

Uptake of phenol from aqueous solution by burned water hyacinth

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The potential of burned water hyacinth (BWH) for phenol adsorption from aqueous solution was studied. Batch kinetic and isotherm studies were carried out under varying experimental conditions of contact time, phenol concentration, adsorbent dosage and pH. The pH at the point of zero charge (pH_{PZC}) of the adsorbent was determined by the titration method and the value of 8.8 ± 0.2 was obtained. The FTIR of the adsorbent was carried out in order to find the potential adsorption sites for the interaction with phenol molecules. The Freundlich and Langmuir adsorption 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. Maximum adsorption capacity of the adsorbent was found to be 30.49 mg/g. Batch adsorption models, based on the assumption of the pseudo-first-order and pseudo-second-order models, were applied to examine the kinetics of the adsorption. The results showed that kinetic data closely followed the pseudo-second-order model.

Keywords: Phenol, Adsorption, Burned water hyacinth, Equilibrium, Adsorption Kinetics.

INTRODUCTION

Phenols are common contaminants in wastewater generated from oil, gasoline, coal, paper, textile, petroleum, petrochemicals, pharmaceuticals, phenol producing industries and plants, which are processing phenols to plastics. They are considered to be one of the priority pollutants in wastewater, because they are harmful to organisms even at low concentrations. Many phenols have been classified as hazardous pollutants because of their potential toxicity to human health. Human consumption of phenol contaminant water can cause severe pain leading to the damage of the capillaries, ultimately causing death. Its presence in water supplies is noticed as bad taste and odor¹. In the presence of chlorine in drinking water, phenols form chlorophenol, which has a medicinal taste and which is quite pronounced and objectionable. Therefore, Environmental Protection Agency regulations call for lowering phenol content in wastewater to less than 1 mg/L².

There are many methods, such as, adsorption, microbial degradation, chemical oxidation, precipitation, ion exchange and solvent extraction to remove phenols from the aqueous solution. Adsorption is an effective separation process for treating industrial and domestic effluents. Activated carbon is the most widely used adsorbent. It has the advantage of high adsorption capacity for organic compounds, but its use is usually limited due to its high cost³⁻⁵.

The adsorption characteristics of phenol on various adsorbents have previously been extensively investigated for many purposes of separation and purification. However, most of the work regarded the adsorption behavior of the activated carbon. The adsorption of phenol from the aqueous solution by using carbonized beet pulp was investigated⁶. The result indicated that the adsorption capacity of the adsorbent was considerably affected by the initial pH, temperature and the initial phenol concentration. The equilibrium data were well described by the Freundlich model and the pseudo-second-order equation provided the better correlation for the adsorption data. In another experiment, it was reported that the adsorption of

phenol onto chitin was endothermic and increased with temperature⁷. The increase in active bentonites mass or the initial pH of the solution also resulted in the more significant phenol removal from the solution⁸. It was also indicated that peat, fly ash and bentonite were found to adsorb 46.1%, 41.6% and 42.5% phenol, respectively, from the solution of the initial concentration of approximately 1 mg/L⁹. Other adsorbents used to remove phenol from the aqueous solution are bentonite¹⁰, silica gel, activated alumina and activated carbon¹¹, titanium oxide (TiO_2)¹², activated carbon derived from solid waste such as PET, waste tires, refused derived fuel and waste generated during lactic acid fermentation from garbage¹³, powdered and granular activated carbon prepared from Eucalyptus wood¹⁴, mesoporous activated carbon prepared from waste tires¹⁵, aspergillus niger biomass¹⁶, pumice¹⁷ and papermill sludge¹⁸.

Water hyacinth (WH) is available in the river and pond in Bangladesh. It grows and reproduces at a very high rate and is considered the worst aquatic plant¹⁹. The dense mats of WH float on the water surface, blocking navigation and interfere with irrigation, fishing, recreation, and power generation. These mats also prevent sunlight penetration and reduce the aeration of water, leading to oxygen deficiency, competitively exclude submerged plants, and reduce biological diversity. The control of WH invasion, mainly by mechanical collection and dumping is expensive and presents a solid waste problem to get rid of the WH dumps. Much research has been conducted in efforts to find application for the dumped WH. This includes the research on biogas generation²⁰, fish feed¹⁹ and animal feed²¹.

In this study, burned water hyacinth (BWH) is used as an adsorbent to remove phenol from aqueous solution. The objective of this study was to produce burned water hyacinth as an adsorbent for the adsorption of phenol and to investigate the effects of initial phenol concentration, contact time, pH and adsorbent dosage on the adsorption of phenol on burned water hyacinth. The pH_{PZC} of the adsorbent was determined by the titration method. The equilibrium isotherm data were fitted to Langmuir and

Freundlich equations and constants of isotherm equations were determined. Adsorption kinetics of phenol onto burned water hyacinth was also analyzed by using the pseudo-first-order and pseudo-second-order models to the data.

MATERIALS AND METHODS

Materials

The water hyacinth was collected from the local ponds. The roots of the collected water hyacinth were separated and washed thoroughly with water for several times to remove the earthy matter and all the dirt particles. It was then dried in an oven at the temperature of 105°C for about 16 hours. The dried roots were then burned at 300°C. The remaining was then ground and sieved to the particle size of 180 – 300 μm , and stored in a plastic bottle for use as the adsorbent.

Chemicals

A stock solution of 1000 mg/L phenol was prepared by dissolving 1.0 g of the analytical reagent grade phenol (Sigma Chemical Co., Germany) in 1 L distilled water. The test solution of desired concentration was then prepared by diluting the stock solution. The pH of the solution was adjusted to the required value ($\text{pH } 6 \pm 0.5$) with 0.1N HCl and 0.1 N NaOH solutions before mixing with the adsorbent. While there was no significant change observed on pH in the equilibrium, the uptake pH was assumed constant during the experiments.

Sorption experiments

Determination of pHPZC of the adsorbent

The surface charge (Q) and the pH_{PZC} of the adsorbent in the aqueous phase were analyzed with different system pH values by using the titration method described elsewhere²². 0.1 g adsorbent was taken in 50 ml 0.1 M KNO_3 solution and agitated with a magnetic stirrer. Then the pH of the solution was measured after the equilibrium time of 30 minute. The titration was carried out with 0.1 M NaOH and 0.1 M HCl, respectively.

Fourier transform infrared spectroscopy (FTIR) analysis

Fourier transform infrared spectroscopy (FTIR) of the adsorbent was conducted by using the FTIR spectrophotometer (Model: FTIR 2000, Shimadzu, Kyoto, Japan). About 150 mg KBr disks containing approximately 2% of JLP samples was prepared shortly before recording the FTIR spectra in the range of 400 – 4000 cm^{-1} and with a resolution of 4 cm^{-1} . The resulting spectra were the average of 30 scans.

Effect of pH

The effect of pH on the amount of phenol removal was analyzed over the pH range of 2.5 – 12. In this study, 150 ml of phenol solution of 50 mg/L was taken in the stopper plastic conical flask and was agitated with 1.0 g of BWH using the flash shaker (Stuart Scientific Co. Ltd. Model SF1, U.K.) at room temperature ($27 \pm 2^\circ\text{C}$). Agitation was made for 5 h at constant oscillation of 500 osc/min. The samples were then centrifuged, and the left out concentrations in the supernatant solutions were analyzed using the spectrophotometric method. Phenol at alkaline condition ($\text{pH } 7.9 \pm 0.1$) reacts with potassium

ferricyanide and 4-aminophenazone to form a red colored complex. The absorbance of the complex at a maximum wavelength of 505 nm is a direct measurement of phenol concentration. The solution was made alkaline to develop color by the concentrated ammonia solution.

Each experiment was repeated three times and the average value of the measured phenol was plotted. The deviation of each measurement was less than 2% from the average value.

Effect of adsorbent dosage

The effect of BWH mass on the amount of removal of phenol solution was obtained by contacting 150 ml of phenol solution of the initial concentration of 70 mg/L with different weighed amount (0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, and 1.6 g) of BWH in the stopper conical flask. Each sample was then agitated for 5 h at a constant oscillation of 500 osc/min. The samples were then centrifuged and the concentrations in the supernatant phenol solutions were then analyzed as before.

Adsorption equilibrium

Equilibrium studies were carried out by contacting 0.75g of BWH with 150 ml of phenol solution of different initial concentrations (40, 50, 60, 70, 80, 90, 100 and 110 mg/L) in 250 ml stopper conical flasks. The samples were then shaken at a constant oscillation of 500 osc/min for 5 h at $27 \pm 2^\circ\text{C}$. After equilibrium the concentrations in the samples were analyzed as before.

Adsorption kinetics

Sorption kinetics experiments were carried out by contacting 200 ml phenol solution of different initial concentrations ranging from 50 to 70 mg/L with 0.5 g BWH in a 250 ml stoppered conical flask. The samples were then shaken at a constant oscillation speed of 500 osc/min for 5 h. Samples were then pipetted out at different time intervals. The collected samples were then centrifuged and the concentration in the supernatant solution was analyzed as before.

RESULTS AND DISCUSSIONS

Determination of pH_{PZC} of the adsorbent

The surface charge Q of the adsorbent was calculated from the experimental titration data according to the following equation²².

$$Q = \frac{1}{w} (C_A - C_B - [H^+] - [OH^-]) \quad (1)$$

where, w – dry weight of adsorbent in aqueous system (g L^{-1}); C_A is the concentration of added acid in the aqueous system (mol/L); C_B is the concentration of the added base in the aqueous system (mol/L); $[H^+]$ is the concentration of H^+ (mol/L); $[OH^-]$ is the concentration of OH^- (mol/L). Then the pH value at the point of zero charge was determined by plotting Q versus pH. Fig.1 shows the surface charge of the adsorbent as a function of pH. From Fig. 1 it is obvious that the surface charge of the adsorbent at $\text{pH } 8.8 \pm 0.2$ is zero. Hence the pH_{PZC} of the BWH is 8.8 ± 0.2 .

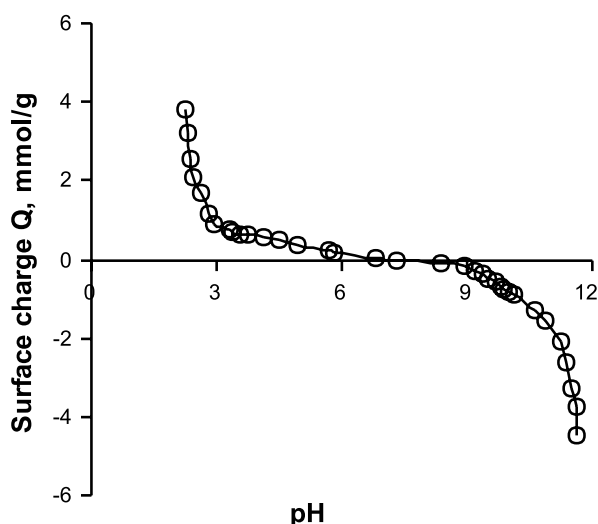


Figure 1. Surface charge of the adsorbent as a function of pH

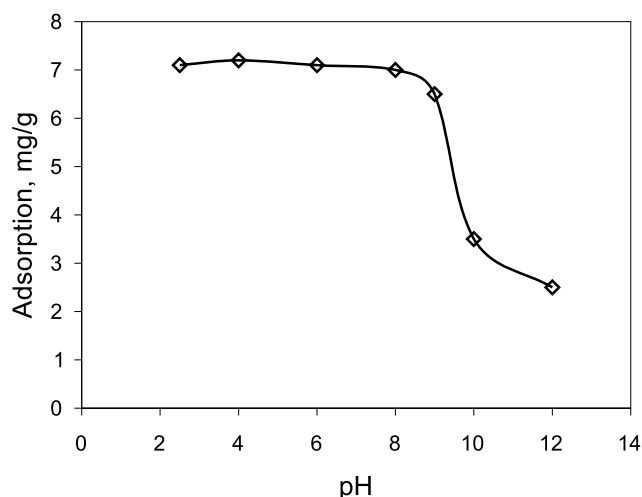


Figure 2. Effect of pH on the adsorption of phenol onto burned water hyacinth (Initial concentration $C_0 = 50$ mg/L, Volume of solution $V = 150$ ml, Amount of adsorbent $M = 1.0$ gm, Temperature $= 27 \pm 2^\circ\text{C}$)

Effect of pH on phenol adsorption

The initial pH of adsorption medium is one of the most important parameters affecting the adsorption process. Fig. 2 shows the effect of pH on the adsorption of phenol. From Fig. 2, it was observed that the uptake of phenol by BWH was almost constant in the pH range of 2.5 – 9. When pH exceeded 9, the removal dropped suddenly. This can be attributed to the dependency of phenol ionization on the pH value and point of zero charge (PZC) for BWH. Fig. 3 shows, the FTIR spectrum of BWH. As seen from the figure, BWH contains several functional groups such as hydroxyl peak at 3410 cm^{-1} and asymmetric carboxylate peak at 1622 cm^{-1} . The peaks observed at 1110 cm^{-1} could be assigned to C–O stretching of ether groups.

The pH primarily affects the degree of ionization of phenol and the surface properties of BWH. The ionic fraction of phenolate ion (ϕ_{ions}) can be calculated from the following equation¹⁸:

$$\phi_{ions} = \frac{1}{1 + 10^{pK_a - pH}} \quad (2)$$

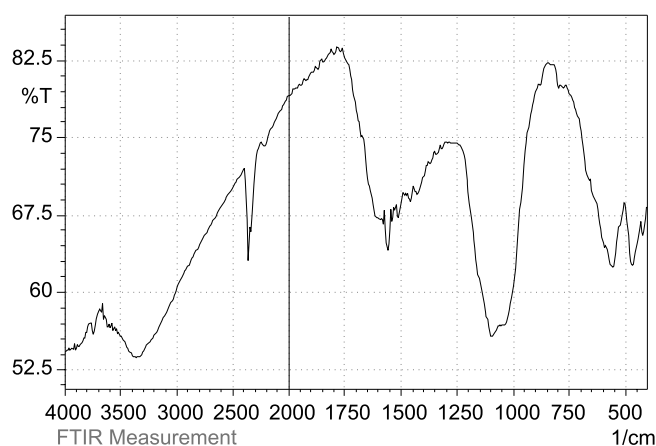
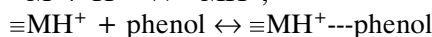
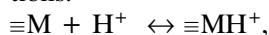
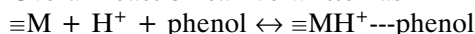


Figure 3. The FTIR spectra of burned water hyacinth

Obviously, ϕ_{ions} increases as the pH value increased. Considering pK_a of 9.89 of phenol, it is present in a molecular form, which has polar characteristic, in the aqueous phase when pH is less than 9, however, it is present in the form of the phenolate ion when the pH of the equilibrium solution is higher than 9.89. The pH_{pzc} at the point of zero charge of BWH is about 8.8 ± 0.2 (Fig. 1). At pH values above pH_{pzc}, the surface of BWH particles is negatively charged. Therefore, phenol will be adsorbed to a lesser extent at pH above pH_{pzc} due to the repulsive forces between phenolate ion and the negatively charged surface of the adsorbent due to COO^- groups and deprotonated hydroxyl groups. At pH below pH_{pzc}, polar phenol molecules can be adsorbed on the protonated surface of the adsorbent according to the following equations:



Overall reaction can be written as



where M is the adsorbent.

Effect of contact time and initial concentrations

The adsorption data for the uptake of phenol versus contact time at different initial concentrations is presented in Fig. 4. The results showed that the equilibrium time

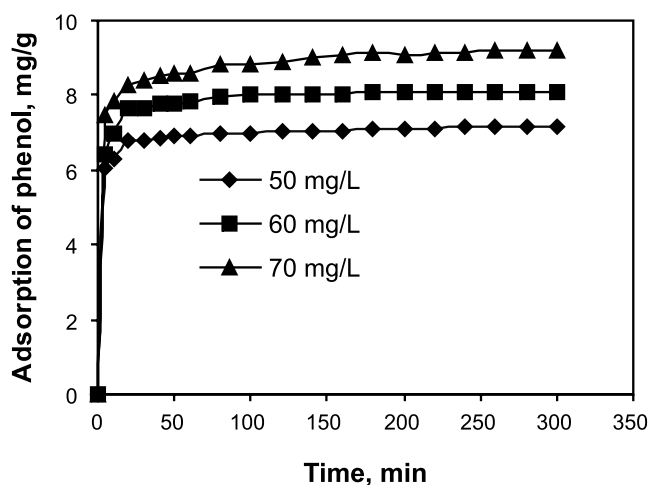


Figure 4. Effect of contact time and initial concentrations on the adsorption of phenol onto burned water hyacinth (Initial concentration $C_0 = 50, 60$ and 70 mg/L, pH $= 6 \pm 0.5$, Volume of solution $V = 200$ ml, Amount of adsorbent $M = 0.50$ gm, Temperature $= 27 \pm 2^\circ\text{C}$)

required for the adsorption of phenol on BWH was almost 120 minutes (2 h). However, for subsequent experiments, the samples were left for 5 h to ensure equilibrium. These results also indicated that up to 90 – 95% of the total amount of phenol uptake was found to occur in the first rapid phase (30 min) and thereafter the sorption rate was found to decrease. The higher sorption rate at the initial period (first 30 min) may be due to an increased number of vacant sites on the adsorbent available at the initial stage, as a result there exist increased concentration gradients between the adsorbate in the solution and the adsorbate on the adsorbent surface. This increase in concentration gradients tends to increase in phenol sorption at the initial stages. As time precedes this concentration is reduced due to the accumulation of phenol particles in the vacant sites leading to a decrease in the sorption rate at the later stages from 30 to 300 min²³. It was also seen that an increase in initial concentration resulted in increased phenol uptake.

Effect of adsorbent dosage

In order to investigate the effect of mass of adsorbent on the adsorption of phenol, a series of adsorption experiments was carried out with different adsorbent dosage at an initial phenol concentration of 70 mg/L. Fig. 5 shows

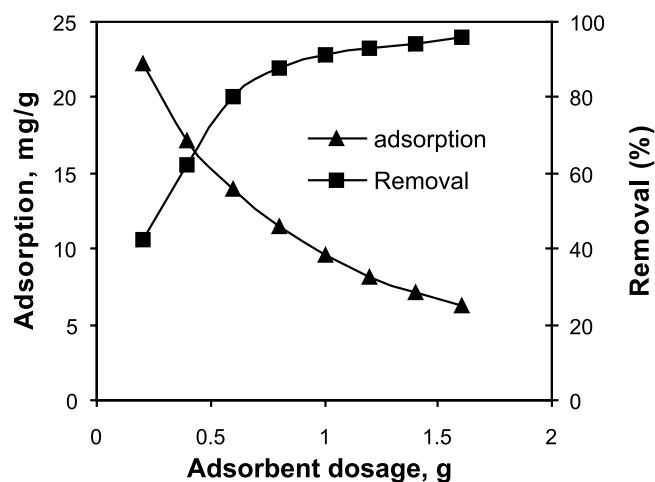


Figure 5. Effect of adsorbent dosage on the adsorption of phenol onto burned water hyacinth (Initial concentration $C_0 = 70$ mg/L, pH = 6 ± 0.5 , Volume of solution $V = 150$ ml, Temperature = $27 \pm 2^\circ\text{C}$)

the effect of adsorbent dosage on the removal of phenol. The percentage removal of phenol increased with the increase in adsorbent dosage. This can be attributed to increased adsorbent surface area and availability of more adsorption sites resulting from the increase adsorbent dosage. But the amount of phenol adsorbed per unit mass of BWH decreased with increase in the adsorbent dosage.

Adsorption equilibrium

Equilibrium study on adsorption provides information on the capacity of the adsorbent. An adsorption isotherm is characterized by certain constant values, which express the surface properties and affinity of the adsorbent and can also be used to compare the adsorptive capacities of the adsorbent for different pollutants. Equilibrium data can be analyzed using the commonly known adsorption isotherms, which provide the basis for the design of adsorption systems. The most widely used isotherm equation for the modeling of the adsorption data is the Langmuir equation, which is valid for monolayer sorption onto the surface with a finite number identical site and is given by eq. (3).

Where q_0 and K_L are Langmuir parameters related to maximum adsorption capacity and free energy of adsorption, respectively. C_e is the equilibrium concentration in the aqueous solution and q_e is the equilibrium adsorption capacity of the adsorbent. The linearized form of Langmuir equation can be written as

$$q_e = \frac{q_0 K_L C_e}{1 + K_L C_e} \quad (3)$$

The linearized form of Langmuir equation can be written as

$$\frac{1}{q_e} = \frac{1}{q_0} + \frac{1}{q_0 K_L} \cdot \frac{1}{C_e} \quad (4)$$

The Langmuir constant q_0 and K_L can be calculated by plotting $1/q_e$ versus $1/C_e$.

The Freundlich model is an empirical equation based on sorption on the heterogeneous surface. It is given as

$$q_e = K_F C_e^{\frac{1}{n}} \quad (5)$$

Where K_F and n are the Freundlich constants that indicate adsorption capacity and adsorption intensity, respectively.

The linearized form of Freundlich isotherm can be written as

$$\ln q_e = \ln K_F + \frac{1}{n} \ln C_e \quad (6)$$

The value of K_F and n can be calculated by plotting $\ln q_e$ versus $\ln C_e$.

Fig. 6 and Fig. 7 show the Langmuir and Freundlich curves for phenol adsorption onto BWH, respectively. The isotherm constants and correlation coefficients are shown in Table 1. From Fig. 6 and Fig. 7, it was observed that the equilibrium data were very well represented by the Langmuir isotherm equation when compared to the Freundlich equation. The sorption equilibrium data fitted the Langmuir and Freundlich equations with correlation coefficients values of 0.99 and 0.96, respectively. The best fit of the equilibrium data in the Langmuir isotherm expression predicted the monolayer coverage of phenol onto

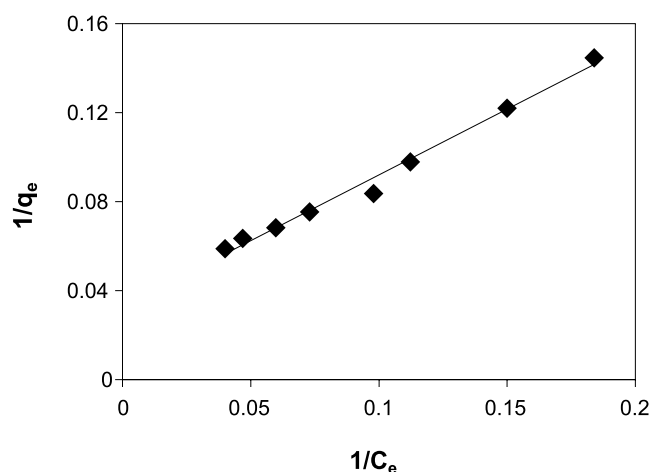
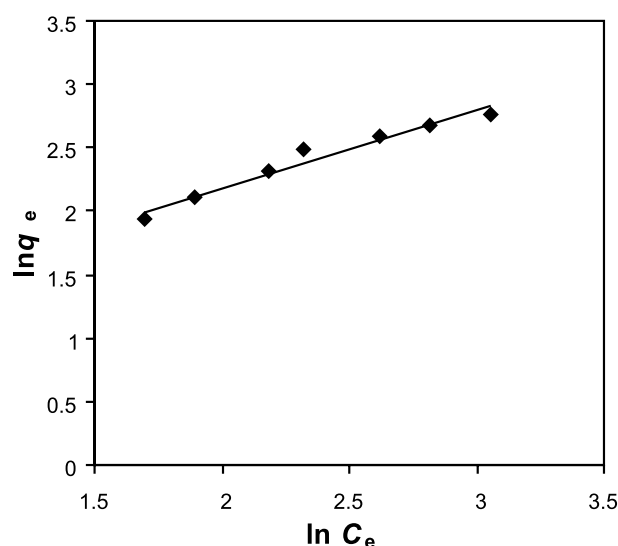


Figure 6. Langmuir isotherm for phenol adsorption onto burned water hyacinth (Initial concentration $C_0 = 40, 50, 60, 70, 80, 90, 100$ and 110 mg/L, pH = 6 ± 0.5 , Volume of solution $V = 150$ ml, Amount of adsorbent $M = 0.75$ gm, Temperature = $27 \pm 2^\circ\text{C}$)

Table 1. Comparison of isotherm constants and adsorption capacity of different adsorbents for phenol adsorption

Adsorbents	Freundlich isotherm		Langmuir isotherm	
	K_F (mg/g)(L/g) ^{1/n}	n	K_L (L/mg)	q_o (mg/g)
Coal ²⁵	1.44	3.14	0.008	13.23
Residual coal ²⁵	6.35	3.66	0.013	45.45
Coal treated with H ₃ PO ₄ ²⁵	7.27	2.55	0.002	142.8
Rice husk ²⁵	0.11	2.14	0.001	4.508
Coke breeze ²⁵	0.91	0.35	0.001	0.172
Neutralized red mud ²⁶	0.51	2.43	0.051	4.127
Rice husk ash ²⁷	1.26	1.63	0.0383	18.62
Activated coal ²⁸	0.97	0.79	0.065	1.481
Resin AP-246 ²⁸	0.11	0.35	0.584	0.071
Carbonized beet pulp ⁵	25.58	4.64	89.96	0.0639
Chitin ⁷	1.51	2.21	0.0124	24.15
Bentonite ¹⁰	0.10	2.56	0.0158	0.842
Titanium oxide ¹²	1.12	0.50	0.01599	19.1656
Burned water hyacinth (This study)	2.62	1.64	0.0555	30.49

**Figure 7.** Freundlich isotherm for phenol adsorption onto burned water hyacinth (Initial concentration $C_0 = 40, 50, 60, 70, 80, 90, 100$ and 110 mg/L, pH = 6 ± 0.5 , Volume of solution $V = 150$ ml, Amount of adsorbent $M = 0.75$ gm, Temperature = $27 \pm 2^\circ\text{C}$)

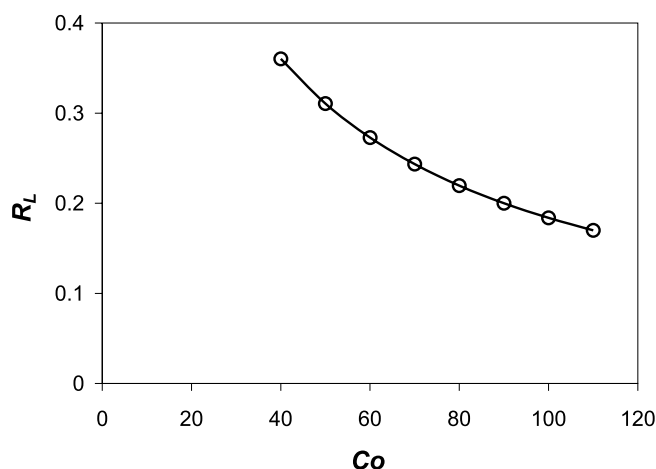
BWH. From Table 1, it was also observed that the maximum sorption capacity of BWH for phenol was found to be 30.49 mg/g. A comparison of isotherm constants and adsorption capacity for the adsorption of phenol by non-conventional adsorbents are presented in Table 1.

To determine if the phenol adsorption process by BWH is favorable or unfavorable for the Langmuir type adsorption process, the isotherm shape can be classified by a

Value of R_L	Type of isotherm
$R_L > 1$	Unfavorable
$R_L = 1$	Linear
$0 < R_L < 1$	Favorable
$R_L = 0$	Irreversible

term R_L , a dimensionless constant separation factor, which is defined below²⁴

$$R_L = \frac{1}{1 + K_L C_0} \quad (7)$$

**Figure 8.** Separation factor for phenol sorption onto burned water hyacinth (Initial concentration $C_0 = 40, 50, 60, 70, 80, 90, 100$ and 110 mg/L, pH = 6 ± 0.5 , Volume of solution $V = 150$ ml, Amount of adsorbent $M = 0.75$ gm, Temperature = $27 \pm 2^\circ\text{C}$)

where R_L is a dimensionless separation factor, C_0 is the initial solution concentration and R_L is Langmuir constant (L/mg). The parameter indicates the shape of the isotherm accordingly:

The calculated R_L values, ranging from 0.17 to 0.36 for different initial phenol concentration is shown in Fig. 8. The values of R_L in the present investigation have been found to be below 1.0 for phenol showing that the adsorption of phenol is very favorable.

Adsorption kinetics

Kinetic models are used to examine the rate of the adsorption process and the potential rate-controlling step. In the present work, the kinetic data obtained from batch studies have been analyzed by using the pseudo-first-order and the pseudo-second-order models.

The first order equation of Lagergren is generally expressed as follows²⁹

$$\frac{dq}{dt} = k_1(q_e - q) \quad (8)$$

where q is the amounts of phenol adsorbed (mg g⁻¹) at time t (min), and k_1 is the rate constant of the pseudo-first-order sorption (min⁻¹).

The integrated form of Eq.(8) becomes

Table 2. Pseudo-first-order kinetic constants for the adsorption of phenol onto burned water hyacinth

C_0 (mg/L)	$q_{e, exp}$ (mg/g)	$q_{e, cal}$ (mg/g)	k_1 (min^{-1})	r_1^2
50	13.48	3.48	0.0103	0.9751
60	15.30	4.46	0.0105	0.9853
70	16.65	4.53	0.0074	0.9124

$$\ln(q_e - q) = \ln q_e - k_1 t \quad (9)$$

A plot of $\ln(q_e - q)$ against t should give a linear relationship with the slope k_1 and intercept of $\ln q_e$.

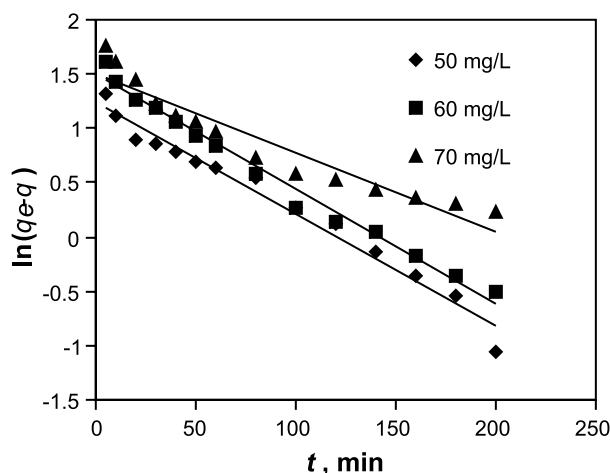
The pseudo-second-order kinetic rate equation is expressed as follows³⁰

$$\frac{dq}{dt} = k_2(q_e - q)^2 \quad (10)$$

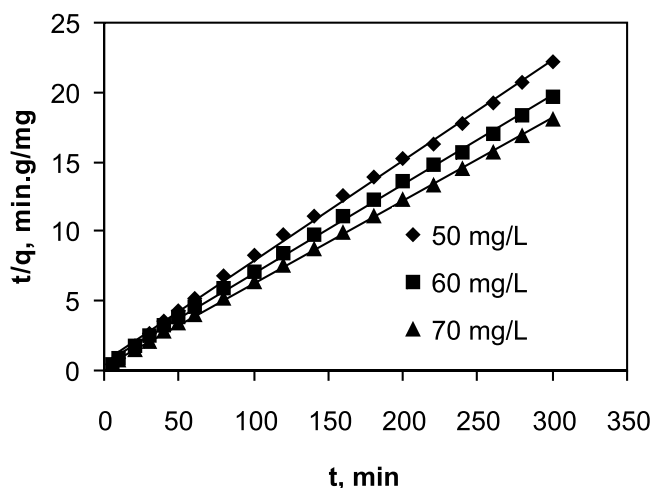
Where k_2 is the rate constant of the pseudo-second-order sorption ($\text{g mg}^{-1}\text{min}^{-1}$). The integrated form of Eq. (10) becomes

$$\frac{t}{q} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e} t \quad (11)$$

If the second order kinetic equation is applicable, the plot of t/q against t of Eq. (11) should give a linear relationship. The q_e and k_2 can be determined from the slope and intercept of the plot.

**Figure 9.** Pseudo-first-order kinetics for the adsorption of phenol onto burned water hyacinth (Initial concentration $C_0 = 50, 60$ and 70 mg/L, pH = 6 ± 0.5 , Volume of solution $V = 200$ ml, Amount of adsorbent $M = 0.50$ gm, Temperature = $27 \pm 2^\circ\text{C}$)

The plot of the linearized form of the pseudo first-order equation is shown in Fig. 9. The pseudo first-order rate constant k_1 , the amount of phenol adsorbed at equilibrium, and correlation coefficient are shown in Table 2. The results showed that the correlation coefficients obtained for all initial concentrations, C_0 were higher than 0.9. Although the correlation coefficient values were higher than 0.9, the experimental q_e did not agree with the calculated ones, obtained from the linear plots. Therefore,

**Figure 10.** Second order kinetics for adsorption of phenol onto burned water hyacinth (Initial concentration $C_0 = 50, 60$ and 70 mg/L, pH = 6 ± 0.5 , Volume of solution $V = 200$ ml, Amount of adsorbent $M = 0.50$ gm, Temperature = $27 \pm 2^\circ\text{C}$)

the pseudo-first-order kinetic model did not describe the adsorption results of phenol onto BWH.

Fig. 10 shows the linearized form of the pseudo-second-order kinetic model. The pseudo-second-order constant k_2 , amount of phenol adsorbed at equilibrium q_e , and the corresponding correlation coefficient values are given in Table 3. From Table 3, it was noticed that the r_2^2 values were found to be higher than that of r_1^2 at all initial phenol concentrations. The theoretical q_e values were closer to the experimental q_e values. In the view of these results, it can be said that the pseudo-second-order kinetic model provided a good correlation for the adsorption of phenol onto BWH in contrast to the pseudo-first-order model.

CONCLUSION

The results indicated that adsorption capacity of the adsorbent was considerably affected by the initial pH, initial phenol concentration, contact time and the adsorbent dosage. The amount of phenol adsorbed increased with increasing the initial phenol concentration. The uptake of phenol took place at a pH in the range of 2.5 – 9. Then the adsorption of phenol decreased with increasing the pH. The pH at the point of zero charge was determined by the titration method and was found to be 8.8 ± 0.2 .

The equilibrium data fitted very well in a Langmuir isotherm equation, confirming the monolayer sorption capacity of phenol onto BWH with a monolayer sorption capacity of 30.49 mg/g.

The pseudo-first-order and the pseudo-second-order kinetic models were used to analyze the data obtained for phenol adsorption onto BWH. The result indicated that the pseudo-second-order equation provided the better correlation for the adsorption data.

Table 3. Pseudo-second-order kinetic constants for the adsorption of methylene blue onto burned water hyacinth

C_0 (mg/L)	$q_{e, exp}$ (mg/g)	$q_{e, cal}$ (mg/g)	k_2 (g/mg min)	r_2^2
50	13.48	13.79	0.0083	0.9985
60	15.30	15.65	0.0067	0.9987
70	16.65	16.86	0.0099	0.9997

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