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THE EFFECTIVENESS OF CARBONIZED NEEM LEAVES ADSORBENT FOR THE REMOVAL OF PHENOL FROM SYNTHESIZED EFFLUENT USING THE BATCH PROCESS METHOD

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ABSTRACT: *The adsorption of phenol in aqueous solution was investigated using carbonized neem leaves adsorbents. The effect of various factors such as contact time, phenol concentration, pH, temperature, and amount of adsorbent on the adsorption capacity of the adsorbents was determined. The results show that maximum adsorption was obtained at a contact time of 150 minutes, at a phenol concentration of 50 mg/L, optimum adsorption temperature of 45°C, pH of 2 and adsorbent dosage of 3 g/L. The equilibrium data was well described by the Freundlich isotherm equation (R^2= 0.955). This shows a heterogenous adsorption process. The kinetics of the process were explained by the intra-particle diffusion models (R^2>0.9). This fitted data indicates a degree of boundary layer control and is not limited to intra-particle diffusion.*

KEYWORDS: Phenol, Adsorption, Adsorbent, Concentration, pH, Temperature, Neem.

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INTRODUCTION

The introduction of contaminants into the water body that causes adverse change is called water pollution. Water pollution is one of the world's major problems (Pink *et al.,* 2006). Phenol and phenolic compounds are the most common pollutants which include a wide range of organic chemicals (Almarauzzam, 2008). Phenol is usually released from industries which use its derivatives as an intermediate in the synthesis of dyes, pesticides, insecticides and other sources of phenol are from petrochemicals, refinery, and coke conversion (Alhamed, 2009). The disposed phenolic waste in the waterways affects not only humans but also the flora and fauna as well (Alhamed, 2009). Various technologies exist for the treatment of phenol pollutants. These techniques include adsorption, chemical reaction, filtration, ion exchange, coagulation/flocculation, reverse osmosis, electrodialysis and others (Baccaloni, 2000). Good as they are, the above methods aside adsorption is usually very expensive and could impact negatively on the environment Adsorption has become one of the alternative treatment method of phenol in recent years, because it is readily available, cheap and more environmentally friendly (Siri *et al.*, 2013). This brings about the search for low-cost adsorbents that have high organic and inorganic binding capacities (Leung *et al.*, 2000). Neem leaves adsorbent falls under the low-cost adsorbent and it shall be produced to treat phenol in the synthesised wastewater. Neem trees belong to the Maliaceae family and is native to the Indian sub-continent. Its seeds and leaves have been in use since ancient times to treat several humans and ailments and also household pesticides (Babu & Grupta, 2008). Neem tree can survive in a harsh climatic condition (Babu & Grupta, 2008). Neem leaves have been found to be a good source of biological adsorbent to treat effluent containing heavy metals (Elangovan et al., 2014) and remove dyes from waste water (Ghashyam *et al.*, 2013). This synthesized waste water will be prepared by weighing 1 g of phenol and dissolving it in 1000ml distilled water which represent the waste water that contains phenol as a pollutant. Parameters to be used are varied adsorbent dosage, contact time, pH, initial concentration of phenol and effect of temperature.

LITERATURE/THEORETICAL UNDERPINNING

Wastewater

Wastewater is any water in which quality has been affected by human activities; it may be from domestic, agricultural or industrial use of water (Britz *et aI., 2006).* Waste water is usually contaminated with either solid, liquid or gaseous substances and sometimes compounds, all these cause some changes in the physical and chemical properties of water. Industrial waste water contains a variety of harmful substances such as heavy metals, total hydrocarbon, coliform and others (Crabias-Martinez, 2004). Chemicals are now used on a large scale in various human activities due to ever-growing urbanization and industrialisation over the last few decades (Britz *et aI., 2006).* Release of the industrial wastewater into the water bodies is the major reason for water pollution. The organic and inorganic pollutants find their way to water bodies such as waterways and rivers. Industrial wastewater affects the chemical, physical and biological properties of water (Britz *et al.,* 2006*).* The ever water demand has caused considerable attention to be focused towards the recovery and reuse of water (Crabias-Martinez, 2004).

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Phenol

Phenol is one of the most common organic water pollutants. Phenol and substituted phenols are toxic organic pollutants, usually present in industrial wastewaters, especially those from oil refineries, coal conversion plants, pharmaceuticals, *etc*. And as a class of organics, they are similar in structure to the more common herbicides and insecticides, which can explain the fact that they are resistant to biodegradation (Petroval *et al.*, 2010). Phenol, also known as carbolic acid, is an aromatic organic compound with the molecular formula C_6H_5OH. It is a white crystalline solid that is volatile. The molecule consists of a phenyl group ($-C_6H_5$) bonded to a hydroxyl group (−OH). It is mildly acidic and requires careful handling due to its propensity to cause chemical burns. Phenol was first extracted from coal tar, but today is produced on a large scale (about seven billion kg/year) from petroleum (Rengaraj *et al.*, 2001). It is an important industrial commodity as a precursor to many materials and useful compounds. It is primarily used to synthesize plastics and related materials. Phenolic constitutes are 11th of the 126 chemicals which have been pointed as priority pollutants according to the United States Environmental Protection Agency (EPA, 2002). Phenol is an organic compound. Phenol is appreciably soluble in water, with about 84.2 g dissolving in 1000 mL (0.88 M). Homogeneous mixtures of phenol and water at phenol-to-water mass ratios of ~2.6 and higher are possible. Phenol is a colorless-to-white solid when pure. Commercial phenol is a liquid that evaporates more slowly than water. Phenol has a distinct odour that is sickeningly sweet and tarry. The sodium salt of phenol, sodium phenoxide, is far more water-soluble (Afila, 2014**)**. Long-term exposure to phenol at work has been associated with cardiovascular disease. Ingestion

of liquid products containing concentrated phenol can cause serious gastrointestinal damage and

even death. Application of concentrated phenol to the skin can cause severe skin damage (Naheds *et al.*, 2008). Short-term exposure to high levels of phenol has irritated the respiratory tract and muscle twitching in animals. Longer-term exposure to high levels of phenol caused damage to the heart, kidneys, liver, and lungs in animals. Drinking water with extremely high concentrations of phenol has caused muscle tremors, difficulty walking, and death in animals (Naheds, *et al.*, 2008). Short-term application of phenol to the skin has produced blisters and burns in animals. Several technologies exist to eliminate phenol from industrial wastewater. They include cross-linked cyclodextrin particles, using adsorbents, pervaporation and adsorption, membrane techniques, electrochemical treatment continuous electrochemical treatment, solvent extraction process (These methods listed are usually very expensive in their applications and require the use of chemicals in their operation) and the use of agricultural waste (Oilgae, 2016). From an economic point of view, it is infeasible to utilise commercial activated carbon for large-scale wastewater treatment. To that end, the focus of phenol adsorption studies has been altered toward natural materials that are available in vast amounts, as well as certain waste products from industrial and agricultural operations (Oilgae, 2016). Neem leaves is a natural material which is readily available, cheap, environmentally friendly and high adsorption capacity when carbonized (Elangovan *et al.*, 2014)

The United States Environmental Protection Agency (USEPA) put the upper permissible level at 0.03 mg/L in industrial effluent, while it is 0.001 mg/L level in Nigerian drinking water (Omotayo, 2014). This critical value is usually based on levels that affect animals; they are then adjusted to levels that will help protect humans.

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Adsorbent

For adsorption to occur one of the key components is the adsorbent material, irrespective of the form of adsorption that fluid-solid phase the nature of the adsorbent plays a vital role in the rate of adsorption. Over the years various types of adsorbents has been used for various adsorption experiments; however, two of the most common adsorbents are zeolites and activated carbon (Wang *et al.*, 2000).

Types of Adsorbents

The typical adsorbents used in the industry due to their high adsorptive capabilities include:

Activated Carbon

Activated carbon has undoubtedly been the most popular and widely used adsorbent in wastewater treatment throughout the world aside from others. Charcoal, the forerunner of modern activated carbon has been recognized as the oldest adsorbent known in wastewater treatment. Its ability to purify water dates back to 2000 B.C. Activated carbon is produced by a process consisting of raw material dehydration and carbonization followed by activation. The starting material is dehydrated and carbonized by slowly heating in the absence of air. Carbonization converts this organic material to primary carbon, which is a mixture of ash, tars, amorphous carbon and crystalline carbon (elementary graphitic crystallites). During carbonization, some decomposition products or tars are deposited in the pores but are then removed in the activation step. Activation is essentially a two-phase process requiring burn off of amorphous decomposition products (tars), plus enlargement of pores in the carbonized material. Burn-off frees the pore openings, increasing the number of pores, and activation enlarges these pore openings. The resulting product obtained is known as activated carbon and it generally has a very porous structure with a large surface area ranging from 600-2000 m^2/g. Activated carbons can be prepared from a variety of carbon-containing materials such as coke, olive stones, pinewood, rice hulls, palm shell, sawdust, anthracite, palm kernels, *Moringa oleifera* seed husks, peat, bituminous coal, agricultural waste such as coconut shell, leaves, the palm fruit bunch particles, etc. (Jumichi *et al.*,2002). However, the activated carbon used in wastewater treatment is generally prepared from agricultural wastes such as coconut shells, and neem leaves fall within the agricultural waste (Elangovan *et al*., 2014). Others are, peat, sawdust, wood char, lignin, petroleum coke, bone char, anthracite coal etc (Ghashyam *et al.*,2013).

Activated carbon (AC) possesses several properties which make it a good material for various adsorption processes some of these properties include, a large pore volume ranging from 0.2-0.6 cm^3/g and in some cases it has been discovered to exceed 3000 m^2/g. The surface area should contain mostly micro pores of diameters less than 2 nm (Leimkuehlear, 2010). The adsorption process of adsorbent is affected by various factors which include the concentration of the adsorbate, temperature, nature of the adsorbate and adsorbent, surface area of the solid adsorbent, the pH of the medium, Solubility of the Adsorbate, contact time between the adsorbent and the solution, adsorbent dosage

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MATERIALS AND METHODS

Materials

The materials used for this experiment include; Weighing balance, Oven, Sieve shaker, Beakers, Water bath, Separating funnel, Conical flask, 10 ml Syringe, Muffle furnace, pH meter, Stopwatch, Crucible, UV/VIS spectroscopy, Neem leaves, Phenol, Sodium hydroxide, Iodine crystals, Distilled water and Hydrogen Chloride

Methodology

Preparation of synthetic wastewater

1 g of phenol was weighed and added to a 1000 ml volumetric flask. It was diluted to the mean mark on the volumetric flask with distilled water and mixed properly by shaking vigorously and the stock solution was kept for further use.

Preparation of adsorbent

This was carried out according to the method of Ioannidou *et al.* (2006). Neem leaves that weighed 1000 g were collected into a plastic bucket from Gidan Kwanu and rinsed with distilled water to remove dust and dirt. The leaves were placed in an oven to dry for 150 minutes at a regulated temperature of 110^0C. The dried leaves were ground with a grinding machine to obtain fine powder. The ground leaves were sieved using a Ro-tap sieve shaker to 125 µm size. 10 g of each aggregate size were collected into 5 different crucibles and placed in a muffle furnace for 30 minutes at a regulated temperature of 600 ^{0}C to obtain a dark brown coloured adsorbent.

Plate 1: Neem plant

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Plate 2: Uncarbonized and **Plate 3: Carbonized neem leaves**

Effect of adsorbent dosage

50 ml of effluent was added to each of the five conical flasks. To these, a varying quantity of each adsorbent i.e. 0.5 gm, 1.0 gm, 1.5 gm, 2.0 gm, 2.5 gm and 3.0 gm (activated adsorbent) was added. The pH was maintained at 7.0 at room temperature. The setup was placed in a controlled-temperature shaker for 150 minutes at 120 rpm. After 150 minutes, the amount of phenol left in the solution was checked by UV/VIS spectroscope. A graph of adsorbent dosage vs percentage of phenol removed was plotted.

Effect of concentration

The concentration was varied by preparing 50, 100, 150, 200, 250, and 300 mg/lit by serial dilution of phenol respectively from a 1000 ml stock solution in the volumetric bottle. 50 ml of each of the synthesised wastewater was taken and contacted with 1 g of the adsorbent of mesh size 125µm. All were maintained at pH 7.0 and a room temperature. The samples were agitated for 150 minutes at 120 rpm. The absorbent and the solution were separated by filtration using Whatman filter paper No.1001-110 and the phenol left in the solution were checked by UV/VIS spectrophotometer method and the percentage recovering was calculated. A graph of percentage removal vs pH of phenol was plotted.

Effect of pH

50 ml of the synthesised waste water was added into five flasks with 100 ml capacity and their pH was maintained at 2, 3, 4, 5, 6, 7, 8, and 9 respectively. 1 molar of HCl and NaOH were used to get the desired pH and a pH meter was used to measure the pH of the solution accurately. To these flasks, the activated adsorbent 1 gm was added. The setup was then placed in a shaker for 150 minutes at 120 rpm. The absorbent and the solution were separated by filtration using Whatman filter paper No. No.1001-125 and the phenol left in the solution were checked by UV/VIS Spectrophotometer and the percentage recovery was calculated. A graph of percentage removal vs pH of phenol vs was plotted.

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Effect of Contact Time

50 ml of synthetic wastewater was added each to 12 conical flasks, having 100ml capacity each phenol solutions of initial concentration of 100mg/l were taken and 1gm of the activated adsorbents of 125 mesh size added respectively. This was maintained at a neutral pH and a room temperature of 27ºC. The setup was placed in a shaker and oscillated at a constant speed of 120 rpm. Each flask was drawn at a temperature between 15 and 180 minutes at the interval of 15 minutes. The amount of phenol left in the solution was separated by filtration using Whatman filterpaper No.1001-125 and the filtrate was analysed using ultraviolet spectroscopy. The percentage recovery was calculated and plotted versus the time (Saikiran *et al.*, 2016).

Effect of Temperature

50ml of the synthesised aqueous samples were contacted with 1g of adsorbent varying the temperature at 27, 30,35,40,45 and 50ºC . The samples were agitated for 150 minutes, withdrawn, filtered and analysed in a UV/VIS spectrophotometer to determine the phenol concentrations and the percentage removal was calculated and plotted versus the temperature.

Isotherm Studies

The adsorption isotherms developed by Langmuir and Freundlich were commonly used to fit the equilibrium data with different equilibrium phenol concentrations. The isotherms that predict adsorption behaviour can be used to design the sorption system. Langmuir isotherm is related to the sorption taking place at specific homogeneous sites within the adsorbent. Freundlich isotherm is based on the assumption that a heterogeneous surface with a non-uniform heat distribution of the sorption along the surface. The linear equations of the Langmuir and Freundlich isotherm equations, from Eqs (3) and (6) respectively, are shown below

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

Where q_{max} is the maximum adsorption capacity or limiting sorption (mg/g) and k is the Langmuir constant (L/mg). The parameters can be evaluated from the slope and intercept of the linear plot of C_e/q_e against C_e.

$$log\ log\ q_e = log\ log\ k_f + \frac{1}{n} log\ log\ C_e$$

Where k_f is the Freundlich characteristic constant (mg/g) and $1/n$ is the heterogeneity factor of adsorption. The parameters are obtained respectively from the intercept and slope of the linear plot of $logq_e$ versus $logC_e$.

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Kinetic Models

To predict the mechanisms related to phenol, the kinetic data were fitted by kinetic models and intra-particle diffusion models.

Intra-Particle Diffusion Model

This model is given by Eq. 7

$$q_t = K_p t^{\frac{1}{2}} + C$$

K_p is the intra-particle diffusion rate constant ($mgg^{-1}min^{-1/2}$) and C is a measure of the boundary layer effect. The intercept of the plot gives the boundary layer effect. The larger the intercept, the greater the contribution of the surface sorption in the rate-controlling step.

RESULTS/FINDINGS AND DISCUSSION

Effect of Concentration of Phenol

The effect of concentration on the adsorption rate of phenol was investigated using carbonised neem leaves' adsorbents (125µm). Experiments were carried out at fixed adsorbent dosage, (1 gm) room temperature (27^0C) and neutral pH (7.0) illustrated in Fig 4.3. The concentrations were varied between 50 to 300 mg/l. The trend indicates that at increasing concentration, the percentage removal decreases, this is owing to the fact that the available adsorption sites of the adsorbent has been occupied by the increasing phenol molecules. The low phenol concentration provides the driving force to overcome the mass transfer resistance (Abdelwahab *et al*., 2013). A further increase in concentration from 250 to 300 mg/l, an equilibrium was attained, In which case the adsorbent active sites are almost occupied by the phenol molecules thereby preventing further adsorption (Abdelwahab, 2013).

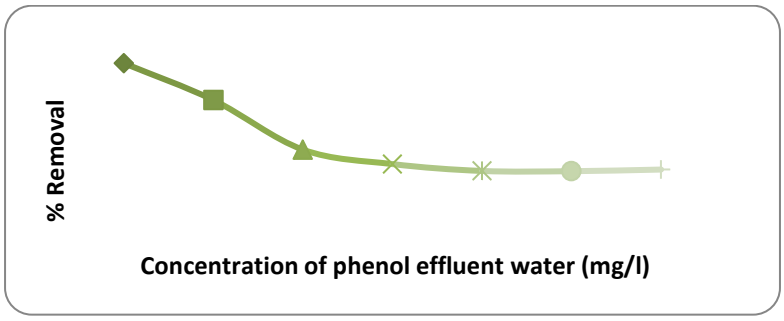

Figure 1: Variation in % Removal of phenol from effluent solution with concentration

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Effect of Contact Time

Experiments were carried out at a fixed adsorbent dose, (1 gm) room temperature (27^0C) and neutral pH (7.0) with varied times between 15 minutes and 180 minutes. Figure 4.4 plot shows the contact time versus percentage removal for adsorbent. The initial concentration 100 mg/l, volume: 50 ml. From the results, the percentage removal increases from the initial stage gradually to time 150 minutes which indicates the maximum adsorption of the phenol. This is because at increasing contact time, more of the phenol will contact with the adsorbent (Sai *et al.*, 2016) and a further time increment results in equilibrium.

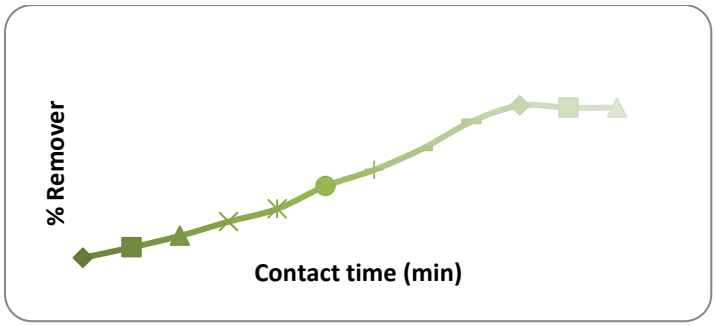

Figure 2: Variation in % Removal of phenol from synthesised effluent with time.

Any further increment of the time will have no significant effect on the percentage removal of phenol. This is because there is not much driving force between the phenol and the adsorbent as a result of the saturation of the adsorption sites of the adsorbent by the phenol (Naema, *et al.*, 2014).

Effect of Adsorbent Dosage Variation

The effect of adsorbent dosage on the adsorption of phenol was investigated using neem leaf adsorbents (125 µm). Experiments were carried out at fixed adsorbent dose, (1 gm) at room temperature (27 ^{0}C) and neutral pH (7.0). The study of the effect of adsorbent dosage variation on the adsorption of phenol is shown in Figure 4.5. This experiment was carried out at a concentration of 100 mg/L. It was observed that the % removal increased with an increase in adsorbent dosage. At a lower adsorbent weight of 0.5 grams, adsorption sites are few and which results in a low phenol being adsorbed on it (Sai *et al.*, 2016). At 1 gram of the adsorbent, the adsorption of phenol is much This is a result of the availability of more adsorption sites on the adsorbent for phenol adsorption (Ghanshyam *et al.*, 2013).

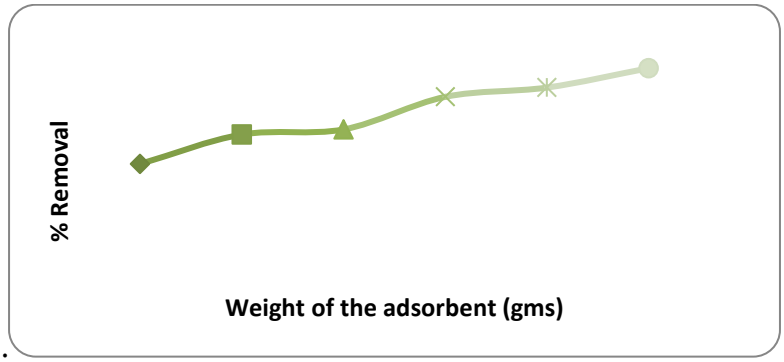

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Figure 3: Variation in % Removal of phenol from effluent with Dosage of adsorbent

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Effect of pH

The effect of adsorbent dosage on the adsorption of phenol was investigated using neem leaf adsorbents(125 µm). Experiments were carried out at a fixed adsorbent dose, (1gms) at room temperature (27 ^{0}C) and 100 mg/l concentration of phenol. The study of the effect of pH variation on the adsorption of phenol is shown in Figure 4.6. The pH was varied between 2 and 9. At a lower pH of 2, the percentage removal of phenol is at optimum. This is owing to the fact that phenol is usually present in an un-dissociated form in high acidic conditions, this makes it more attractive to the negative carbon of the adsorbent site. As the pH value tends towards 7 there is a steady decrease in percentage removal of the phenol and a sharp drop after pH 7.

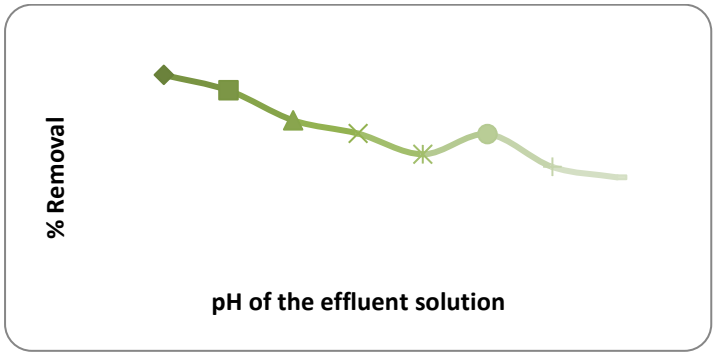

Figure 4: Variation in % Removal of Phenol from Effluent with pH of Solution

This means that at a high pH value, the phenol ion is highly negative in charge. This means that there will be a higher electrostatic repulsion force between the carbon in the adsorbent and the phenol negative ion and this repulsion force prevents further adsorption of phenol. This is a negation of the work of (Abdelwahab, 2013), in which optimum percentage removal takes place at pH 2 which corresponds to the work of (Sai *et al.*, 2016) indicating that optimum percentage removal takes place at pH 2.

Effect of Temperature

The effect of adsorbent dosage on the adsorption of phenol was investigated using neem leaf adsorbents(125 µm). Experiments were carried out at a fixed adsorbent dose, (1 gm) at room temperature (27 ^{0}C) and 100 mg/l initial concentration of phenol. The study of the effect of temperature variation on the adsorption of phenol is shown in Figure 4.7 The temperature varied between 27 and 50.

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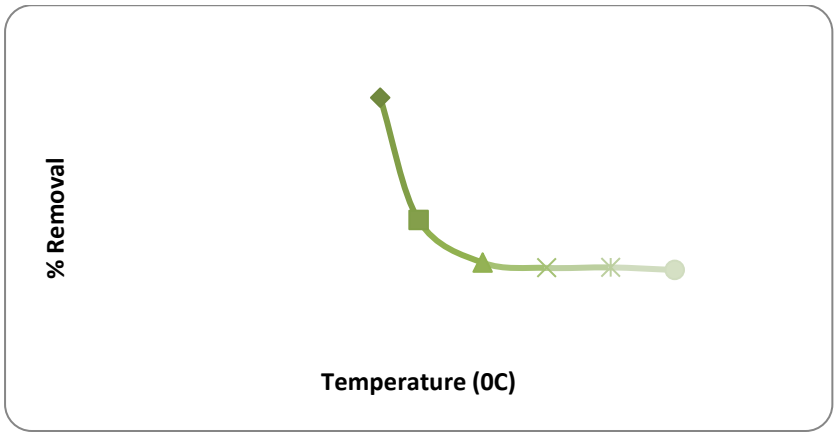

Figure 5: Variation in % Removal of phenol effluent with the temperature of the solution

Optimum adsorption takes place at the lowest temperature 27 ^{0}C and as temperature increases, percentage adsorption decreases. The decrease in adsorption at increasing temperatures is due to the weakening of the adsorption site of the adsorbent which results in the weakening of the sorptive force between the phenol and sorptive site of the adsorbent (Abdelwahab, 2013).

Isotherm Studies

The equilibrium relationship between adsorbent and adsorbate is determined by adsorption isotherm which is the ratio between the amount of adsorbed and the residual solute in solution at a fixed temperature at equilibrium (Foo *et al.*, 2012). Table 4.2 summarises the results of both Langmuir and Freundlich isotherms and the plots of their graphs are presented in figure 4.8 and 4.9 respectively. The comparison of the results in Table 4.2 indicates that Freundlich isotherm best describes the adsorption of phenol by carbonized neem leaves adsorbent as can be seen from the higher correlation coefficient R^2 =0.955 as against Langmuir of 0.9135. The K_f =1.219 and n=05.0304 are the Freundlich adsorption constants indicating the adsorption capacity and adsorption intensity respectively. The value n > 1 indicates favourable and heterogeneous adsorption. The R_L value of the Langmuir model indicates that the nature of the adsorption process is favourable.

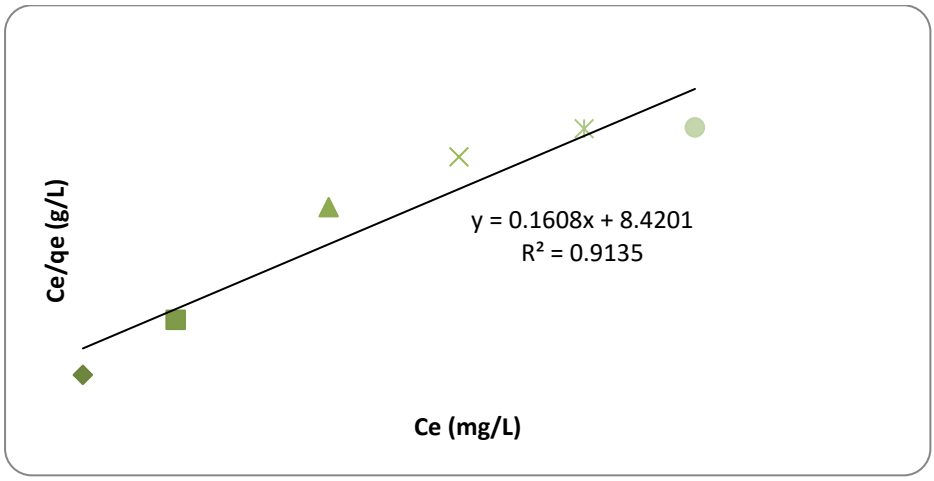

Figure 6: Langmuir isotherm model linearized to equilibrium data for Phenol adsorption by Carbonized Neem leaves.

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The characteristics of the Langmuir isotherm can also be explained by the separation factor R_L.

$$R_L = \frac{1}{1+KCo}$$

This indicates the shape of the isotherm and the nature of the adsorption process given below:

R_L Value	**Nature of Proces**
$R_L = 0$	Irreversible
$R_L > 1$	Unfavourable
$R_L = 1$	Linear
$0 < R_L < 1$	Favourable

The values of the Langmuir isotherm as well as the correlation coefficient (R^2) of the Langmuir equation for the adsorption of phenol are shown in Table 4.2

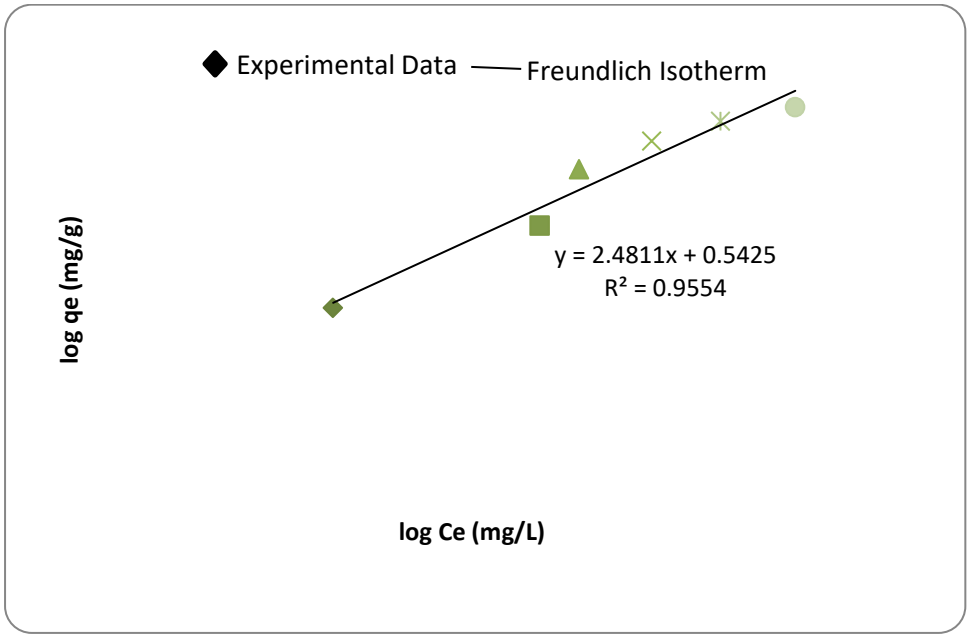

Figure 7: Freundlich isotherm model linearized to equilibrium data for Phenol adsorption on Carbonized Neem leaves.

The values and parameters of the Langmuir and Freundlich isotherm are shown in Table 4.2

Table 1: Values and parameters of the Freundlich and the Langmuir isotherm models for the adsorption of phenol.

Langmuir Isotherm				Freundlich Isotherm		
q_{max} (mg/g)		R_L	R^2	k_f (mg/g)	n	R^2
0.109		$1.67x10^{-5}$	0.926	1.219	5.0304	0.955

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The kinetic model of the adsorption is important in that it controls the efficiency of the adsorption process. The Intra-particle diffusion models was used to describe the adsorption process.

Intra-Particle Diffusion Model

The intra-particle diffusion model is based on the assumption that surface sorption is the rate-limiting step. From the plot of q_t versus $t^{1/2}$, a linear relationship is observed from which q_e and K_p were determined from the slope and intercept respectively.

The intercept observed on the plots reflects the boundary layer effect. The larger the intercept, the greater the contribution of the surface sorption in the rate-controlling step.

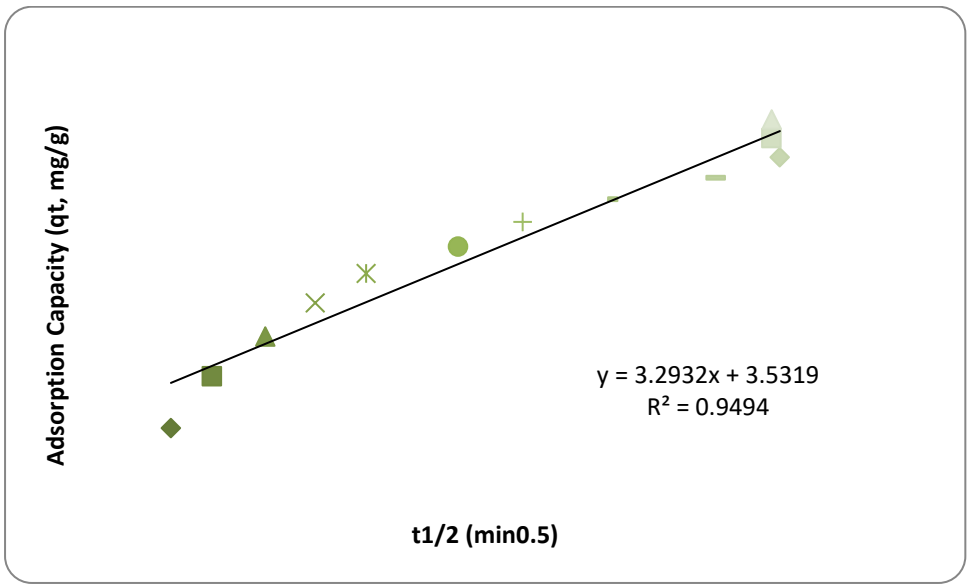

Figure 8: Intra-Particle Diffusion Model of phenol adsorption

The results observed from Figure 4.10 show that the line does not pass through the origin, indicating the existence of some boundary layer effect and further shows that the intra-particle diffusion was not the only rate-limiting step. The kinetic constants of the model are presented in Table 4.3. The tested kinetic models fitted well to the adsorption kinetic data with high correlation coefficients ($R^2 > 0.9$)

Table 2: Parameter of Intra-Particle diffusion models for the adsorption of phenol

Kinetic Model	Constant	Concentration (100 mg/L)
Intra-particle diffusion	k_p (mg/g.min$^{0.5}$)	0.2883
	R^2	0.949

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IMPLICATION TO RESEARCH AND PRACTICE

Researchers will be focusing on the best conditions for the performance of carbonized neem leaves as a treatment of phenol in industrial effluents.

CONCLUSION

Judging from the results it was observed that the maximum adsorption of the phenol (i.e. greater % removal) is seen at the agitation time of 150 minutes and the percentage removal is 58 %. As the agitation time further increased the adsorption remained fairly constant. From the factor of the effect of adsorbent dosage on the percentage removal, as the adsorbent dosage increases the percentage removal of phenol increases. The percentage removal decreases as the pH increases and the temperature effect is the inverse of the percentage removal. From these results obtained for carbonized neem leaves, its adsorption capacity for phenol is low, 58 % when compared to commercial activated carbon.

FUTURE RESEARCH

i. The use of other preparatory methods such as chemical activation can be further researched to see if the adsorption capacity will be enhanced.

ii. More studies on the kinetic modern should be carried out so that it finds useful applications in the design of adsorption columns and systems for industrial effluent treatment applications.

iii. Further study should be conducted to evaluate the effect of more parameters such as; agitation speed and other conditions.

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