Adsorption of Phenol from Aqueous Solution Using Carbonized Maize Tassels

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Authors' contributions

This work was carried out in collaboration between all authors. Author NM designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript and managed literature searches. Authors LC, DS, MM managed the analyses of the study and literature searches. All authors read and approved the final manuscript.

Research Article

ABSTRACT

The adsorption of phenol which is one of the most important organic pollutant was studied using carbon from maize tassels. The effect of contact time, adsorbent dosage and temperature on the adsorption capacity was investigated. The maximum phenol adsorption was obtained as 54% at a temperature of 75ºC and at a pH of 6. Freundlich and Langmuir adsorption models were used for mathematical description of the adsorption equilibrium. The experimental data fitted well into the Langmuir isotherm.

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1. INTRODUCTION

Phenols are generally considered to be one of the important organic pollutants discharged into the environment causing unpleasant taste and odour of drinking water [1]. Phenols are pollutants of high priority concern because of their toxicity and possible accumulation in the environment. They are introduced into surface water from industrial effluents such as those from pharmaceutical, steel industries, domestic wastewaters, wastewaters from paints, pesticide, coal conversion, resin, petroleum and petrochemical industries and agricultural run-off. Traditionally, biological treatment, reverse osmosis, coagulation, sedimentation, ion exchange and solvent extraction are the most widely used techniques for removing phenols and related organic substances. Activated carbon from coal is widely used for the removal of a variety of organics from water but the disadvantage associated with it is the high regeneration cost and the generation of carbon fines due to the brittle nature of carbons used for the removal of organic species [2]. Research interests into the production of alternative adsorbents to replace the costly activated carbon have intensified and have led to more effective and economic natural materials such as those of agricultural origin because of their low cost and local availability [3]. Activated carbons starting from agricultural low-value by products have the advantage of exhibiting a high adsorption capacity for organic pollutants due to their high surface area or porous structure [1]. The application of agricultural materials in wastewater treatment has been reported [4,5,6,7,8]. From the more than hundred agricultural materials reported, no studies have been carried out on use of maize tassels to remove phenol. Zvinowanda and coworkers [9]. [10] found maize tassels to have immense potential as an alternative adsorbent for toxic metal ion remediation in polluted water and wastewater. Maize tassels are found in large quantities from maize producing countries such as South Africa, Mexico, Brazil, China, Indonesia, Argentina and USA. Many studies have been conducted on the adsorption of phenol using synthetic resins and low cost adsorbents such as coal, red mud, bagasse fly ash, coal fly ash, sewage sludge, clay and many other materials. The adsorption capacities obtained for some of these materials are red mud-59.2mg/g, bagasse fly ash-23.8mg/g, coal fly ash-17.9mg/g, rice husk-4.5mg/g and coal-18.1mg/g. Most of these materials have shown good adsorption characteristics however, there has not been much done on obtaining a comparative overview on removal performance, adsorption capacity and cost effectiveness. [3]. Another study was performed using activated carbon synthesized from pecan shells through the modification with sodium dodecyl sulphate surfactant and the results obtained showed moderate adsorption for phenol with a low adsorption capacity of 18mg/g at pH 11. [11]. In this study carbon from maize tassels was used to remove phenol from aqueous solution. To the best of our knowledge this has not been reported in literature.

2. MATERIALS AND METHODS

2.1 Preparation of Maize Tassels

The maize tassels were collected from a local farm in Bindura, Mashonaland Central Province and they were placed in polythene bags. The maize tassels were first cut into small pieces about 10 cm and washed to remove dust particles. Then they were dried in

an oven at 105ºC for 24 hours. The tassels were then ground and sieved to 75 mesh size to separate the materials into discrete particle size ranges [1]. Then 25g of the powder was placed in a muffle furnace at 400ºC for 1 hour and later allowed to cool to room temperature. The carbon was then stored in a closed bottle [9], buffer 10.

2.2 Preparation of Stock Solution

The stock solution was prepared by dissolving 1.0030 g of phenol in $1dm^3$ of distilled water. The test solutions were prepared by diluting the stock solution to the desired concentrations. The concentration range varied from 25-500 mg/dm^3.

2.3 Adsorption Studies

Phenol adsorption was performed at various initial temperatures at constant 150rpm shaking glass flasks of $0.25dm^3$ containing $0.1dm^3$ phenol solution at desired concentration including 0.05g of maize tassel carbon using a shaker. $5cm^3$ samples were taken before mixing the carbon and phenol and during mixing at 30 minutes intervals for determining the residual phenol concentration in the medium. Before analysis the samples were filtered by using Whatman filter paper and the supernatant fluid was analyzed for the remaining phenol.

2.4 Effect of pH

The effect of pH on adsorption was investigated in the pH range 2-10 at 25ºC.The pH of solution was adjusted to the desired value by adding a few drops of 1N HCl or1N NaOH solutions to the initial solution.

2.5 Effect of Adsorbent Dosage

Adsorption dose experiments were performed with 100ml of 150mg/L phenol solution with the following adsorbent masses 0.4, 0.8, 1.2, 1.6 and 2.0g at 25ºC. The pH of the solution was adjusted to optimum pH of 6. After 1 hour the suspension was filtered and the filtrate analyzed for unabsorbed phenol.

2.6 Effect of Contact Time

Experiments for the effect of time were performed following the same procedure as described earlier, but an optimum pH for phenol, fixed temperature (25±2ºC), fixed concentration (150mg/L) and adsorbent dose (1.0g/100ml). Six sets of samples were prepared in triplicate and placed in a water bath with a shaker set at 150rpm. After every 30 minutes, three samples were removed and filtered immediately and the filtrate analyzed for residual phenol.

2.7 Effect of Solution Temperature

Experiments for the reaction temperature were also performed following the same procedure with all other parameters fixed, but at different temperature range 25, 50, 75, 100 and 125ºC.

2.8 Analysis

The concentration of initial and residual phenol in the adsorption media was determined spectrophotometrically at an absorbance of 270 nm [12].

3. RESULTS AND DISCUSSION

The adsorption percentage of phenol was calculated by the difference of initial and final concentration using the equation expressed as follows.

$$\text{Adsorption yield (\%)} = \frac{(C_o - C_t)V}{C_o} \times 100 \tag{1}$$

The adsorption capacity of phenol adsorbed per gram adsorbent (mg/g) was calculated using equation (2) below.

$$q = \frac{(C_o - C_t)V}{W} \tag{2}$$

where C_o and C_t are the initial and at any time (t) concentration (mg/L) of phenol in the solution, V the volume (L) of solution and W is the weight (g) of the adsorbent. For the equilibrium conditions in these equations, C_e (equilibrium concentration) and q_e (adsorbed phenol at equilibrium) must be written instead of C_t and q. C_e and q_e have the same unit with C_t and q, respectively.

Langmuir isotherm is often used to describe the maximum adsorption capacity of the adsorbent. The Langmuir equation is written as follows.

$$q_e = \frac{q_{max} K C_e}{1 + K C_e} \tag{3}$$

Equation (3) above can be written in a linear form as follows:

$$\frac{C_e}{q_e} = \frac{1}{Kq_{max}} + \frac{C_e}{q_{max}}$$

Where q_{max} and K are Langmuir constants related to maximum adsorption capacity and bonding energy of adsorption. A plot of *Ce/qe* versus *Ce* should be a straight line with a slope 1/*q*max and intercepts 1/*Kq*max (as shown in Fig. 2,5,8 and 11) $\frac{C_o-C_e}{n})v$

3.1 Effect of pH

The effect of pH was investigated from pH 2-10 and the results obtained showed that as the pH increased the adsorption also increased up to pH 6, then from there the adsorption decreased as pH increased as shown by Fig. 1. According to Horsfall [14], adsorption is a pH dependent process and pH dependent binding suggests that phenol is adsorbed by the adsorbent through carboxyl, carbonyl or hydroxyl ligands. The decrease in phenol adsorption from pH = 6 to 2 was due to the increased H^+ adsorption on the carbonyl sites, which suppresses phenol adsorption on these sites. On the other hand, the decrease in the phenol amount adsorbed from pH = 6 to 10 was probably attributed to both greater solubility of dissociated phenol at pH > pK_a and increased repulsion forces between the dissociated form of the adsorbate and the carbon surface. Mattson [14], indicated that phenol and its derivatives adsorb on activated carbon via a donor-acceptor complex mechanism that involves carbonyl surface-oxygen groups acting as electron donor and the aromatic ring of the solute acting as an acceptor.
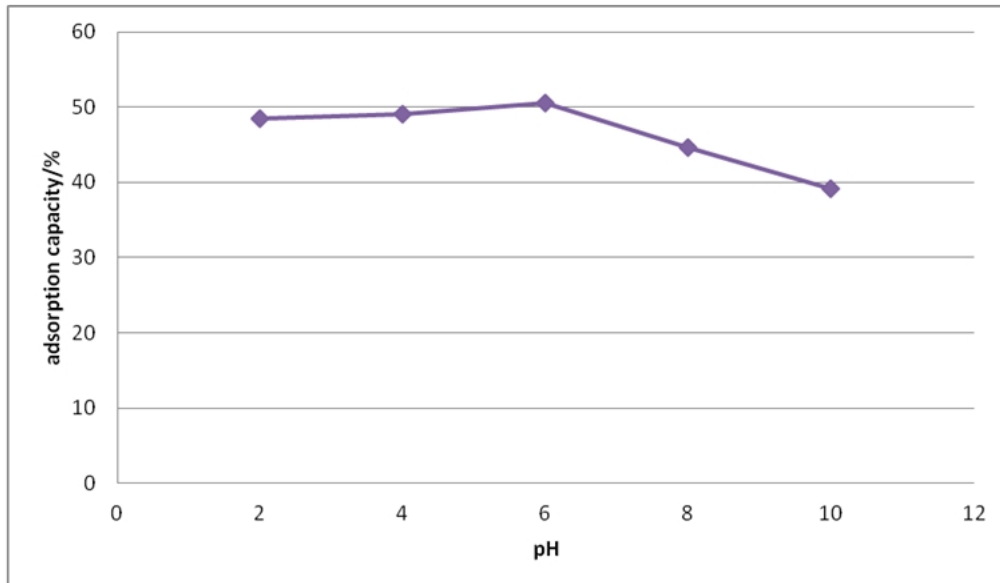

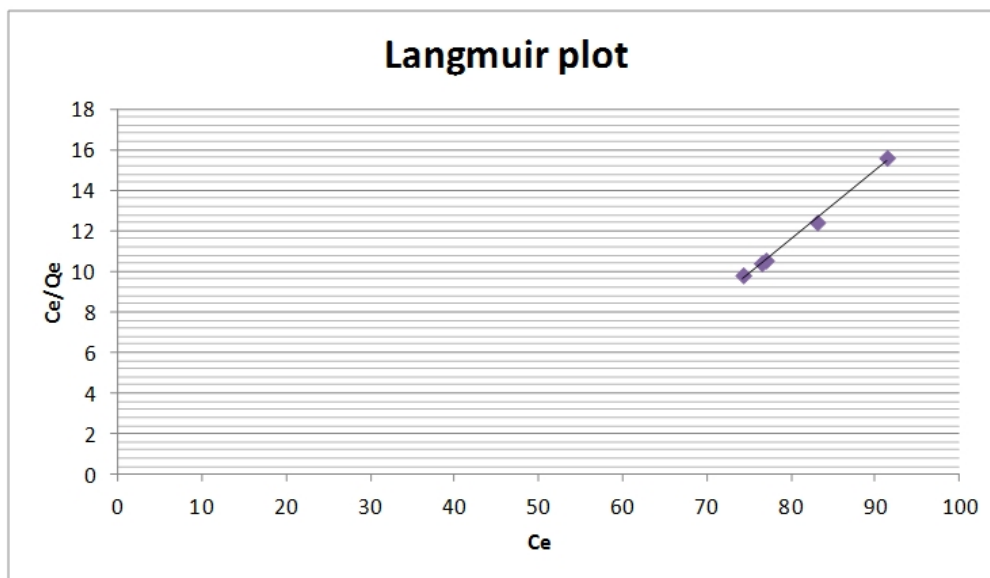**Figure 1. Graph for the effect of pH against adsorption capacity**

Langmuir plot

Figure 2. Langmuir adsorption isotherm for the effect of pH
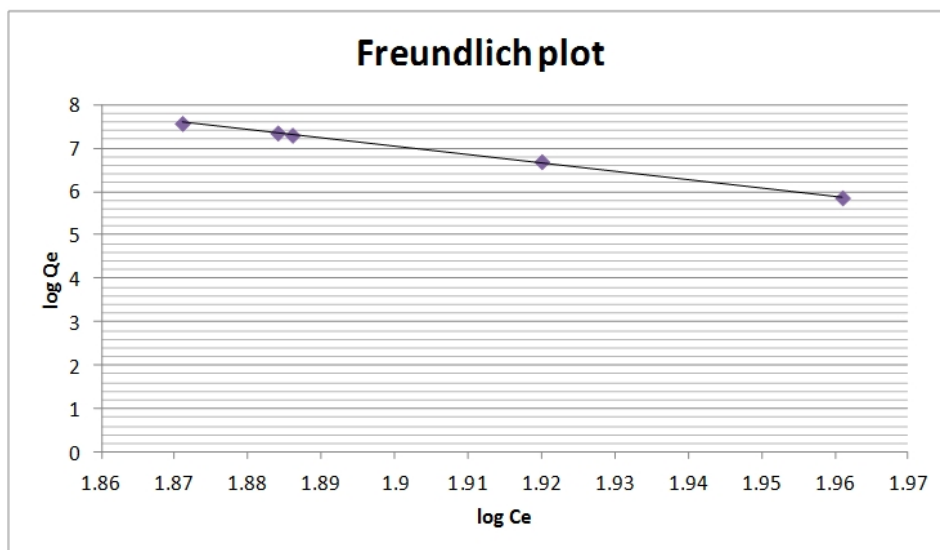
Freundlich plot

Figure. 3. Freundlich adsorption isotherm for the effect of pH

3.2 Effect of Adsorbent Dosage

The effect of adsorbent dosage was investigated using adsorbent dosages which ranged from 0.4 to 2.0g. This was investigated at the optimum pH 6 and the results showed that as the adsorbent dosage increased the adsorption capacity also increased. The more the adsorbent dosage meant more adsorption sites therefore more phenol

was adsorbed .The maximum adsorption capacity was observed for the 2g adsorbent dosage as shown by Figure 4. According to a study by Srivastava, [12], the removal of phenol increased with increase in adsorbent dosage.
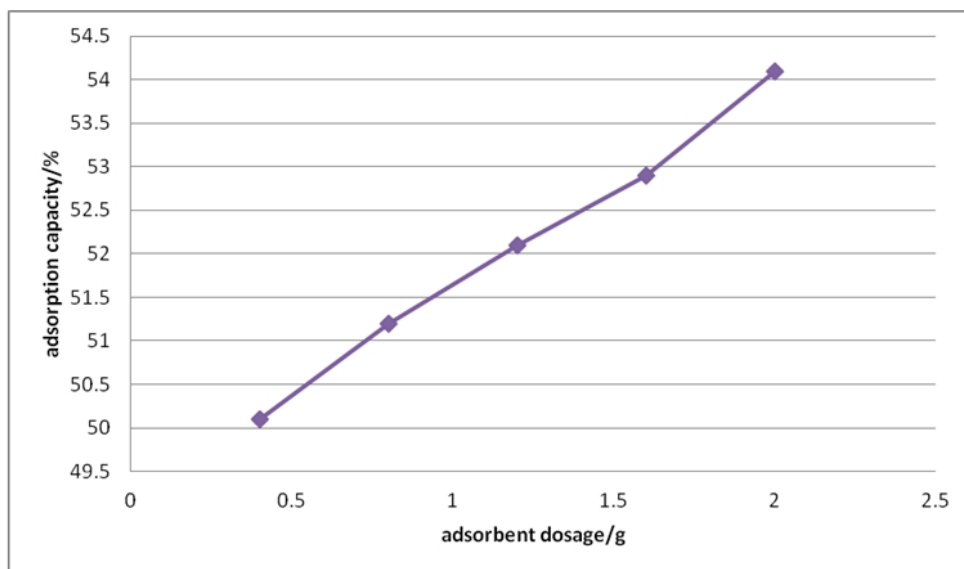
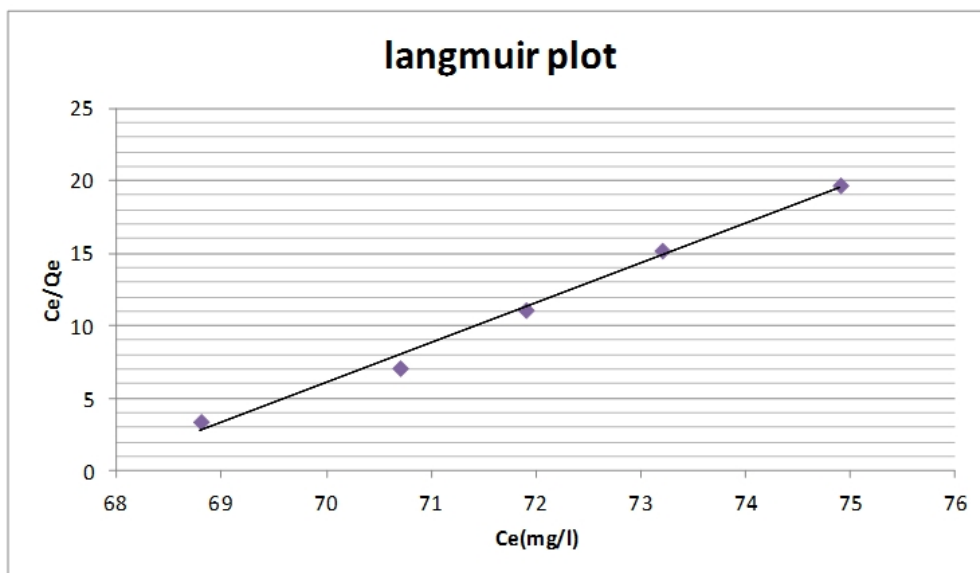**Figure 4. Graph of adsorbent dosage against absorption capacity**

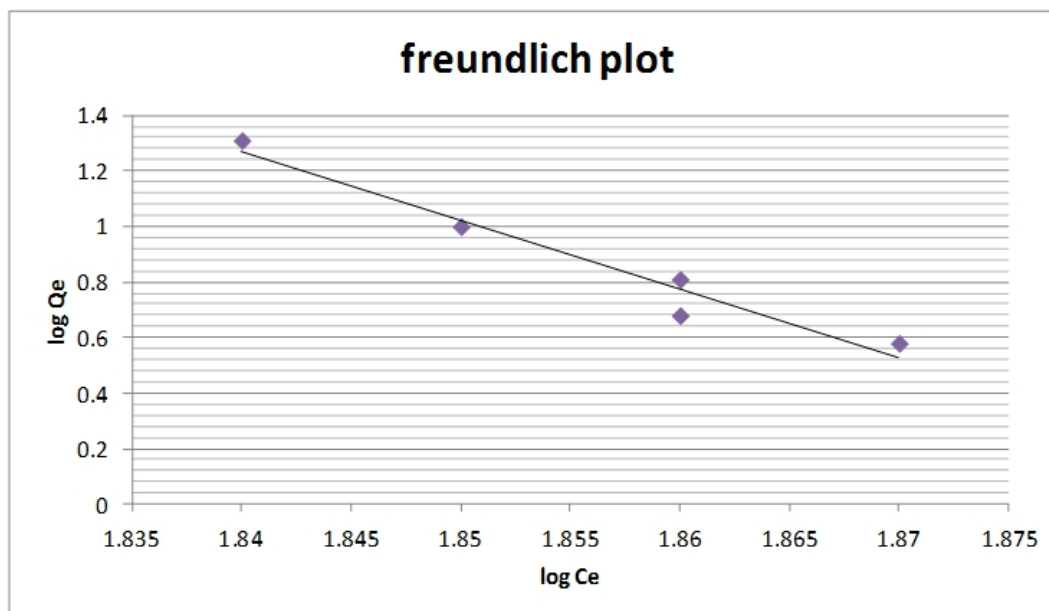**Figure 5. Langmuir adsorption isotherm for the effect of adsorbent dosage**

Figure 6. Freundlich adsorption isotherm for the effect of adsorbent dosage

3.3 Effect of Contact Time

The effect of contact time was investigated at pH 6 and an adsorbent dosage of 1.0g. It was noted that as the contact time increased adsorption capacity also increased meaning more phenol was adsorbed with an increase in contact time, this might have been due to the increased number of vacant sites on the adsorbent. However there was a decrease as the contact time increased this might have been caused by the fact that all the adsorbent sites were already occupied. The maximum adsorption capacity was seen after 120 minutes. (Figure 7). Similar trends were also observed in other investigations [15].
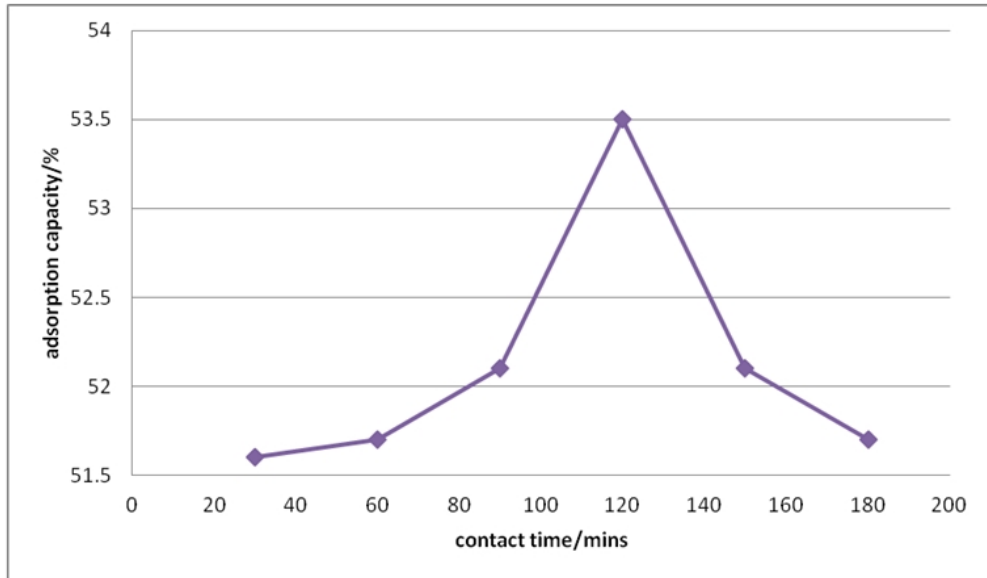
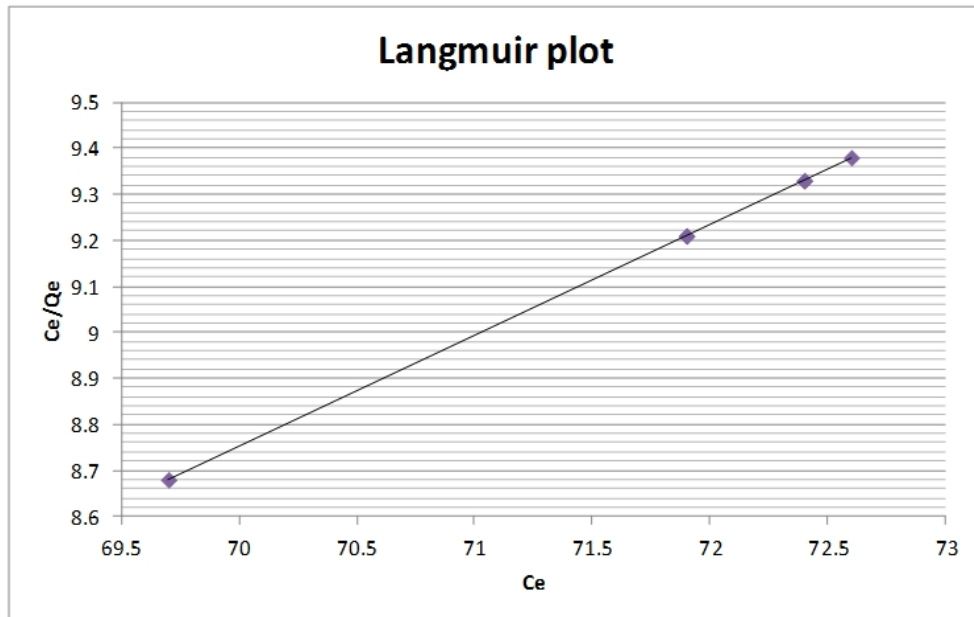**Figure 7. Graph of contact time against adsorption capacity**

Figure 8. Langmuir adsorption isotherm for the effect of contact time
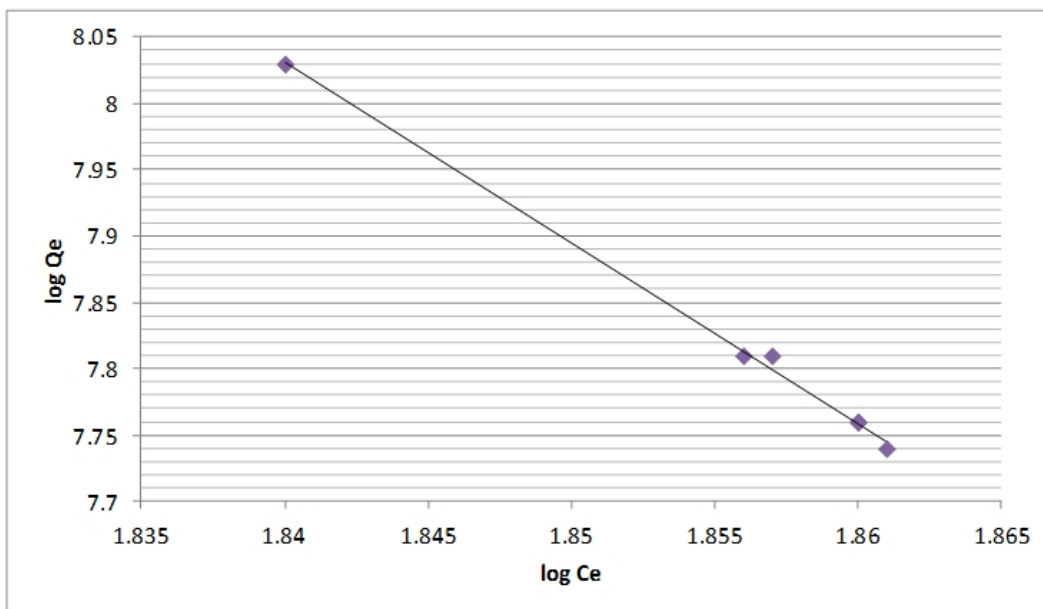
Figure 9. Freundlich adsorption isotherm for the effect of contact time

3.4 Effect of Temperature

This was investigated at a pH of 6, an adsorbent dosage of 1.0g and contact time was set at 1 hour. At the beginning adsorption capacity increased with the increase in temperature as shown by the graph in Figure 10. The adsorption decreases with increasing temperature because theoretically the process of physisorption takes place at low temperature and decreases with increasing temperature. The maximum adsorption capacity was observed at 75ºC. A similar trend was also observed by Horsfall and Spiff [16].
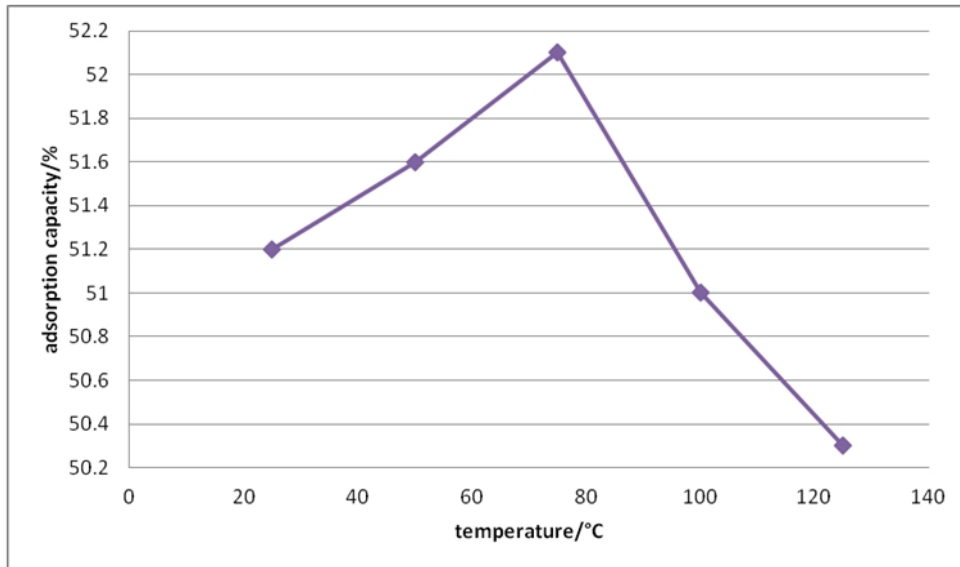
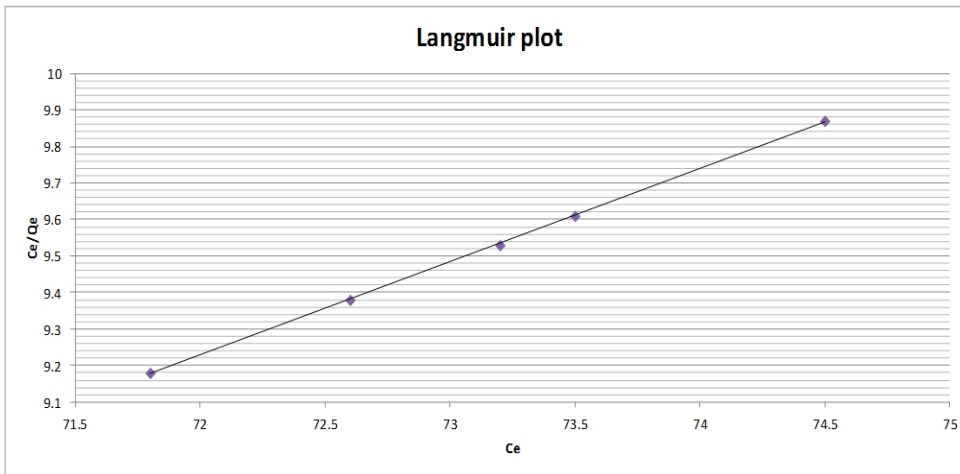**Figure 10. Graph for the effect of temperature against adsorption capacity**

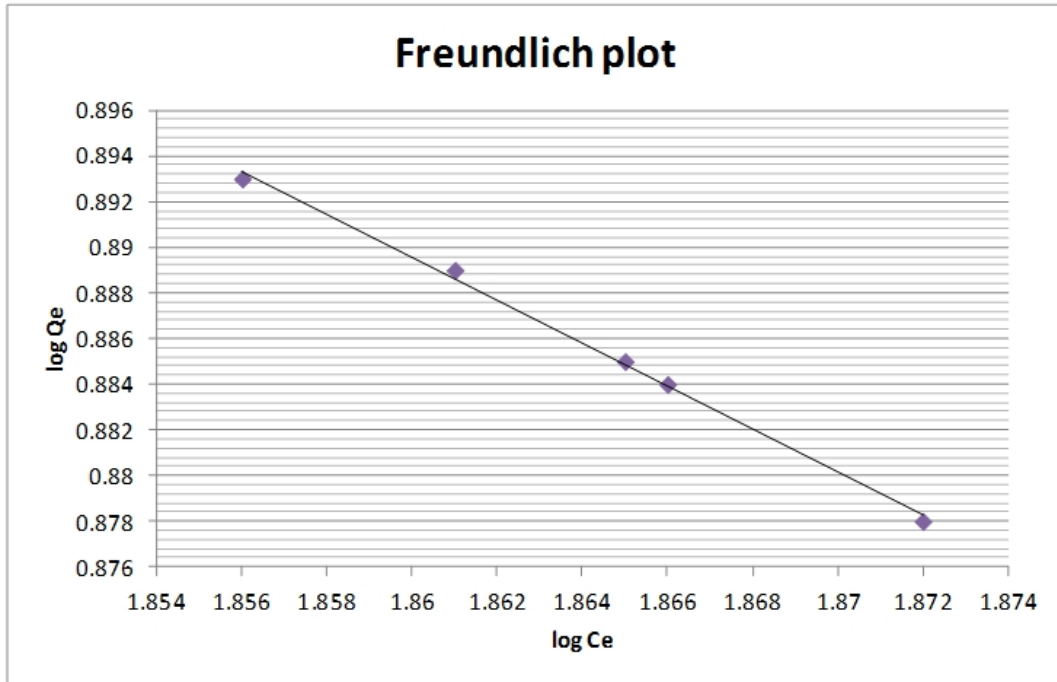**Figure 11. Langmuir adsorption isotherm for the effect of temperature**

Freundlich plot

Figure 12 Freundlich adsorption isotherm for the effect of temperature

Table I. Langmuir adsorption isotherms constants

	K	R^2
Adsorption dosage	0.01	0.9917
Contact time	0.0297	1
pH	0.0218	0.9957
Temperature	0.0278	0.99998

The data related to the equilibrium obeyed well the Langmuir modes as seen from the values of regression coeffients presented in Table I, r^2, ranged from 0.9917-1. The K value was calculated using equation (3) for the Langmuir plots shown in Figures 2, 5,8 and 11. The K values indicates the affinity for binding of phenol. A higher K value was obtained when the contact time was investigated. Dursun et al. [1] reported a K value of0.0639 at 25ºC.The data did not fit very well in the Freundlich adsorption isotherm as shown in Figures 3,6,9 and 12.

4. CONCLUSION

The carbon from maize tassels has great potential as an adsorbent.The results of the study show that the adsorption capacity of the activated carbon maximum adsorption took place at optimum pH of 6, adsorbent dosage of 2g and at a temperature of 75°C and contact time of 120 minutes. The adsorbent was required in large amounts for the

process to attain equilibrium faster. Generally the removal of phenol required lower temperatures. The data fitted well into the Langmuir adsorption isotherm and not the Freundlich adsorption isotherm. The Langmuir model assumes that adsorption takes place at specific homogeneous sites on the surface of the adsorbent and also, when a site is occupied by an adsorbate molecule, no further adsorption can take place at this site.

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COMPETING INTERESTS

Authors declare that there are no competing interests.

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