Full Length Research Paper

Removal of phenol from aqueous solution by adsorption using zeolite

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The adsorption of phenol by sodium zeolite was investigated to assess its possible use as an adsorbent. The adsorption of phenol is found to be the most important problem being faced by many industries like textiles, pharmaceuticals, petrochemical industries etc. The optimum conditions for maximum adsorption in terms of pH (3 to 6), contact time, amount of the adsorbent and adsorbent equilibrium were identified. The Freundlich and Langmuir models were used for the mathematical description of adsorption equilibrium and it was found that the experimental data fitted very well to the Langmuir model. The results indicate that sodium zeolite can be employed as a low cost alternative to commercial adsorbent in the removal of phenol from aqueous solutions.

Key words: Phenol, adsorption, sodium zeolite, Freundlich, Langmuir.

INTRODUCTION

Phenol and substituted phenols are toxic organic pollutants commonly present in industrial waste streams especially in industrial wastewater from oil refineries, coal conversion plants, petrochemicals, polymeric resins, coal tar distillation, pharmaceuticals, etc. The effective removal of these pollutants from wastewater is a problem of great importance and interest. Great research efforts on adsorption processes and adsorbent materials for separating organic pollutants from waste streams have been developed.

The waste solution generated from coal conversion processes contains substantial amounts of phenol, that is, 200 to 600 mg/L (Singer and Sen, 1981), 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 concentrations (Knop and Pilato, 1985). 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 pancreas (Knop and Pilato, 1985). The threshold value of phenol in water is 4000 µg/L.

Human consumption of phenol contaminant water can cause severe pain leading to damage of the capillaries ultimately causing death. Their presence in water supplies is noticed as bad taste and odor (Mostafa et al., 1989). In fact, by 2001, the global phenol production has reached an impressive 7.8 million tons (Phenol, 2002). Normally, discharges from the aforesaid phenol-yielding industries find their way to water bodies and subsequently affect the water quality adversely. As per the studies by various authors, phenol and its derivatives have been reported to cause undesirable and deleterious effect in water, even at a concentration as low as 0.1 ppm (Mahajan, 1994). In fact, the adverse effects of phenol have been observed on the central nervous system, cardiovascular system as well as urino-genital systems of human being, often expressed by the multiple symptoms: convulsions, coma, cardiac disorders, respiratory failure and collapse (ATSDR, 1998). As per literature, the

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various analytic methods attempted for dephenolation of wastewater include steam stripping, solvent extraction, oxidation (O_3, H_2O_2, and ClO_2), ion exchange, biodegradation and adsorption methods (Lanouette,1977; Spiker et al., 1992; Srihari and Das, 2005). Out of all these, adsorption methods are the most-widely used techniques and activated carbon has been the predominant adsorbent all over the world (Mostafa et al., 1989; El-Geundi, 1997). However, due to its high cost and low regeneration capacity, since the last three decades, extensive researches have been directed towards investigating the adsorption characteristics and potentials of cheaper materials and solid wastes, such as fly ash, peat, soil, rice husk, sawdust, bagasse and so forth (Rengaraj et al., 2002; Street et al., 1995; Banat et al., 2000; Kummar et al., 1987).

Therefore, Environmental Protection Agency regulations call for lowering phenol content in wastewater to less than 1 mg/L (Dutta et al., 1992). There are many methods, such as, adsorption, microbial degradation, chemical oxidation, precipitation, ion exchange and solvent extraction to remove phenol from aqueous solution. Adsorption is an effective separation process for treating industrial and domestic effluents.

In another experiment, it was reported that the adsorption of phenol onto chitin was endothermic and increased with temperature (Dursun et al., 2005). The increase in active bentonites mass or initial pH of the solution also resulted in more phenol removal from solution (Asheh et al., 2003). Other adsorbents used to remove phenol from aqueous solution are bentonite (Banat et al., 2000), silica gel, activated alumina and activated carbon (Roostaei and Tezel, 2004), titanium oxide (TiO_2) (Bekkouche et al., 2004). Therefore, it is considered necessary to remove the phenol from industrial effluent before discharging into the water stream. Though bioaccumulation and biosorption are mainly preferred for this task as the phenols are easily biodegradable, adsorption onto sodium zeolite is also effective. In this study, sodium zeolite is used as an adsorbent to remove phenol from aqueous solution.

The objective of this study was to make use of the sodium zeolite as an adsorbent for adsorption of phenol, to characterize it and to investigate the effects of initial phenol concentration, contact time, pH and adsorbent dosage on the adsorption of phenol on sodium zeolite. Equilibrium isotherm data were fitted to the Langmuir and Freundlich equations.

MATERIALS AND METHODS

Experimental procedure

A commercially available sodium zeolite was used for these experiments and all the impurities and unwanted materials were removed as the adsorption. The adsorption of phenol on sodium zeolite was carried out using batch techniques at room temperature.

Effect of pH

The effect of pH on the amount of phenol removal was analyzed over the pH range from 3 to 9. In this study, 100 ml of phenol solution of different concentrations (100, 200, 300, 400, and 500 ppm) was taken in a stopper flask and was agitated with about 2.0 g of sodium zeolite using a shaker. Agitation is made for about 2 h at constant oscillation of about 150 osc/min. The pH is varied for each and every sample separately. The samples were then filtered using a filter paper and analyzed.

Contact time

About 100 ml of the phenol solution having concentration of about 100 ppm is taken in a stopper flask. About six samples of same concentration were taken and agitated with about 2.0 g of the adsorbent. Agitation was carried out at a constant oscillation of about 150 osc/min. The agitation of each sample was carried out for about 10, 20, 30, 40, 50, and 60 min, respectively. Then the sample was filtered and then analyzed. The above experiment is repeated for different concentrations (200, 300, 400, and 500 ppm).

Effect of adsorbent dosage

The effect of the sodium zeolite on the amount of removal of phenol solution was obtained by contacting 100 ml of the phenol solution of initial phenol concentration of 100 ppm with different weight of sodium zeolite in a stopper conical flask. Each sample was then agitated for about 40 min at a constant oscillation of about 150 osc/min. The samples were then filtered and then analyzed. The above experiment is repeated for different phenol concentrations and adsorbent amounts.

Adsorption equilibrium

The equilibrium studies is carried out by contacting 0.2 to 2 g of the adsorbent with 100 ml of phenol solution of different initial concentrations (100, 200, 300, 400, and 500 ppm) in stopper conical flasks. The samples were then shaken at a constant oscillation of 150 osc/min for about 40 min in a shaker. After the equilibrium is achieved, the concentrations of the samples were then analyzed.

RESULTS AND DISCUSSION

Effect of pH

The initial pH of adsorption medium is one of the most important parameters affecting the adsorption process. Figure 1 shows the effect of pH on the adsorption of phenol. It was observed that the uptake of the phenol by sodium zeolite was almost constant in the pH range of 3 to 6. Then the adsorption decreased with the increasing pH and it decreased from pH 7.0 to 9. So an optimum pH of about 5.0 is taken for all the other experiments.

Contact time
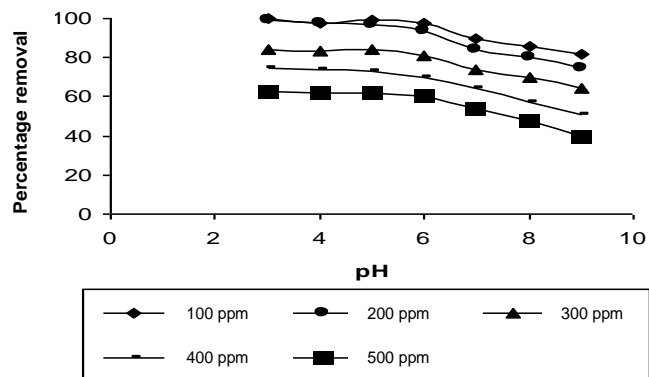
The result of the contact time experiments is shown in

Figure 1. Effect of pH on the adsorption of phenol.
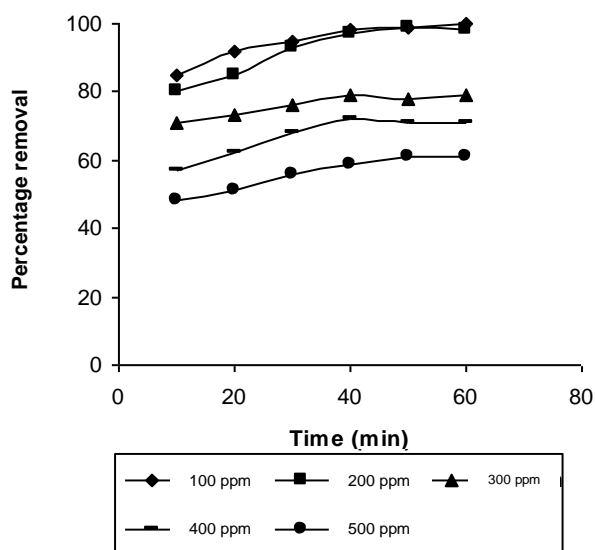

Figure 2. Effect of contact time on the phenol adsorption.

Figure 2. From the figure, it is clear that the optimum contact time for the experiment to be carried out is about 40 min above which the equilibrium is achieved and the adsorption remained constant above 40 min.

Effect of adsorption dosage

To investigate the effect of the mass of the adsorbent on the adsorption of phenol, a series of adsorption experiments was carried out with different adsorbent dosage at an initial phenol concentration of 100 mg/L. The percentage removal of the phenol increased with increasing adsorbent dosage. This can be attributed to increased adsorbent surface area and availability of more adsorption sites resulting from the increase adsorbent dosage as shown in (Table 1 and Figure 3).

Table 1. Effect of adsorption dosage.

ppm	Adsorbent dosage (g)	Percentage removal
100	0.8	96
	1.0	100
	1.2	100
200	1.8	93
	2.0	100
	2.2	99
300	2.8	96
	3.0	100
	3.2	100
400	3.8	94
	4.0	100
	4.2	99
500	4.8	96
	5.0	100
	5.2	100

Adsorption equilibrium

Equilibrium study on adsorption provides information on the capacity of the adsorbent. The study of adsorption was carried out using isotherm models of Freundlich (1906) and Langmuir (1916) using standard procedures used various authors (Rengaraj et al., 2002; Aksu and Yener, 2001; Mahvi et al., 2004) which provide the basis for the design of adsorption systems. The most widely used isotherm equation for modeling of the adsorption data is the Langmuir and Freundlich models. Figures 4 and 5 show the Langmuir and Freundlich curves for phenol adsorption onto sodium zeolite, respectively. It was observed that the equilibrium data were very well represented by the Langmuir isotherm equation when compared to the Freundlich equation. The adsorption data fitted Langmuir and Freundlich equations with correlation coefficients value of 0.9988 and 0.9440, respectively. The best fit of equilibrium data in the Langmuir isotherm expression predicted the monolayer coverage of phenol onto sodium zeolite from Table 1, and it was also observed that the maximum adsorption capacity of sodium zeolite was found to be 13.051 mg/L.

Conclusion

In this study, adsorption of phenol from aqueous solution was investigated using sodium zeolite as an adsorbent. The results indicated that adsorption capacity of the
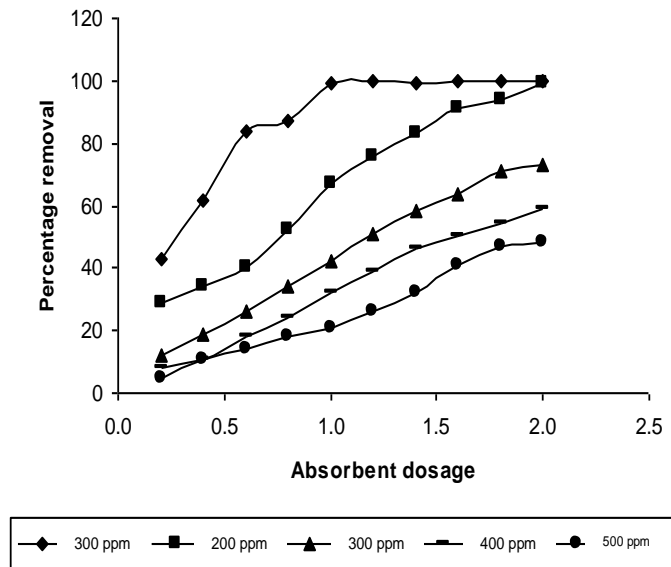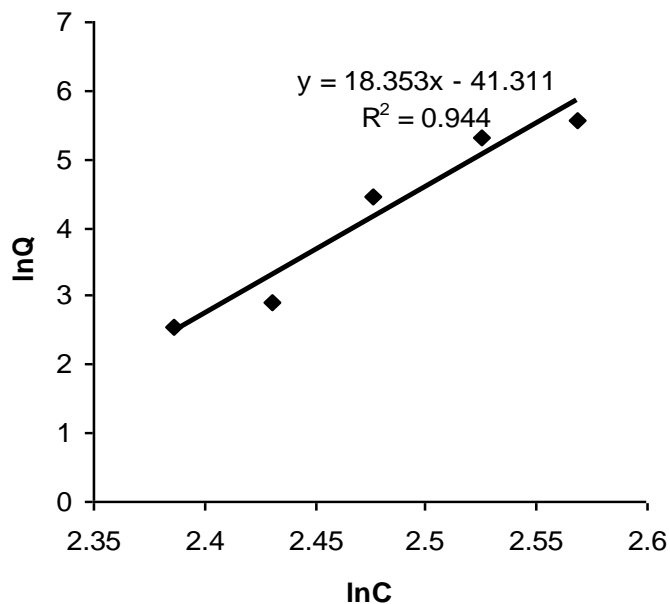
Figure 3. Adsorption equilibrium.

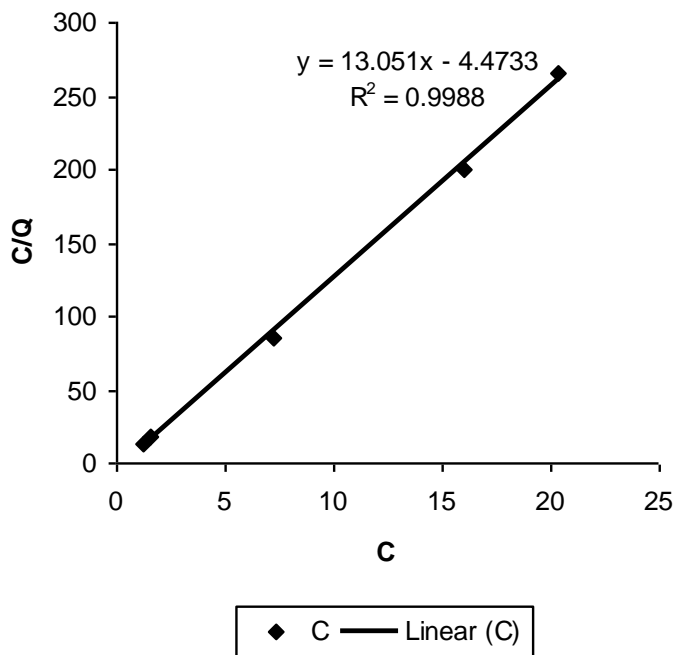**Figure 5.** Freundlich isotherm.

Figure 4. Langmuir isotherm.

adsorbent was considerably affected by initial pH, contact time, and adsorbent dosage. The result also indicated that the uptake of phenol took place at a pH range of 3 to 6. Then the adsorption of phenol decreased with increasing pH. Equilibrium data fitted well in a Langmuir isotherm equation, confirming the monolayer sorption capacity of phenol onto sodium zeolite with a monolayer sorption capacity of 13.051 mg/L.

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