active carbon employed. Under the selected condition for shaking time (10 minutes), phenol concentration of 0.01 g/l, the amount of active carbon was varied from 0.02 to 0.14 g. Figure 1 indicates that the percentage adsorption increases as the amount of active carbon increases. At 0.1 g of active carbon, almost 99% phenol was recovered from solutions. Therefore, 0.1 g of active carbon was used in all subsequent studies. Figure 1 also indicates that even at 0.02 g of active carbon, the percentage adsorption is quite high, i.e. 94%.

The effect of phenol concentration on its own adsorption on active carbon was studied under optimum conditions of a shaking time of 10 minutes and 0.1 g of active carbon. The concentration of phenol was varied from 0.1 to 0.7 g/l. The results in Figure 2 show that the value of percentage adsorption up to 0.3 g/l of phenol concentration remained >99%. After that the value of percentage adsorption decreases as the concentration of phenol increases, indicating that less favorable sites became involved in the process with increasing concentration.

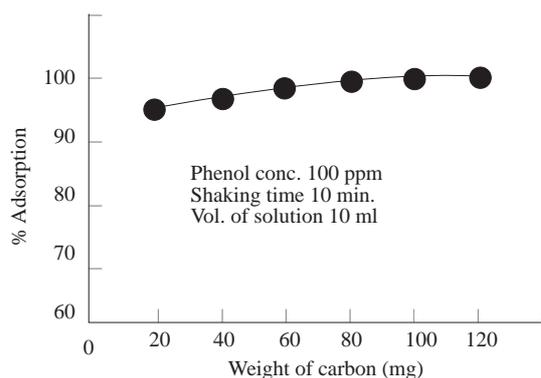


Figure 1. Influence of weight of active carbon on phenol adsorption

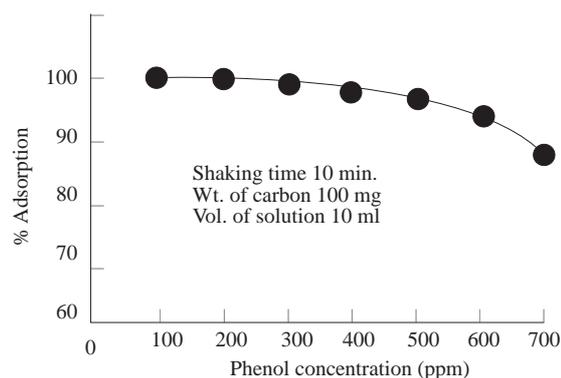


Figure 2. Effect of phenol concentration on its own adsorption on active carbon

The Freundlich and the Langmuir isotherm equations were used to study data concerning the dependence of the adsorption on the phenol concentration. The linearized form of the Freundlich's equation $\log X = \log A + 1/n \log C$ was applied to the data of Figure 2 and is depicted in Figure 3, where X is the amount of the phenol adsorbed per gram of the active carbon, C is the concentration of phenol (g/l) left in the solution, i.e. the final concentration, 1.n is the slope showing the variation of adsorption with concentration and A is the intercept, showing the adsorption capacity from solution of unit concentration. This figure demonstrates the non-validity of the equation over the whole range of concentrations studied.

The Langmuir equation was applied to the data of Figure 2 in the linear form $(C/X) = 1/KX + C/X_m$, where C and X have already been defined. X_m is the measure of monolayer capacity and K is the constant related to the heat of adsorption. A straight line is obtained by plotting (C/X) versus C (Figure 4), indicating the conformity of the data to the Langmuir equation in the concentration range studied. The value of correlation (r) for linear regression analysis comes out to be 0.9957.

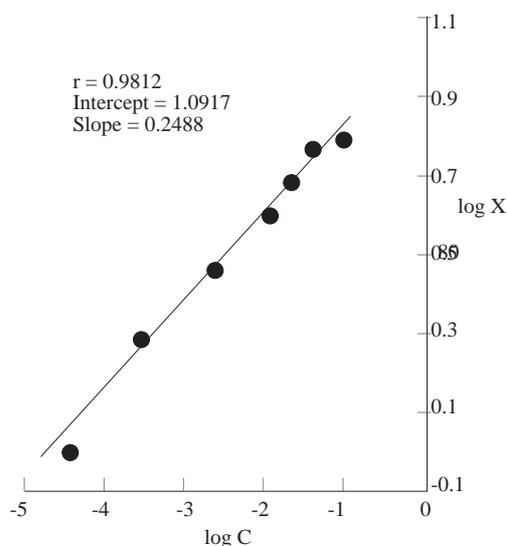


Figure 3. Freundlich plot for phenol adsorption on active carbon from aqueous solution

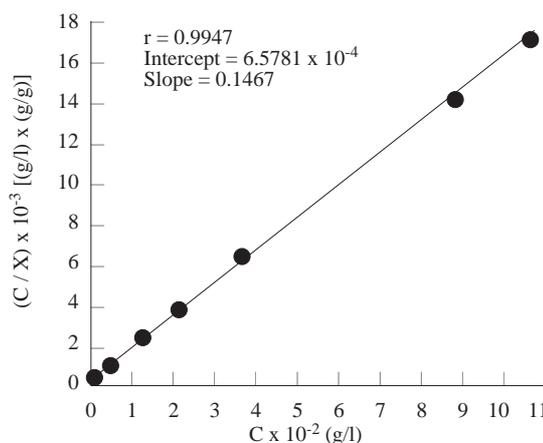


Figure 4. Langmuir plot for phenol adsorption on active carbon

Percentage adsorption of the other organic compounds (picric acid, pyrogallol, salicylic acid) was measured at the optimum adsorption conditions employed for phenol to check the selectivity of active carbon. The results presented in Table 2 indicate that these compounds show high values of percentage adsorption, and hence would be recovered along with phenol from aqueous solution by carbon.

Table 2. Measured values of the percentage adsorption of different organic compounds on active carbon at optimized conditions for phenol*.

Compound	λ_{\max} (nm)	% adsorption
Phenol	269	>99%
Picric acid	309	>99%
Salicylic acid	296	98.30%
Pyrogallol	267	88.20%

*Shaking time = 10 minutes; m/v ratio = 0.01 g/cm³

The feasibility of active carbon for the removal of phenol was assessed by elution studies. For such studies, a glass column (30 cm x 0.7 cm i.d.) containing a known amount of active carbon on a glass wool support was used. The column was loaded with a solution containing 0.1 g/l of phenol and kept for 10 minutes. More than 99.8% phenol was adsorbed on active carbon. The elution of adsorbed phenol was carried out with distilled H₂O, 0.5M NaOH and 0.1 M HCl. Figure 5 shows the elution profiles of phenol. The elution tendency as percentage recovery of phenol followed the sequence as

$$0.5\text{M NaOH (99\%)} > 0.1\text{M HCl (12\%)} > \text{distilled H}_2\text{O (6\%)}$$

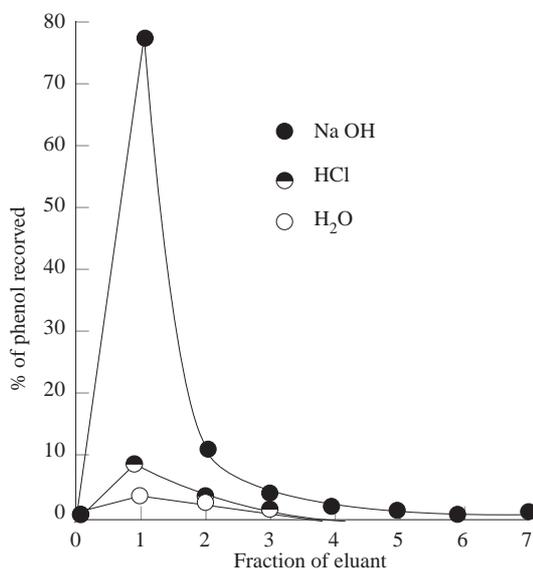


Figure 5. Elution profile of phenol recovery from active carbon

This observed trend may be due to the formation of ions. Phenoxide ions have more resonance energy than phenol itself due to no charge separation in the canonical structures as well as having negative charge on the more electronegative element, oxygen. Thus the ion is more stable in water. Therefore, it is expected that the adsorbed phenol should be eluted more easily with sodium hydroxide than with simple water. HCl can protonate the oxygen of phenol but the ion formed is less stable due to charge separation in the canonical

structures and positive charge on the more electronegative element (oxygen). However, the elution should be better than with water due to the ion formation, which should increase the solubility. In conclusion, sodium hydroxide should be a more suitable reagent for elution than acid or simple water. This effect was observed and shown in Figure 5. NaOH elutes 99%, while HCl only 12% and simple H₂O 6%.

Conclusion

On the basis of the data, it is concluded that active carbon can be used to remove phenol from aqueous waste solutions before discharging into the hydrosphere. The method is simple, economical, fast and requires no chemical treatment. Adsorbed phenol can be eluted and used as a raw material in different industries while active carbon column could be reused, thus no waste management problem arises.

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