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Activated Carbon Derived from Cassava Peels (*Manihot esculenta*) for the Removal of Diclofenac

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Abstract: *This study explored the transformation of cassava peels (Manihot esculenta) into activated carbon via chemical activation with phosphoric acid, and investigated by varying impregnation ratios and temperatures to optimize adsorption efficiency for diclofenac removal. It examined the feasibility of using cassava peels as precursors for activated carbon specifically for diclofenac removal. Cassava peels were impregnated with phosphoric acid at a ratio of 1:1.5 and 1:2 followed by carbonization at 450 °C, 500 °C for 1 and 2 hours to convert organic matters into a carbon-rich residue. The parameter analysis was conducted to characterize the activated carbon samples, by assessing parameters such as yield, pH, moisture content, functional groups, and particle size. Subsequently, the carbonized samples were activated using an activating agent to enhance their adsorption properties from CPAC1 to CPAC8. The resulting activated carbon from cassava peels demonstrated the yields of activated carbona were 33.88%, 37.98%, 44.01%, 45.54%, 35.1%, 34.98%, 45.99% and 48.84%, respectively. The pH values of these activated carbons were 6.75, 6.78, 6.71, 6.78, 6.61, 6.75, 6.5 and 6.78, respectively. The moisture contents of activated carbons were 2.38%, 3.04%, 3.64%, 2.37%, 2.94%, 2.75%, 2.44% and 2.33%, respectively. Conversely, the selected three conditions based on characteristics of the activated carbon derived from cassava peels displayed corresponding percentages of removal efficiency of 84.32%, 90.46% and 91.35%, respectively. The study utilized a series of batch adsorption experiments to investigate the adsorption capacity, kinetics, and isotherms of produced activated carbons.The adsorption process was found to be highly dependent on contact time, initial concentration, and pH. The activated carbon exhibited a maximum adsorption capacity of 10 mg/g at optimal conditions. The adsorption data were best described by the Freundlich isotherm model, indicating a heterogeneous surface with a non-uniform distribution of heat of adsorption. Kinetic studies revealed that the adsorption followed a pseudo-second-order model, suggesting chemisorption as the rate-limiting step. These findings demonstrate the potential of cassava peels derived activated carbon as a cost-effective and sustainable adsorbent for the removal of Diclofenac contaminants from water.*

Keywords: Activated carbon, Cassava peels, Kinetic adsorption, Isotherm adsorption, Diclofenac.

1. INTRODUCTION

Emerging pollutants represent a significant global threat to water quality, posing serious risks to human health and ecosystems. These pollutants originate from widespread use of synthetic organic chemicals in everyday products, eventually becoming environmental waste. This waste can potentially contaminate water bodies, which serve as sources of drinking water, thereby compromising raw water quality [1]. Some studies have detected these compounds and their metabolites in surface water, groundwater, and treated drinking water at low concentrations [2-10].

Some porous materials, including carbonaceous materials, metal organic frameworks (MOFs), magnetic materials,

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mesoporous silica, clays and biosorbents have been tested as adsorbents for the treatment of pharmaceutical and personal care products (PPCPs) in water effluent [4]. Among these, activated carbon (AC) stands out in large-scale water remediation as it possesses a highly porous structure that provides high surface area and pore volume, excellent adsorption properties at ambient conditions, hydrophobicity, good recyclability and stability, easy regeneration method and environmentally friendly nature [5].

Activated carbon is now made from fossil sources and therefore with feedstocks that are depletable, i. e. not sustainable and expensive [6]. To make the process competitive, much effort has been put into using low-cost abundant or even waste materials like biomass and agricultural residues [7]. Beyond economic considerations, using these materials for making activated carbon is a drastic solution to decrease the volume of waste thrown into the environment. Chemical activation has been adapted to produce porous carbons from numerous agricultural wastes, mostly including potato residue [8], olive stones, cotton waste [9], corn straws [10], nutshells [11], pomegranate seeds [12], sugarcane bagasse [13] and cassava peels [14]. For different cassava varieties, KU 72 is a high-yield cassava variety in Cambodia, recognized for its disease resistance and lower cyanogenic glycoside levels, ensuring safer consumption. It is ideal for research on improving productivity, sustainable agriculture, and food safety, making it valuable for enhancing cassava cultivation and food security [15]. They have been found to exhibit superior performance in a broad range of applications, such as adsorption catalysis, gas storage and separation energy storage [16]. While activated carbon production is valuable for pollution control, it has environmental downsides. The process is energy-intensive, often leading to high carbon emissions, and chemical activation can create waste and disposal concerns. Sourcing from non-renewable materials like coal further increases its carbon footprint, emphasizing the need for sustainable practices in production [17].

Therefore, this study aimed at utilizing the cassava peels as agricultural waste for producing environmental, economic, social benefits through proper waste utilization, source conservation and a valuable sustainable product. Diclofenac removal is justified due to its high environmental toxicity, especially to aquatic life, and increased cardiovascular risks compared to safer non-steroidal anti-inflammatory drugs (NSAIDs) like ibuprofen or naproxen. The main objective is also production and characterization of cassava peels, to determine the techniques such as adsorption kinetic, isotherm model, surface functional group test and investigate the effect of carbonization step of activated carbon production from cassava peels on diclofenac removal.

2. METHODOLOGY

2.1 Collection of raw materials

To improve the worth of readily economical local and cheap material such as activated carbon, the variety of cassava peels (*Manihot esculenta*) was employed as the precursor. Large quantity of KU 72 cassava peels was provided from a farmer located in Steung Treng province of Cambodia's northeast region which primarily focuses on cassava food items as a cash crop. After that, they were taken to the GCA lab of the Faculty of Chemical and Food Engineering at the Institute of Technology of Cambodia.

2.2 Production of activated carbon

In this study, all chemicals utilized for activation were of analytical grade. The samples were prepared by a chemical activation process using phosphoric acid (H_3PO_4, supplied by Merck at 85% purity) as the activating agent. This method entailed blending the precursor material with a 10% weight of H_3PO_4 (activated carbon and phosphoric acid (CPAC)) prior to carbonization. After a thorough wash with tap and distilled water to remove residual soil and impurities, the cassava peels were brushed to strip the outer thin skin, cut into smaller pieces, and oven dried at 110 ºC for over night. The method entails preparation of the precursor material in the process of carbonization. A total of 100 g of samples was impregnated with activating agent solutions (H_3PO_4) in the desired weight ratios of 1:1.5 and 1:2 (Cassava peels : H_3PO_4), respectively. Initially, the treated samples were semi-carbonized by heating them to 300 ºC for 3 hours in a Nabertherm Muffle Furnace in the absence of oxygen, in the second stage carbonized to 450 °C and 500 °C for 1 and 2 hours, respectively. After cooling to room temperature, the activated carbons were thoroughly washed with distilled water and treated with sodium hydroxide (NaOH, 0.1 M) from Fisher Scientific International (Pellets Pure) to remove any phosphate ion traces. They were then washed extensively with distilled water until the pH of the ACs was between 6 and 7, oven-dried at 110 °C for 24 hours, ground, and sieved to obtain particles with diameters of 75 -106 µm. CPAC1 is cassava peel activated carbon with ratio of 1:1.5 (Cassava peels : H_3PO_4) at 450 °C for 1 hour, CPAC2 is cassava peel activated carbon with the ratio of 1:1.5 at 450 °C for 2 hours, CPAC3 is cassava peel activated carbon with the ratio of 1:2 at 450 °C for 1 hour, CPAC4 is cassava peels activated carbon with the ratio of 1:2 at 450 °C for 2 hours, CPAC5 cassava peel activated carbon with the ratio of 1:1.5 at 500 °C for 1 hour, CPAC6 is cassava peel activated carbon with the ratio of 1:1.5 at 500 °C for 2 hours, CPAC7 is cassava peel activated carbon with ratio of 1:2 at 500 °C for 1 hour and CPAC8 is cassava peel activated carbon with the ratio of 1:2 at 500 °C for 2 hours.

2.3 Characteristics of activated carbon

2.3.1 Process yield

The yield of the process was determined by percentage of the activated carbon mass to the initial raw material mass from **Eq. 1**.

$$\% \text{ Process yield (Py)} = \frac{M_1}{M_2} \times 100 \qquad \textbf{(}\text{Eq. 1}\textbf{)}$$

Where:
M_1 = mass of activated carbon (g)
M_2 = mass of raw material (g)

2.3.2 Moisture content

The moisture content of activated carbons was determined by using AOAC, 2012 Method. First, aluminum cups were placed in oven (Memmert Beshickung/loading Modell 100-800 from Germany) at 105 ºC for 1 h. Then, they were transferred in a desiccator for 15 mins to cool down and weighed (M_0). Next, 2 g of samples were weighed by analytical balance in aluminum cup (M_1) and dried at 105 ºC until it reached a constant weight (M_s). Each sample was done in duplicate. The moisture content was then calculated with the following formula (**Eq. 2**).

$$\% \text{ Moisture} = \frac{Ms-(M1-M0)}{M1} \times 100 \qquad \text{(Eq. 2)}$$

where:
M_0 = mass of aluminum cup (g)
M_1 = mass of sample (g)
M_s = mass of dried sample with an aluminum cup (g)

2.3.4 Particle size analysis

Laser diffraction particle size analyzer, SALD-2300 has been employed to determine the particle size distribution of synthesized activated carbon. Particle size distribution is calculated using the light intensity distribution pattern of scattered light that is generated from carbon particles when laser irradiates them. 0.2 g of activated carbon sample was mixed with distilled water in the dissipation bath of the analyzer; after that, it is circulated through the flow cell in the measuring unit where it is irradiated with a laser beam [18].

2.3.5 Surface functional groups

The solution of reaction bases (NaOH, Na_2CO_3, and $NaHCO_2$) were made at a concentration of 0.1 M with a volume of 50 ml and combined with 0.5 g of activated carbon in the 250 ml of Erlenmeyer flash. The experiment was carried out using an orbital shaker speed of 125 rpm for 48 hours and the Erlenmeyer flash was covered by parafilm. After 48 hours, the solution was filtered with a syringe filter of 0.45 µm. For the filtered solution of reaction bases (NaOH, Na_2CO_3, and $NaHCO_2$) 10 ml were titrated with solution hydrogen chloride HCl 0.1 M to determine the acid group. The titration runs were carried out in duplicate and employed methyl orange as an indicator.

For acid groups: $n = ([B]V_B - [A]V_{A.eq}.V_B/V_a)/m_{AC}$ (Eq. 3)

For basic groups: $n = ([A]V_A - [B]V_B.eq)/m_{AC}$ (Eq. 4)

where:

n = mole of solution reaction
[B] = concentration (g/l) of reaction solution bases
V_B = volume (L) of reaction solution bases
[A] = concentration (g/l) of solution acid use for titration
$V_{A.eq}$ = volume equilibrium (L) of solution acid use for titration
V_a = volume (L) of reaction solution base use for titration
$V_{B.eq}$ = volume equilibrium (L) of solution NaOH use for titration basic group
m_{AC} = mass of AC (g).

The activated carbon's acidic groups and the basic group were calculated by the following equations:

$$\text{Phenolic groups} = n_{NaOH} - n_{Na2CO3} \qquad \text{(Eq. 5)}$$

$$\text{Lactonic groups} = n_{Na2CO3} - n_{NaHCO3} \qquad \text{(Eq. 6)}$$

$$\text{Carboxylic groups} = n_{NaHCO3} \qquad \text{(Eq. 7)}$$

$$\text{Basic groups} = n_{HCl} \qquad \text{(Eq. 8)}$$

2.4 *Performance of activated carbon*

2.4.1 Kinetic adsorption

The study of the kinetic adsorption of Diclofenac (DCF) on the activated carbon was performed by Jar test to determine the adsorption capacity of DCF solution at different times. The solution was stirred with 0.1 g of activated carbon in 500 mL distilled water, at an agitation speed of 125 rpm. The experiment took time 48 hours to attain equilibrium starting from 0, 5, 10, 15, 30, 60, 120, 180, 240, 300, 360, 1440, and 2880 minutes. The mixture was then filtered by using a 0.45 µm syringe filter after attaining equilibrium. A UV-Vis spectrophotometer (Shimadzu UV-1280 UV-Vis Spectrophotometer) was used to quantify the concentrations of DCF in the solutions before and after adsorption at a wavelength of 290 nm. The intraparticle diffusion, pseudo-first order, and pseudo-second-order kinetic models were investigated. The following formulas were used to compute the quantity of adsorbate at the time, (mg/g) which is the amount of adsorbate at random time usually applied in kinetic adsorption.

$$q_e = \frac{Co-Ce}{m} \times V \qquad \text{(Eq. 9)}$$

$$q_t = \frac{Co-Ct}{m} \times V \qquad \text{(Eq.10)}$$

$$\text{Removal efficiency (\%)} = \frac{Co-Ce}{Co} \times 100 \qquad \text{(Eq. 11)}$$

where:
q_e = equilibrium adsorption capacity (mg/g)

q_t = adsorbate adsorbed onto adsorbent at time t (mg/g)
C_e = equilibrium concentration DCF (mg/L)
C_0 = initial concentration of DCF at time t=0 (mg/L)
C_t = concentration of DCF at any time t=t (mg/L)
V = volume of solution (L)
m = mass of activated carbon (g)

2.4.2 Isotherm adsorption

To obtain equilibrium isotherms or adsorption isotherm was conducted at the varying initial concentrations of the DCF solution 1, 2, 4, 6, 8, and 10 mg/L, each one-liter DCF solution contained 0.1 g of activated carbon based on cassava peels, respectively, in 500 mL distilled water. The solutions were held under an agitation speed of 125 rpm for 24 hours by utilizing the Jar Test by filtering using a 0.45 µm syringe filter. The UV-Vis spectrophotometer (Shimadzu UV-1280 UV-Vis Spectrophotometer) at wavelength 290 nm immediately assessed the filtrated solutions to estimate the final concentration of the studied solution based on the calibration curve. The collected data of the isotherm adsorption were modified to fit the Freundlich and Langmuir isotherm models. The following formulas can be used to compute the quantity of adsorbate at equilibrium time, which corresponds to the adsorption capacity, (mg/g).

3. RESULTS AND DISCUSSION

3.1 Characteristics of activated carbon

3.1.1 Physicochemical characteristics of activated carbon

The results of yield, moisture and pH of different activated carboons made from cassava peels are shown in **Table 1**.

Table 1. Physicochemical characteristics of activated carbon

Proximate components	Activated carbon made from cassava peels		
	Yield (%)	pH	Moisture (%)
CPAC1	33.88 ± 1.74^{c}	$6.75\pm0.01^{a,b}$	2.38 ± 0.06^{d}
CPAC2	37.98 ± 0.22^{c}	6.78 ± 0.00^{a}	$3.04\pm0.06^{a,b}$
CPAC3	44.01 ± 0.71^{b}	6.71 ± 0.03^{b}	3.64 ± 0.04^{a}
CPAC4	45.54 ± 0.06^{b}	6.78 ± 0.03^{a}	2.37 ± 0.04^{d}
CPAC5	35.1 ± 1.27^{c}	$6.61\pm0.01^{a,b}$	$2.94\pm0.05^{b,c}$
CPAC6	34.98 ± 2.83^{c}	$6.75\pm0.01^{a,b}$	$2.75\pm0.01^{b,c,d}$
CPAC7	$45.99\pm1.2^{a,b}$	$6.5\pm0.07^{a,b}$	$2.44\pm0.32^{b,c,d}$
CPAC8	48.84 ± 0.42^{a}	$6.78\pm0.03^{a,b}$	$2.33\pm0.16^{c,d}$

The values are presented as the mean ± standard deviation (n = 3). In the same column, values with different uppercase letters (a-d) indicate a significant difference ($p < 0.05$).

Table 1, where each result represents the mean ± standard deviation from measurements conducted in triplicate. The highest yield content of 48.84 ± 0.42% was observed in activated carbon produced with a 1:2 cassava ratio at 500 °C for two hours. Conversely, the lowest yield, 33.88 ± 1.74%, was achieved with a 1:1.5 cassava ratio and one hour of processing at 450 °C. Notably, the amount of the activation agent exhibits a consistent impact on yields at various carbonization temperatures; an increase in the impregnation ratio correlates with higher activated carbon yields [19]. Elevated temperatures can accelerate the breakdown of the initial material, leading to the development of larger pores and consequently, a greater absorption capacity [20]. Following two hours at 500 °C, the activated carbon derived from 1:2 cassava peels exhibited the highest pH of 6.78 ±0.01%. On the other hand, the activated carbon with the lowest fixed carbon content, 6.5 ± 0.07%, was produced through the processing of a 1:2 cassava ratio at 500 °C for one hour. Final samples generally exhibited pH values within the range of 6 to 7 [14].The highest moisture content of 3.64 ± 0.04% was recorded in activated carbon produced using a 1:2 cassava ratio at 450 °C for one hour. In contrast, the activated carbon obtained from a 1:2 cassava ratio treated for two hours at 500 °C yielded the lowest amount, 2.33 ± 0.16%. The moisture content significantly influences the characteristics of activated carbon, ideally ranging between 1 and 8% [14].

Based on these results, it can be concluded that they can be used as promising materials for obtaining activated carbon.

3.1.2 Surface functional groups of activated carbon

The results obtained from the 3 best selected conditions such as CPAC4, CPAC7 and CPAC8 of surface functional groups analysis based on results of physicochemical characteristics of activated carbon are enlisted in **Table 2**.

Table 2. Surface functional groups of activated carbon

Functional group	Activated Carbon made from cassava peels		
	Carboxylic	Latonic	Phenolic
CPAC4	0.64	0.14	0.31
CPAC7	0.64	0.14	0.32
CPAC8	0.65	0.15	0.33

*CPAC4= cassava peel activated carbon with the ratio of 1:2 at 450 °C for 2 hours
CPAC7= cassava peel activated carbon with the ratio of 1:2 at 500 °C for 1 hour
CPAC8= cassava peel activated carbon with the ratio of 1:2 at 500 °C for 2 hours

The carboxylic in every conditions had highest latonic and phenolic. Carboxylic acids are more reactive and play a significant role in adsorption processes due to their activated acyl groups. Lactonic acids and phenolic acids have different reactivity levels and contribute to the overall adsorption behavior of activated carbon [21]. The previous study showed that acidic functional groups like carboxylic (COOH), lactonic (-C=O) and phenolic (-OH-alternatively weakly basic C=O-) enhanced the adsorptive capacity of activated carbons in many types pollutants such as dyes, heavy metals, organics etc [22]. CPAC8 showed a significant increase in DCF removal due to acidic surface functional groups, especially carboxylic groups formed during oxidation, as seen in Table 2. Boehm titration confirmed these functional groups, and identified CPAC8 as the optimal condition for maximum DCF adsorption due to its high carboxylic content [23]. It is indicated that more acid groups of the activated carbon prepared from cassava peels could be introduced by a high temperature treatment (500 °C, 2 h).

3.1.3 Particle size of activated carbon

In this study, the activated carbon particles ranging from 75-106 µm were used.

Table 3. Particle size distribution of activated carbon

Distributions	Particle size (µm)
$D_x(10)$	18.08
$D_x(50)$	71.22
$D_x(90)$	103.01
D[4,3]	72.22

Table 3 illustrates the volume and number distribution of CPAC in µm. The results of Laser Diffiteration Particle Size analyser indicated that while there was the highest volume distribution of 128 µm, the number distribution was low. On the other hand, several particles below or equal to 60 µm had the most number distribution, but a less volume distribution. **Table 3** shows the particle size distribution of activated carbon employed in this work. Thus, D[4,3] means that the particle size is 72.22 µm and at graph Dx (90) only 10% of particules were bigger than 103.1 µm. Dx (50) represents the fact that 50% of the particles were below 71.22 µm, and Dx (10) means that, of the particles, 10% was below 18.08 µm. Accordingly, these findings indicated that the particle sizes were analysed in this study, which mean that the adsorption capacity increased when particle's size decreased [24].

3.2 Kinetic adsorption of activated carbon

3.2.1 Pseudo-first-order

The study of pseudo-first-order kinetics is crucial in activated carbon since it enables one to gain valuable information on the adsorption capacity, the rate of adsorption and comparison with experimental data as indicated in **Fig. 1**.

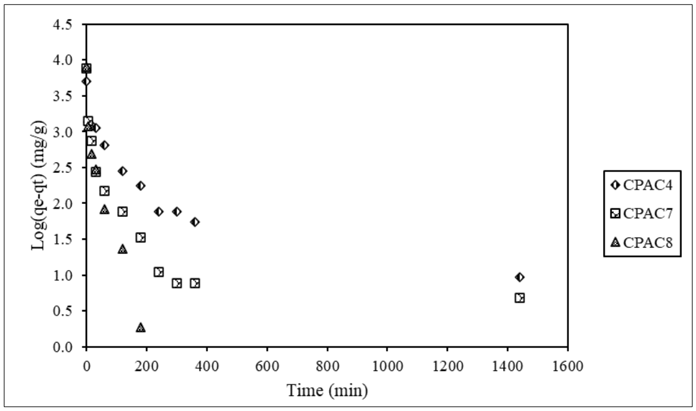

Fig. 1. Pseudo-first-order of activated carbon

The R^2 values for pseudo-first-order kinetics under three conditions were below 0.8, which is considered low. One study indicated that R^2 values typically range from 0.90 to 0.99 when fitting experimental data to pseudo-first-order kinetics [25]. An R^2 value lower than 0.8 indicated that the model may not be a good fit for the data, suggesting that the pseudo-first-order kinetic model might not sufficiently characterize the adsorption process of diclofenac onto activated carbon produced from cassava peels.

Table 4. Kinetic adsorption of activated carbon

Activated carbon	q_e (mg/g)	q_t (mg/g)	Removal efficiency (%)
CPAC4	40.57	42.11	84.32
CPAC7	48.68	45.17	90.46
CPAC8	49.56	45.61	91.35

* CPAC4= cassava peel activated carbon with the ratio of 1:2 at 450 °C for 2 hours
CPAC7= cassava peel activated carbon with the ratio of 1:2 at 500 °C for 1 hour
CPAC8= cassava peel activated carbon with the ratio of 1:2 at 500 °C for 2 hours

In **Table 4**, CPAC8 demonstrated a steady rise in removal capacity as contact time increased, eventually leveling off. This pattern suggested that activated carbon's surface had a finite number of active sites, leading to reduce the adsorption rates over time [26].

3.2.2 Pseudo-second-order

They are indispensable in the characterization of activated carbon since they provide information relating to the extent of its adsorption capacity, the rate of adsorption among others from pseudo-second-order adsorption data depicted in **Fig. 2**

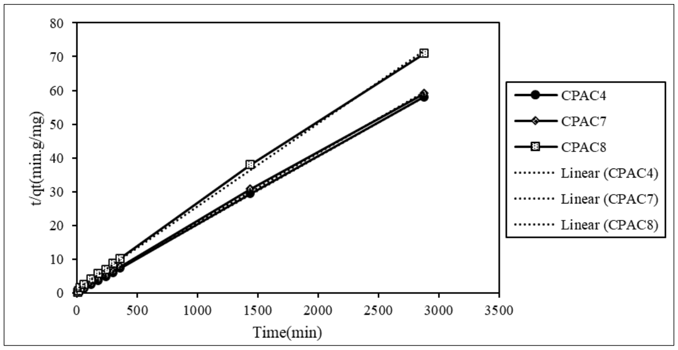

Fig. 2. Pseudo-second-order of activated carbon

Fig. 2 and **Table 4** indicated that the changes in adsorption capacity (qe) CPAC4, CPAC7 and CPAC8 were 40.57, 48.68 and 49.56 mg/g, respectively. This suggested that the adsorption of diclofenac on activated carbon derived from cassava peels likely conformed to the pseudo-second-order model. Furthermore, the R^2 values for the pseudo-second-order of CPAC4, CPAC7 and CPAC8 were 1, 0.997 and 0.999, respectively. Pseudo-second-order of activated carbon shown in **Fig. 2**, the kinetic of adsorption of CPAC4, CPAC7 and CPAC8 were best described by pseudo-second-order model, suggesting that the limiting step the adsorption process was chemisorption mechanism [27].

3.2.3 Intra particle diffusion

The intra particle diffusion was determined by the value q_t and $t^{1/2}$. The intra particle diffusion is actually a process that relate the movement of particles of a material through a substance or a medium.

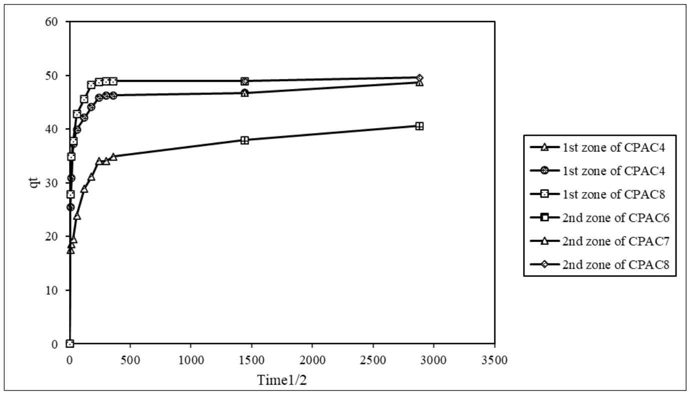

Fig. 3. Intra particle diffusion of activated carbon

Fig. 3 shows the intra particle diffusion kinetic model, which includes two straight line plots of q_t against $t^{1/2}$. These graphs give a rationale of the adsorptive characteristics DCF in AC. The first linear region (1st zone) that takes place in the initial 6 hours is characterized by the external mass transfer resistance related to the particle surface. This stage demonstrated the least time was taken to attain maximum sorption. The second linear plot (2nd zone) The absorbate transported from 6 hours to 48 hours through into the absorbance inner surface is slow, hence ascribed to intraparticle diffusion [28]. On the ability of activated carbon from cassava peels waste to adsorb, kinetic experiments were carried to determine isotherms for activated carbon. These experiments focused on the equilibrium adsorption at time point of 0 minute, 30 minutes, 1 hour, 3 hours, and 48 hours with initial diclofenac concentration of 10 mg/L. For the adsorbate, a longer contact time with the molecules of an adsorbent results in increased interactions and therefore enhanced partition to reach equilibrium so that extends result into enhancing isotherm; by providing more times chances for voc behave as film diffusion surface interaction longer contact periods mean that more molecules will have had the opportunity to absorb onto sites on an abosrbant. An increase in period of contact increases the absorption of pollutants up to a maximum concentration where adsorption equilibrium is achieved.

3.3 Isotherm adsorption

The results obtained from the highest adsorption's equilibrium such CPAC8 based on results of kinetic adsorption for study isotherm adsorption. The adsorption isotherm experiment applied either, Freundlich models to describe the relationship between diclofenac (DCF) and activated carbon (AC) from cassava peel. This procedure was explored at several DCF concentrations, including 1.033, 2.013, 3.974, 5.960, 7.998, to 10.048 at 500 ml at room temperature with an agitation speed of 125 rpm for 24 hours.

3.3.1 Freundlich model

Heterogeneous adsorption process is typically characterized by the Freundlich adsorption isotherm model which is widely used. It has however been established that adsorption that happens at a heterogogeous surface is a multilayer process. The mathematical expression that has been proposed to represent the Freundlich adsorption isotherm is given in the following nonlinear. In **Fig. 4**, the Freundlich model was plotted as a linear to be used to obtain some data regarding the optimization of the Freundlich model.

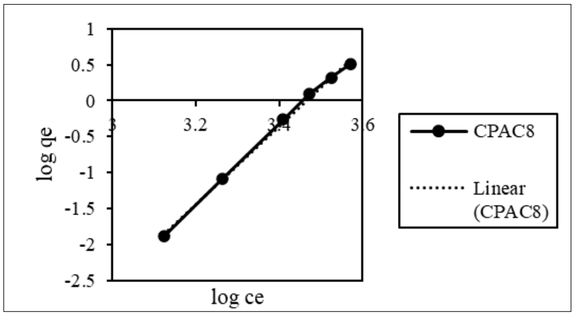

Fig. 4. Freundlich model of activated carbon

The R^2 value for Freundlich model was 0.9997, which is considered high. According to **Fig. 4,** the adsorption data were well fitted by Freundlich isotherm model accurately described the adsorption process, highlighting the heterogeneous nature of the adsorbent surface and suggesting multilayer adsorption [29].

4. CONCLUSIONS

The study successfully synthesized activated carbon from cassava peels using H_3PO_4 as the activating agent. Among various conditions tested, the activated carbon prepared from cassava peels at a ratio of 1:2 and activated at 500 °C for 2 hours demonstrated the highest adsorption capacity and efficiency for diclofenac removal. The equilibrium data fitted well with isotherm and kinetic models, indicating chemisorption and multilayer DCF adsorption mechanisms. The adsorption capacity was notably influenced by contact time, initial DCF concentration, and solution pH. The kinetics followed a pseudo-second-order model, indicating chemisorption as the dominant mechanism. The Freundlich isotherm model accurately described the suggesting multilayer adsorption. Overall, cassava peel-derived activated carbon emerges as a promising, low-cost, and environmentally friendly alternative to commercial activated carbons for DCF removal from water. Future research should focus on scaling up production, evaluating performance in real wastewater treatment, and exploring regeneration and reuse strategies to ensure practical application and economic viability.

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