



Performance of Activated Carbon Prepared from Sawdust as an Adsorbent for Endosulfan Pesticide

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Abstract Pesticides are used world over to protect crops. However, these are poisonous chemicals, and consuming water contaminated with pesticides exceeding safe concentrations could negatively affect human health. A study was conducted to investigate the effectiveness of sawdust carbon as an adsorbent for Endosulfan Pesticide. Laboratory batch experiments using activated carbon and commercial activated carbon were carried out. In each batch, 200 ml of contaminated water were mixed with 0.2 mg of carbon. Investigation was done on the effect of varying pH, agitation rate and contact time, and pesticide concentration, on pesticide adsorption capacity. Activated sawdust carbon was prepared by placing sawdust in a furnace at a temperature of 750°C for one hour. In order to activate the sawdust carbon, steam was passed through it for 30 minutes. Activation of sawdust carbon generated micropores. Iodine number was used to measure the extent of micropore development and iodine rate of adsorption was 658 mg/g of activated sawdust carbon. Once it was established that the activated carbon had capacity to adsorb the contaminant, batch experiments were done by mixing saw dust with contaminated water and sieving it so as to assess the rate of pesticide removal. Similar batches were prepared with commercial carbon for comparison purposes. The removal capacity reached equilibrium at different times depending on the initial concentration of the pesticide. For concentration of less than 30 mg/L, the equilibrium time increased linearly with pesticide concentration. When it was higher than 30 mg/L the equilibrium time remained constant at 250 minutes. The adsorption capacity increased with increasing initial solution pH, reaching an optimum at pH 7, after which time the adsorption capacity decreased with increasing pH. It also increased linearly with the rate of agitation and with increasing pesticide concentration, resulting in pesticide removal rate of higher than 95%. This compared well with commercial activated carbon. The results are best described using the Langmuir and Freundlich isotherms and pseudo first order kinetic adsorption models. Although many outlets are available for the utilization of wood fines, economical disposal of sawdust, shavings, and waste chips remains a problem of growing concern to the wood industry. Piles of sawdust (which can result to fire) are normally sited next to timber industry. Saw dust particle blown up by wind result to pollution of the environment. Disposal of sawdust waste in water bodies also result to adverse effects on the aquatic life. There is therefore need to continually invent methods of using sawdust waste. The study concluded that activated carbon prepared from sawdust can be used as an alternative adsorbent for pesticide removal. Further research is required on the disposal of used carbon to ensure that it doesn't create new environmental problems such as release of toxics into the air, water and soil.

Keywords Sawdust; Activated carbon; Endosulfan; Pesticide; Adsorbent.

1. Introduction

Pests and diseases are responsible for 42-57% loss in agricultural produce in Kenya [1]. The conventional and common way of pest and disease control is through the use of pesticides. Because of their capacity to reduce incidences of vector borne diseases, pesticides have continued to be developed, produced and used all over the world. Until the 1940s the agricultural industry relied

for pest and disease control on a number of natural organic substances; including pyrethrins and nicotine [2]. Since mid-1940's the approach to pest and disease control has been revolutionized by the development of organochlorine compounds, carbamates and organophosphates. Organochlorines (OCs) represent an important group of Persistent Organic Pollutants (POPs) which have caused worldwide concern as toxic



environmental contaminants [3]. The lipophilic nature, hydrophobicity and low chemical and biological degradation rates of organochlorine pesticides have led to their accumulation in biological tissues and the subsequent magnification of chemicals in organisms, progressing through to the food chain. [4], [5], [6], [7]. Various pesticides have been found to contaminate water bodies [8], [9], [10], [11]. The ecological effects of pesticides (and other organic contaminants) are varied and are often inter-related. Effects at the organism or ecological level are usually considered to be an early warning indicator of potential human health impacts.

The major types of effects include death of the organism; cancers, tumors and lesions on animals; suppression of immune system; disruption of the endocrine (hormonal) system; cellular and DNA damage; teratogenic effects (physical deformities such as hooked beaks on birds); poor fish health marked by low red to white blood cell ratio and excessive slime on fish scales and gills. Chemical weed control has the effect of reducing habitat, decreasing the number of weed species, and of shifting the balance of species in the plant community. Pesticides also affect soil fertility by inhibiting nitrification, reducing the uptake of nitrogen by plants, and interfering with the role of microbes in soil [12].

Endosulfan, is one of the most widely used pesticides in the third world countries [13],[14],[15]. Technologies are available for removal of pesticides from contaminated water. These include precipitation, coagulation- Flocculation, ozonation, photo-Fenton degradation, catalytic wet oxidation, electrochemical treatment biological methods, reverse osmosis membranes, and adsorption [16],[17],[18]. However, adsorption is recognized as the most efficient and promising fundamental approach in the treatment of contaminated water. Activated carbon, among a large variety of adsorbents, is still by far the most important one in environmental pollution control. This due to its large surface area, porous structure and ability to selectively adsorb contaminants [19]. The use of commercial activated carbon is expensive and as a result numerous low cost alternatives have been studied for the removal of pollutants from contaminated water. These including eucalyptus bark [20]; seaweeds [21]; coir-pith [22]; peach nut shells [23]; zeolite tuff [24]; river bed sand [25]; bagasse fly ash [26]; wastes from agriculture [27-31] and wood industry [32-35]. However, for non-conventional pesticide adsorbents to fit in the class of low cost alternatives, they have to be locally available. Therefore, additional research is justifiable to develop alternative, cost effective adsorbents to eliminate

pollutants from water in Kenya's farming communities. The aim of this study was therefore to evaluate the potential use of sawdust carbon in the removal of pesticides from contaminated water.

2. Materials and Methods

2.1. Materials, Reagents and Equipment/Apparatus

The materials and reagents which were used in this research include:- concentrated hydrochloric acid, sodium thiosulphate, iodine resublimed crystals, potassium iodide, potassium iodate, anhydrous sodium sulphate, commercial activated carbon (Nuchar WV-DC), iodine, water, Endosulfan, N-hexane, Whatman filter paper grade 1, Nitrogen gas, Gas Chromatograph (model 910 Buck Scientific), detector ECD using Helium as the carrier gas and nitrogen as the make-up gas, UV spectrometer (Model Shimadzu), Electric furnace (model Esklo furnace) with nitrogen as inert gas, Shaker (Promax 2020), Pump, Magnetic stirrer, Assorted volumetric pipettes and burettes, amber bottles, beakers assorted sizes and volumetric flasks, Funnels, Micro scale balance, syringe.

2.2. Synthetic Sample Preparation

All the reagents were of analytical grade. All glassware were cleaned and dried in oven at 110°C. Technical endosulfan standard of 95 % purity was purchased from Kobian Company an agent of Sigma-Aldrich. It was used as the main adsorbate. Distilled water was employed for preparation of all solution and reagents, n-hexane of 99.9% purity was used. Stock solution of endosulfan was made by adding 50mg of endosulfan (95%) to 50ml of hexane. Standards of 10mg/l, 20mg/l, 30mg/l and 40mg/l were prepared from the stock solution. Working samples were made by adding required stock solution to the predetermined quantity of distilled water.

2.3. Analytical Methods

Standard methods, APHA (1995) were used for the analysis of the sample water and ASTM-D 4607-94 was used for determination of iodine number. Gas Chromatograph (Model 910, Buck Scientific GC) fitted with mid-bore (dia.0.53mm) column of 15m long was used for the analysis of endosulfan with Electron Capture Detection. The temperature for column, injector and detector was maintained at 220, 174 and 250°C, respectively. Helium gas (99.9%) purity was used as the



carrier gas at inlet pressure of 18psi while nitrogen gas (99.9) purity was used as a make-up gas at the pressure of 70 psi. Before the actual measurement, the GC column was conditioned for 24 h to avoid column bleeding and contamination of the detector and to maintain ideal condition for every GC run. The retention time required for elution of endosulfan peak using gas chromatograph was determined by injecting a standard sample. The concentrations of the samples were calculated by comparison between known concentration of endosulfan areas and the corresponding sample peak areas.

2.4. Extraction of Endosulfan

Extraction of Endosulfan from samples was carried out using the *Liquid-liquid* method. 100ml of sample water containing endosulfan was extracted in a 125ml-separating funnel using n-hexane. Extraction was done three times using 20ml of n-hexane. During the extraction process the sample mixed with n-hexane mixture was shaken for 5mins and then allowed to settle for 2minutes. The separated layer of the n-hexane was passed through a 60mm bed of an hydrous sodium sulphate to absorb any trace of moisture present in the n-hexane fraction. The extracted n-hexane was then concentrated using rotary evaporator to 2ml that was then used for analysis. From concentrated extract 5 μ l of sample was injected to the GC-ECD machine by use of syringe and the remaining concentration was determined.

2.5. Preparation of Activated Carbon from Sawdust

Sun-dried cypress timber of 2000mm by 150mmx50mm was purchased from a timber yard near JKUAT. Sawdust was prepared from this timber using circular saw machine in the university carpentry workshop. The sawdust was sieved into different sizes and the particles passing sieve opening 4.76mm but retained on sieve opening 2mm was adopted for the experiments. The sawdust fraction was then dehydrated at temperature of 105°C for 24 hours in an electric oven. This was done to ensure that all samples were at the same state of moisture content. The sawdust in a soapstone crucible was heated in a furnace in the presence of nitrogen gas flow of 50cm³ per minute to the required temperature peaks. The nitrogen gas was used to create an inert environment. The carbonization temperatures chosen for this process were 700, 750, 800, 850, 900°C with a soaking period of 30mins and 60mins at each of the temperatures. Soaking period is the time

period the material is carbonized at a particular temperature. Due to limited resources, additional soaking periods were not tried. Steam activation was concurrently done for each of the process for a time span of 30mins after the soaking time. Steam was produced using a pressure cooker. After each run, the products were allowed to cool inside the furnace, then removed and packed for the characterization experiments.

2.6. Iodine Number Test on Micropore Development in the Activated Carbon.

Required quantity of activated carbon sample was ground to pass through 325 microns mesh screen from which 1 gram of each carbon sample were introduced to different conical flask. 10.0-ml of hydrochloric acid solution was put into each flask containing carbon. The flask was corked and swirled gently until the carbon was completely wet. The flask stoppers were vented and placed in a hot plate where it was allowed to boil gently for 30 seconds. This was to remove any sulfur, which could interfere with the test results. The flask was removed from the hot plate and allowed to cool at room temperature. 100ml of the standardized iodine solution was then added to the flask. The flask was immediately corked and the contents shaken vigorously for 30 seconds. The mixture was filtered by gravity, and 25ml of the first portion of the filtrate was discarded and the remainder collected in a beaker.

The filtrate was mixed in the beaker using a stirring rod from which 50ml of the filtrate was pipette into 250ml Erlenmeyer flask. The 50ml sample was titrated with standardized sodium thiosulphate solution until the yellow color had almost disappeared. 2ml of starch solution was added and titration was continued until the blue color just disappeared. The volume of sodium thiosulphate used was then recorded.

2.7. Adsorption Studies using Batch experiments

The effects of physiochemical parameters e.g. agitation rate, pH, contact time and initial concentration on the capability of the sample carbon to remove pesticides from water was evaluated. The adsorption isotherms and kinetics of the adsorption of the pesticides to the activated carbon were also evaluated.

2.7.1. Assessment of Agitation rate on Adsorption of Pesticides

Equal amounts of activated carbon 0.2g were added to four Erlenmeyer flasks. Distilled water 200ml spiked



with 10mg/l of adsorbate/endosulfan was then added to the flasks. The flasks were subjected to different agitation rates of 100,150,200 and 250 rpm for a period of one hour. The pesticide remaining in the sample was extracted after one hour and analyzed using GC-ECD.

2.7.2. Assessment of pH on Adsorption Pesticides

Equal amounts of activated carbon 0.2g were added to five Erlenmeyer flasks. To the flask 200ml of distilled spiked with 10mg/l of adsorbate/endosulfan was then added. The pH of the water at different flasks was adjusted to 2, 4, 7, 10 and 12 by adding either few drops of diluted hydrochloric acid or sodium hydroxide (0.1mol^{-1}).The flasks were subjected to the agitation rate determined at 2.7.1.The pesticide remaining in the sample was extracted after one hour and analyzed using GC-ECD.

2.7.3. Assessment of contact time and initial concentration of endosulfan on adsorption of pesticides.

A series of contact time experiment for endosulfan were carried out at different concentrations that is (10, 20, 30 and 40mg/l) at room temperature.0.2g of activated carbon was added to 10 different Erlenmeyer flasks.200 ml of distilled water spiked with 10mg/l of endosulfan and pH adjusted to 7 were then added to flask. The mix was agitated at the optimum rate 200rpm for different time periods. Contact time of 30, 60, 90, 120, 150, 180, 210, 240, 270, 300 minutes were used. The above steps were repeated for distilled water spiked with 20, 30 and 40mg/l of endosulfan.

2.8. Equilibrium Studies using Batch Experiments

Batch experiments were conducted for the development of the adsorption isotherms for the activated sawdust carbons under the same experimental conditions. Erlenmeyer flasks (250ml) were used. Endosulfan spiked synthetic water sample (200ml) at initial concentrations of 10,20 30 and 40mg/l were placed in the flasks and equal mass of 0.2 g of activated carbon was added and kept in a gyratory shaker at room temperature for 5hrs to reach equilibrium of the solid – solution mixture. Similar procedure was followed with another set of Erlenmeyer flask containing the same endosulfan concentration without activated carbon to be used as a blank. The pH was adjusted to 7 by adding either few drops of diluted hydrochloric acid or sodium hydroxide (0.1mol^{-1}). The flasks were then removed from the shaker and the final concentration of endosulfan in the solution was analyzed using GC-ECD.

The samples were filtered prior to analysis.

2.9. Adsorption Kinetics Studies using Batch Experiments

The procedures of the kinetic batch experiments were basically identical to those of equilibrium test. The aqueous samples were taken at predetermined time intervals, and the concentrations of endosulfan were similarly measured.

3. Results and Discussion

3.1. Optimum Temperature for Activation of Sawdust Carbon

To determine the characteristics of sawdust carbon as adsorbent, the sawdust carbon was activated using steam in furnace. To increase the porosity of the sawdust the contact time of the steam (soaking) time was varied. Soaking times of 30 min and 60 minutes respectively were tried; at temperatures ranging from 700 to 900°C. Due to limited resources additional soaking periods were not tried. To check for micropore development in the material iodine number test was carried out [37], of the two soaking times, 60 minutes gave the higher iodine number. As the furnace temperature was increased, the iodine number increased but started to decrease after a temperature of 800 ° C. It was concluded that the best soaking time was 60 minutes and the best activation temperature range was 750-800 deg C (Fig. 1). In this study sawdust carbon was activated at 750 deg C. This temperature range is comparable to ranges used elsewhere [38]. Increasing in activation temperature reduced macropore development, resulting in reduced adsorption of methylene Blue. As temperature increased more micropores were developed thus increasing the amount of iodine adsorbed (Fig.1).At temperature of 900°C.The micropore developed started to collapse increasing the macropore development

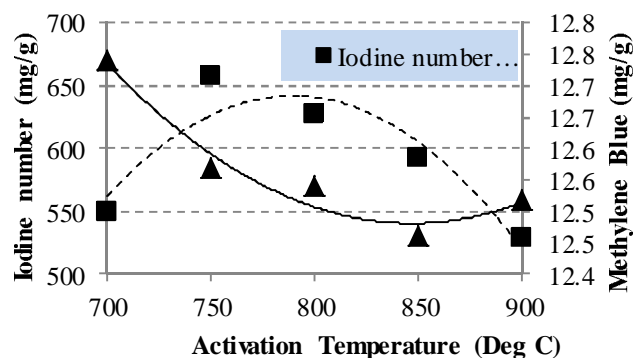


Fig. 1. Optimum range of activation temperature for sawdust carbon



3.2. Effect of Initial Concentration of Pesticide, Contact Time, Agitation and pH on Adsorption

It was observed that, an increase in initial concentration decreased the percentage binding (Fig. 2). These observations can be explained by the fact that at very low concentrations of pesticide, the ratio of adsorptive surface area to the total endosulfan molecules available is high and thus, there is a greater chance for pesticide removal. Thus at low initial pesticide concentrations, the removal capacity is higher. When pesticide concentration is increased, binding sites become more quickly saturated as amount of adsorbent remained constant. The same trend was observed [39-42].

The contact time required for low concentration of endosulfan (10-20mg/l) to reach equilibrium was 1-3 hours (Fig. 3). However, for endosulfan with higher initial concentration (30-40mg/l), longer equilibrium time of 4-5 hours was required. Three consecutive mass transport steps are associated with the adsorption of solute from solution by porous adsorbent [43]. First the adsorbate migrates through the solution that is, i.e. film diffusion, followed by solute movement from particle surface into interior site by pore diffusion and finally the adsorbate is adsorbed into the active sites at the adsorbent particle. This phenomenon takes relatively long contact time.

The optimum agitation rate was found to be 200rpm (Fig. 4). The rate of adsorption is controlled by either film diffusion or pore diffusion, depending on the amount of agitation in the system. If relatively little agitation occurs between the carbon particle and the fluid, the surface film of the liquid around the particle will be thick and film diffusion will likely be the rate-limiting step. If adequate mixing is provided, the rate of film diffusion will increase to the point that pore diffusion becomes the rate-limiting step. According to [44], pore diffusion is generally rate limiting for batch-type contacting systems, which provide a high degree of agitation.

Higher adsorption was recorded at lower pH as compared to higher pH (Fig. 5). At lower pH the amino groups of protein and water molecules become protonated due to increase of H⁺ ion concentration. As a result the adsorbent surface becomes positively charged and negatively charged S and O of endosulfan electrostatically attracted on surface. Whilst at higher pH, OH⁻ of polysaccharides groups become negatively charged consequently repulsion forces come to play between adsorbent surface and adsorbate molecules

[45]. The optimum pH was found to be 7.

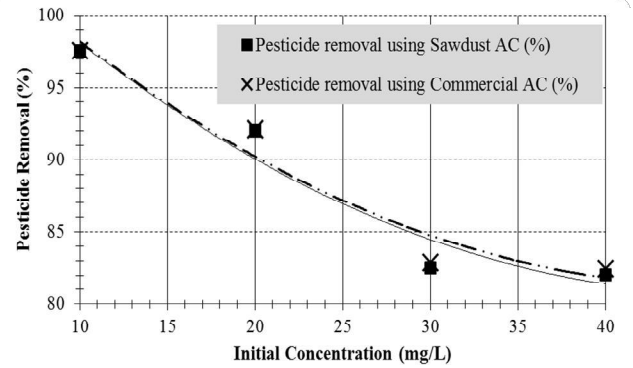


Fig. 2. Effect of initial pesticide concentration on pesticide adsorption

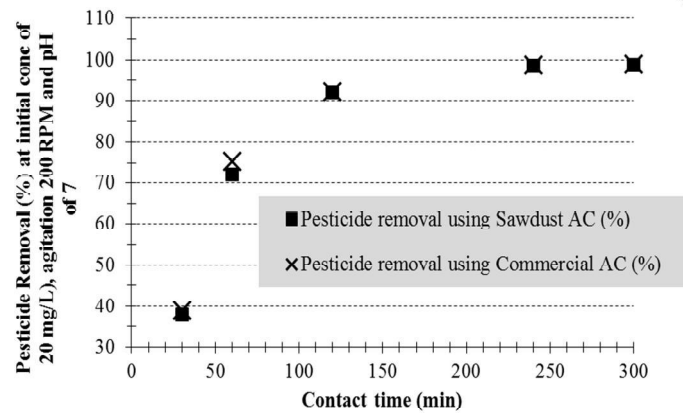


Fig. 3. Effect of contact time on adsorption

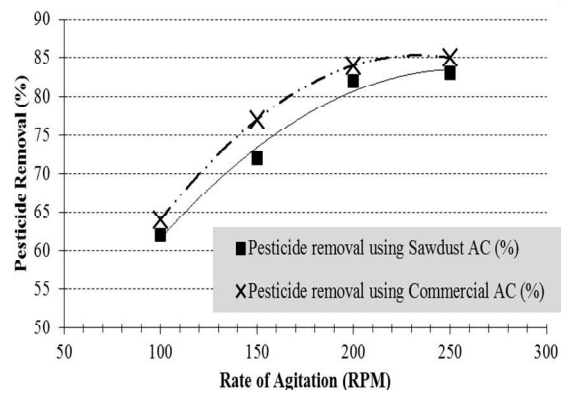


Fig. 4. Effect of agitation rate on adsorption

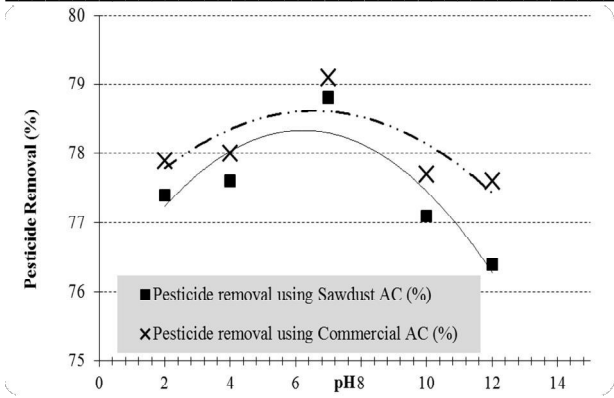


Fig. 5. Effect of pH on adsorption

3.3. Isotherm Models

The Adsorption Isotherm equation (Eq. 1) is used to calculate the amount of solute adsorbed (mg/g). In the equation q_e is the amount of solute adsorbed at equilibrium (mg/L). C_o and C_e (mg/l) are the initial and equilibrium solute concentrations in solution. V is the volume (L) of the solution and W is the mass (g) of dry adsorbent used. Using Equation 1 the Amount adsorbed at equilibrium was calculated (Table 1).

$$q_e = \frac{(C_o - C_e) V}{W} \dots\dots\dots (1)$$

Isotherm models are for predicting the equilibrium distribution of the solute [22]. In this study Langmuir and Freundlich models were used. In the Langmuir model (Eq. 2) q_{max} is the maximum adsorption capacity while b is a constant (L/mg). Eq.3 represents the linear form of the Langmuir model

$$q_e = \frac{q_{max} b C_e}{1 + b C_e} \dots\dots\dots (2)$$

$$\frac{1}{q_e} = \frac{1}{q_{max} b C_e} + \frac{1}{q_{max}} \dots\dots\dots (3)$$

Using Eq. 3 the adsorption of endosulfan on Sawdust Ac and Commercial Ac was plotted as a function of the equilibrium concentration of the pesticide remaining in solution (mg/l). The plot $1/q_e$ Vs $1/C_e$, gave a straight line (Fig. 6) with a slope of $1/(b q_{max})$, which indicates that sawdust, and commercial activated carbon follow the Langmuir isotherm.

The Langmuir and Freundlich parameters and correlation coefficients evaluated from the model are

given in Table 2 .The values of Langmuir constants indicate favorable conditions for adsorption. The essential characteristics of the Langmuir isotherm can be expressed in terms of a dimensionless equilibrium parameter RL [46]. Which is defined by:-

$$R_L = \frac{1}{1 + b C_o} \dots\dots\dots (4)$$

Where b is the Langmuir constant and C_o is the highest pesticide concentration (mg/l).The value R_L indicates the type of the isotherm to be either unfavorable ($R_L > 1$): Linear ($R_L = 1$); Favorable ($0 < R_L < 1$) or irreversible ($R_L = 0$).The value R_L was found to be 0.02 and 0.03 for sawdust carbon and Commercial activated carbon respectively. This confirmed that the activated sawdust carbon is favorable for adsorption of pesticides.

Freundlich isotherm model is given Eq. 5 where; q_e is the equilibrium surface (with units of mass adsorbate/mass adsorbent) and C_e is the solution concentration (with units of mass/volume).Eq. 6 is the linearized form of equation 5 where, K and $1/n$ are Freundlich capacity factor and Freundlich intensity parameter respectfully.

$$q_e = \frac{X}{M} = K C_e^{1/n} \dots\dots\dots (5)$$

$$\text{Log } q_e = \text{log } K + 1/n \text{ log } C_e \dots\dots\dots (6)$$

Plotting $\text{log}(x/m)$ verses $\text{Log } C_e$, the slope $1/n$ and the intercept $\text{log } k$ can be obtained. Freundlich Isotherms was developed by plotting $\text{log } q_e$ verses $\text{Log } C_e$. The data fitted Freundlich isotherm.(Fig. 7) and the Freundlich parameters and correlation coefficients were evaluated and shown in Table 2.

The Slope $1/n$ ranging between 0 and 1, is a measure of adsorption intensity or surface heterogeneity, becoming more heterogeneous as its value gets closer to zero [45]. A value for $1/n$ below one indicates a normal Langmuir isotherm while $1/n$ above one is indicative of cooperative adsorption [45].The value of $1/n$ for both samples was found range between 0 and 1 indicating a favorable adsorption. The equilibrium data were well described by both Langmuir and Freundlich isotherms. Similar results were reported [39].



Table 1: Pesticide adsorption at equilibrium

Initial conc. of pesticide (C _o)mg/l	Sawdust dosage (W)g	Volume of water (L)	Conc. of pesticide at Equilibrium (C _e)mg/l	Pesticide removed (C _o -C _e)mg/l	Amount adsorbed at equilibrium q _e (mg/g)
Sawdust Ac					
40	0.2	0.2	1.5	38.5	38.5
30	0.2	0.2	1	29	29
20	0.2	0.2	0.5	19.5	19.5
10	0.2	0.2	0.2	9.8	9.8
Commercial Ac					
40	0.2	0.2	0.8	39.2	39.2
30	0.2	0.2	0.6	29.4	29.4
20	0.2	0.2	0.37	19.63	19.63
10	0.2	0.2	0.15	9.85	9.85

The removal percentage for activated sawdust at the different initial concentration were as follows; 40mg/l was 96.25%; 30mg/l was 96.67%; 20mg/l was 97.5 and 10mg/l was 98%, while for the commercial activated carbon the removal percentage at the different initial concentration were as follows: 40mg/l was 98%, 30mg/l was 98%, 20mg/l was 98.15 and 10mg/l was 98.5%. The removal capacity of activated sawdust (table 1) at equilibrium was comparable to the activated commercial material. At low pesticide concentration of 10mg/l activated sawdust achieved its highest removal percentage of (98%), while that of the activated commercial carbon was 98.5%.

Table 2: Langmuir and Freundlich isotherm constants for Endosulfan

Langmuir isotherm		
Parameter	Cypress Activated Carbon	Commercial Activated carbon
b(mg-)	1.31	0.788
R ²	0.998	0.995
R _L	0.0187	0.031
Freundlich isotherm		
1/n	0.61	0.81
K _F	30	45.5
R ²	0.997	0.997

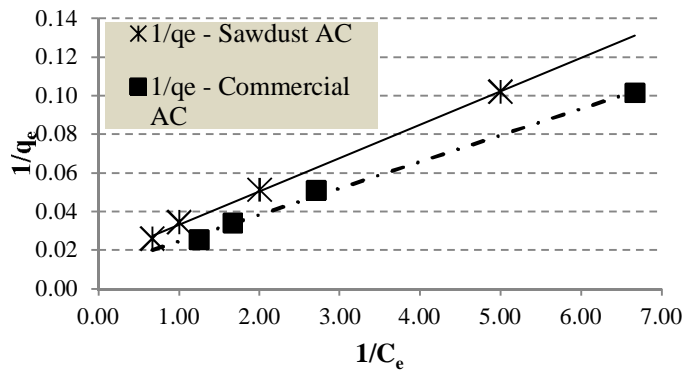


Fig. 6. Langmuir plot for the adsorption of Endosulfan on Sawdust AC and Commercial Ac.

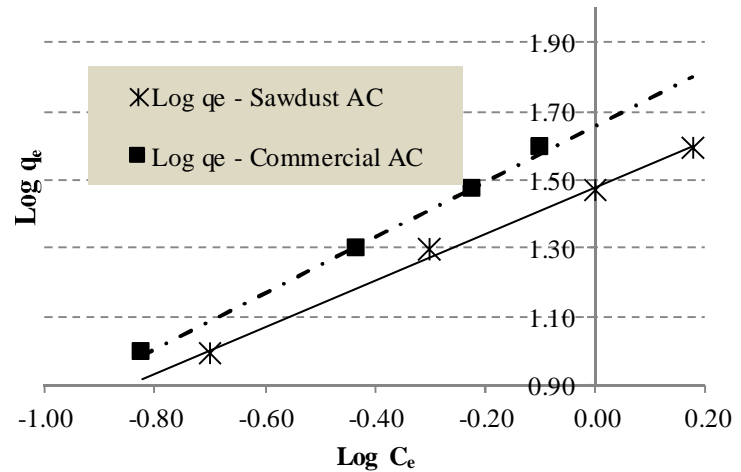


Fig. 7. Freundlich plot for the adsorption of Endosulfan on Sawdust Ac and Commercial Ac.

3.4. Kinetic Models

Adsorption kinetic models are used for modelling the removal of pollutants from waters. In this study, the adsorption - sorption kinetics of endosulfan on activated sawdust carbon and commercial activate carbon were assessed. The data was fitted on the pseudo-first order model represented by Equation 7 [47] and the pseudo-second order models represented by Eq. 8[48].

$$\log(q_{e1} - q_t) = \log q_{e1} - \frac{k_1}{2.303} t \dots\dots\dots (7)$$

$$\frac{t}{q_t} = \frac{1}{k_2 q_{e2}^2} + \frac{1}{q_{e2}} t \dots\dots\dots (8)$$



Where, q_t is the adsorption capacity (mg/g) at time t , q_e is the equilibrium adsorption capacity (mg/g) and k_1 is the pseudo-first order rate constant (min^{-1}) which is obtained from the straight line plots of $\log (q_e - q_t)$ against t for the endosulfan at different initial concentration (Figure 8). q_{e2} (mg/g) is the equilibrium adsorption capacity and k_2 is the pseudo second order rate constant (q/mg/min).

Table 3: Pseudo first order rates

Sawdust Ac				
$C_o(\text{mg/l})$	k_1	$q_e\text{-cal}$	R_1^2	$q_e\text{-exp}$
40	0.016	38	0.9994	38.1
30	0.016	30	0.9965	28.9
20	0.025	19.9	0.992	19.3
10	0.035	9.7	0.9996	9.8

Commercial Ac

$C_o(\text{mg/l})$	k_1	$q_e\text{-cal}$	R_1^2	$q_e\text{-exp}$
40	0.018	38.4	0.994	38.2
30	0.018	29.5	0.999	29
20	0.026	21.3	0.9862	19.4
10	0.052	10	0.9877	9.8

Table 4: Pseudo-second order rates

Sawdust Ac				
$C_o(\text{mg/l})$	K_2	$q_e\text{-cal}$	R_2^2	$q_e\text{-exp}$
40	0.00067	42	0.9866	38.1
30	0.00080	32	0.9842	28.9
20	0.00233	21	0.992	19.3
10	0.01478	10	0.9988	9.8

Commercial Ac				
$C_o(\text{mg/l})$	K_2	$q_e\text{-cal}$	R_2^2	$q_e\text{-exp}$
40	0.01133	40.9	0.9892	38.2
30	0.00088	32.7	0.9796	29
20	0.00210	21.5	0.9843	19.4
10	0.02910	10	0.9882	9.8

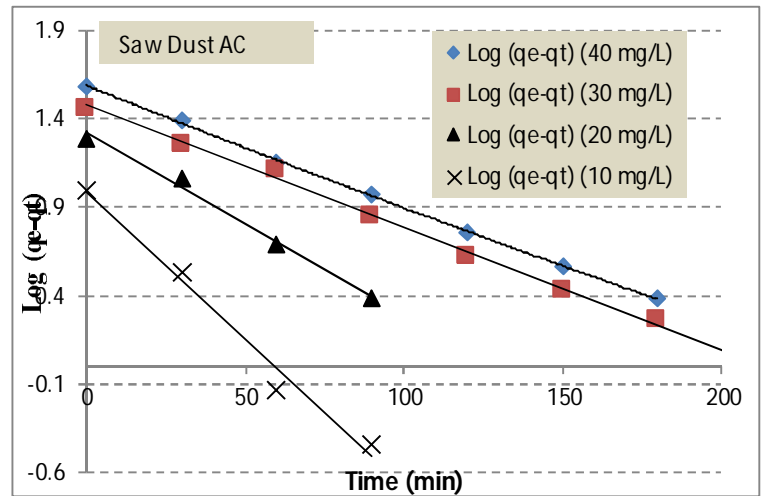


Fig. 8a. Pseudo-first order model plot for endosulfan adsorption on Sawdust AC

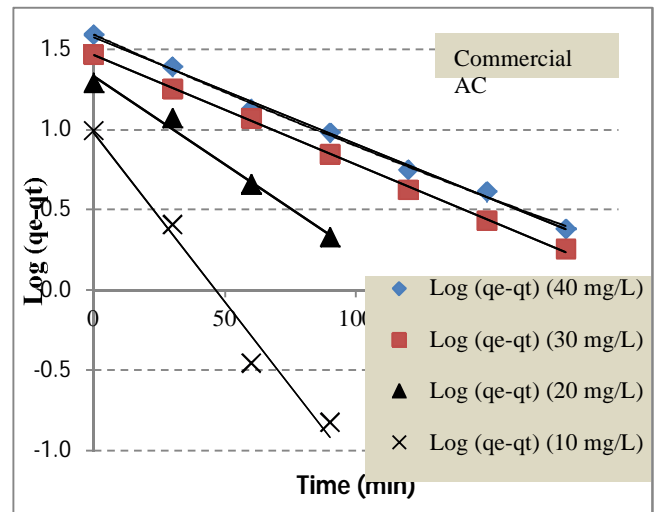


Fig. 8b. Pseudo-first order model plot for endosulfan adsorption on commercial AC

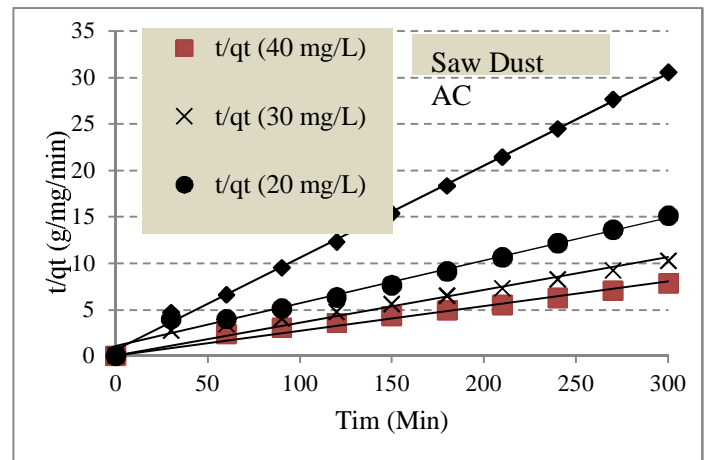


Fig. 9a. Pseudo-second order model plot for endosulfan adsorption on Sawdust AC

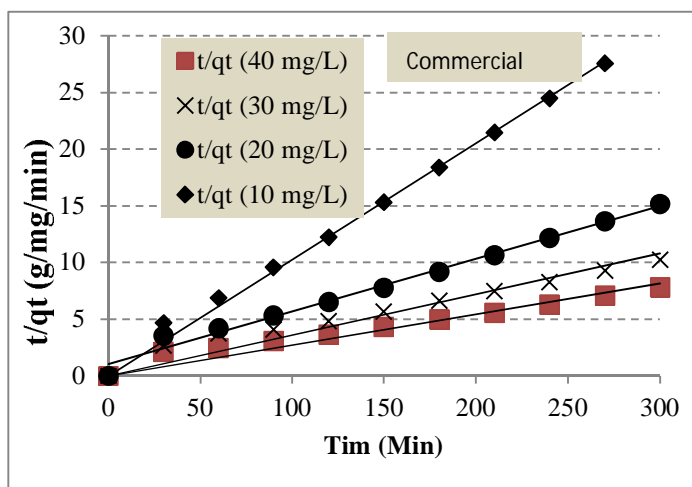


Fig. 9b. Pseudo-second order model plot for endosulfan adsorption on Commercial AC

The linear plot of $\log(q_e - q_t)$ versus t (Fig. 8a & b) for pseudo-first order model and t/q_t versus t (Fig. 9a & b) for pseudo second order model were done. The value of the amount of adsorption at equilibrium (q_e -exp), the rate constants K_1 and K_2 , calculated amount of adsorption at equilibrium (q_e -cal) and the correlation coefficient, R_1^2 and R_2^2 are shown in Table 3 and Table 4 respectively. It was found that pseudo-first order model provided the best description of the data obtained as shown in the highest values of correlation coefficients and the close agreement between the experimental (q_e -exp) values and the calculated values (q_e -cal) obtained from the linear plots. This shows that physical adsorption process could have been predominant physical [42].

4. Conclusions

The observations made from the research indicate that sawdust a waste material from the timber industry can be used to prepare activated carbon that can be used as an adsorbent for pesticides. The temperature of 750 °C with a soaking period of 60 minutes and an activation period of 30 minutes with steam was found to produce an adsorbent material with a high surface area hence large adsorption capacity as was indicated by the large iodine number of 658mg/g. The removal percentage of pesticides by both sawdust activated carbon and commercial activated carbon was observed to be over 95% at equilibrium conditions indicating that the sawdust activated carbon could make a good adsorbent just as the commercial activated carbon. The equilibrium data for the two activated carbons, fitted very well in Langmuir and Freundlich adsorption isotherm models. The values of Langmuir and Freundlich constants indicated favorable conditions for adsorption. Two-adsorption kinetics models i.e. the pseudo-first model

and the pseudo-second models were studied. The pseudo-first model provided the best description for the experimental data obtained compared to the pseudo-second order kinetic models as was indicated in the correlation coefficients. This showed that the adsorption mechanism could have been predominantly physical.

5. Recommendations

Further research on cost analysis between commercial activated carbon and sawdust activated carbon should be done to conclusively report that the sawdust material is cheaper than activated commercial carbon. The activated carbon was produced by consideration of only two soaking period that is 30 and 60 mins. More research should be done to find out the effect of soaking the carbon at different durations e.g. 90 mins, 100 mins and 110 mins. In this study sawdust carbon was produced by use of pyrolysis; other methods of carbon production for example the use of chemicals (potassium hydroxide) can also be investigated. Finally further research on the disposal of used carbon is required to ensure that it doesn't create new environmental problems such as release of toxics into the air, water and soil.

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