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Intra-particle diffusion kinetic model for adsorption of Chlorpheniramine, Ibuprofen and Glipizide using OAC, HAC and BAC of mango kernel seed.

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ABSTRACT

Discharge of pharmaceutical drugs to the environment through various means such as industrial effluents, unused drugs or expired drugs have harmful effects to humans, animals and aquatic organisms. Thus, there is need to adsorb these drugs from pharmaceutical effluents. Surface functionalization of activated carbon has been a useful tool used in curbing this environmental menace. In this study, we evaluated intra-particle diffusion kinetic model for adsorption of Chlorpheniramine (CHP), Ibuprofen (IBU) and Glipizide (GLI) using Oxidized activated carbons (OAC), hydrophobic activated carbons (HAC) and basic activated carbons (BAC) prepared from mango kernel seed. Activated carbons (ACs) were prepared from mango kernel seed (MKSAC), through KOH activation. The ACs were oxidized with HNO_3 to produce OACs that were surface functionalized using ethylene diamine to produce BACs and ethylamine to produce HACs. The intra-particle diffusion kinetic models for adsorption of the three drugs were comparatively evaluated. From our result, equilibrium adsorption was reached faster on HAC and OAC than on BAC with kinetic adsorption data following well pseudo second order model much better than pseudo first order and intra-particle diffusion. The CHP uptake follows the order: HAC > OAC > BAC while adsorption of IBU and GLI follow the order: OAC > HAC > BAC. Adsorption of CHP was found fast reaching equilibrium in 120–150min for OAC, HAC and BAC. Similarly, IBU and GLI adsorption was found faster reaching equilibrium in 150min for OAC HAC and BAC. Drug uptake varies almost linearly with the half power of time in the early stages of drug adsorption. ki for CHP, IBU and GLI diffusion on BAC of almost all the adsorbent, show high values indicating faster diffusion this could be attributed to the electrostatic attraction between opposing charges of the drugs and BAC surfaces, but low for OAC and HAC.

Keywords: Adsorption, Intra-particle diffusion, Pharmaceutical effluents, Activated carbon, mango kernel seed.

INTRODUCTION

A pharmaceutical medicinal product is any chemical substance or product used in the medical diagnosis, cure, treatment, and prevention of diseases. It can also be called a medicine or medication [1]. Despite their numerous beneficial effects, discharge of pharmaceutical drugs to the environment through various means such as industrial effluents, unused drugs or expired drugs have harmful effects to humans, animals and aquatic organisms. Chlorpherinamine, ibuprofen and glipizide are some commonly produced drugs in the pharmaceutical industries in the environment. Chlorpherinamine is a histamine-antagonist used to manage allergic diseases [1]. There are reports of Chlorpheniramine posing dangerous effects to man when its residues are discharged into the environment. Uptake of chlorpheniramine by man and other organisms produces excess reactive oxygen species that could overwhelm the body's internal antioxidant defense system. This could lead to damage of proteins, nucleic acids and other intracellular macromolecules culminating to various diseases [2]. Ibuprofen is an example of nonsteroidal anti-inflammatory drug (NSAID) class of drugs. It is used to treat pain, fever, and inflammation [3]. The toxic effects of ibuprofen to aquatic animals are well-documented [4-8]. Glipizide is a member of

class of drugs called sulfonylureas. Glipizide enhances the release of insulin by the pancreas. Thus, it is used in the treatment of Diabetes mellitus [9]. Discharge of Glipizide contributes to environmental pollution with adverse effects ranging from hyponatremia, low blood glucose, allergic reactions, low blood cell counts, and liver damage [9]. Due to the outlined health implications of indiscriminate discharge of these drugs, there is need to adsorb these drugs from pharmaceutical effluents. Surface functionalization of activated carbon has been a useful tool used in curbing this environmental menace.

Activated carbon, also called activated charcoal is a type of carbon that has been processed to have tiny, low-volume pores that increase the surface area available for adsorption or chemical reactions [10, 11]. The words "active" and "activated" can be used interchangeably. Due to its high microporosity, one gram of activated carbon has a surface area greater than 3,000 m2 (32,000 sq ft), as measured by gas adsorption [0, 11, 12]. It is possible to obtain the activation level needed for practical application just from a large surface area. Adsorption properties are frequently improved by additional chemical treatment.

Typically, charcoal is used to create activated carbon. It is referred to as "activated coal" or "activated coke" depending on whether it is made from coal or coke. Storage of methane and hydrogen uses activated carbon [10, 11]. It also has numerous other uses, including decaffeination, gold extraction, solvent recovery, water purification, medicine, sewage treatment, air filters in gas masks and respirators, compressed air filters, teeth whitening, and the production of hydrogen chloride in dimly lit areas. Adsorption is the process by which atoms, ions, or molecules from a gas, liquid, or solid that has been broken down stick to a surface. A film of the adsorbate is formed on the adsorbent's surface as a result of this process. Unlike absorption, which occurs when a fluid (the absorbate) dissolves in or permeates a liquid or solid (the absorbent), this process does not involve absorption [11]. Absorption affects the entire volume of the material, whereas adsorption is a surface phenomenon. Both processes are referred to as "sorption," while "desorption" is the opposite of both. Mango is an edible fruit produced by *Mangifera indica*. It originated in the Myanmar, Bangladesh and India. Currently, mango has spread across the globe. Mango belongs to the family Anacardiaceae's [13]. Mango seeds are contained in the mango fruit [14]. The presence of pharmaceutical drugs in the effluents is well-documented. According to Ternes, 32 drugs were identified in the effluents of German municipal wastewater treatment plants with a maximum concentration of ibuprofen 3.4 μg/L and 0.53 μg/L in the effluent of sewage treatment plants and river streams, respectively [15]. In another study, in Portugal, 78 drugs were identified in hospital effluents, 50 out of which were found at low concentrations in the effluents of wastewater treatment plants. In that study, the maximum concentration of Ibuprofen in hospital effluents was found to vary from one hospital to another: university hospital (5.82 μg/L), general hospital (11.33 μg/L), paediatric hospital (38.15 μg/L) and maternity hospital (16.63 μg/L). However, after the treatment in a wastewater treatment plant, the maximum Ibuprofen concentration was found to be 0.37 μg/L [16].

The presence of these drugs in surface and wastewater can cause adverse effects such as feminization of male fish, aquatic toxicity, generation of anti-resistant bacteria and biological imbalance in the aquatic ecosystem [17]. Mutations in the genetic coding function are related to genotoxic substances and have been accused of causing cancers in the last few decades. Alabi and Shokunbi [18] reported the genotoxic effects of HWW on mice.

Research efforts have continued to improve and diversify the carbon surface functionality via different treatment methods to enable activated carbon to efficiently remove specific pollutants from wastewater [19]. Surface modification of activated carbon has been carried out chemically, physically, and biologically

after preparation [20]. Surface functionalization can introduce other dominating adsorption forces such as H-bonding, electrostatic interaction, and hydrophobic bonding. An activated carbon surface can be tailored to utilize such powerful adsorption forces via chemical modification.In this study, we evaluated intra-particle diffusion kinetic model for adsorption of Chlorpheniramine (CHP), Ibuprofen (IBU) and Glipizide (GLI) using Oxidized activated carbons (OAC), hydrophobic activated carbons (HAC) and basic activated carbons (BAC) prepared from mango kernel seed.

MATERIALS AND METHODS

Materials

All chemicals used were of analytical grade. Mango kernel seeds (MKS) were collected from Orji village, Amokwe in Udi Local Government area, Enugu State, Nigeria. They were identified by a taxonomist in Botany Department of Nnamdi Azikiwe University, Awka.

METHODS

Preparation of Activated carbon (AC)

Clean dry seeds (25g) were charred differently in a carbon steel tube (internal diameter 5.1 cm and length 61 cm) that was heated in a tube furnace (GSL-1100X-110V, MTI Corporation, USA) under a nitrogen atmosphere at 500 oC for 2 hours. In a weight ratio of 1:3, the chars were impregnated with saturated KOH solution. The mixtures were left in the oven (Hobersal Mon X B2-125 furnace, Hobersal, Spain) overnight at 120°C before being transferred to the tube furnace. The temperature was raised from room temperature to 550°C at a heating rate of ~8.6°C/min and was kept at 550°C for 1 hour under nitrogen for activation. The ACs produced were washed thoroughly with deionized water to remove residual alkalinity. To keep the acidic functional groups on the carbon in H-form, ACs were washed with 0.1M HCl followed by deionized water until no acidity was detected in the wash water. All the ACs of MKS, APS, and VTS were dried at 120 oC until they reached a constant weight. After cooling in a desiccator and grinding, a size range of each between two sieves of 1.19 mm and 0.25 mm was selected for characterization.

Surface modification of activated carbon AC

AC surfaces were heated with concentrated HNO_3 (1 g AC: 10 mL acid) at 80°C to almost dryness to produce Oxidized Activated Carbons (OACs), that were washed thoroughly until no acidity was detected in the wash water. OACs were dried at 120°C until a constant weight was achieved. The surfaces of OACs were functionalized to produce Basic Activated Carbons (BACs) by reacting 15 g of dry OAC with 25% thionyl chloride in toluene (100 mL) under reflux for 6 hours at 70°C. During this stage, surface carboxylic groups were converted to acetyl chloride groups. The carbon was left to dry in the oven at 85°C for 2 hours, and the carbon product was allowed to react with 100 mL of 0.75 M 1,2-diaminoethane (ethylene diamine) at 90°C under reflux for 24 hours. By the end of the reaction, nitrogen-containing functional groups were immobilized on the carbon surface via amide coupling.

For the preparation of hydrophobic activated carbons (HACs), 15 g of dry OAC each was allowed to react with 50 % thionyl chloride in toluene under reflux for 2 hours at 70°C. The product was allowed to cool and the solvents were dried using a rotary evaporator. After evaporation, the product was immediately mixed with 100 mL of ethylamine, and the mixture was kept at 90°C for 2 hours under reflux. At the end of the functionalization steps for both types of surface functionalized carbons (BACs and HACs), the carbons were purified via Soxhlet extraction using 150 mL of acetone for 6 hours, followed by washing with deionized water. Further washing using 2M HCl was carried out to remove residual amines from the carbon surface. Finally, the carbons were thoroughly washed with deionized water to remove residual acid. The carbons were allowed to dry at 70°C in an oven under

vacuum until a constant weight was reached. Surface functionalization using EDA produced Basic Activated Carbon-Mango Kernel Seed (BAC-MKS) of MKS. For hydrophobic carbons, surface modification using EA produced Hydrophobic Activated Carbon (HAC-MKS) of MKS.

Preparations of Stock Solutions of Chlorpheniramine, Glipizide, and Ibuprofen:

All the applied chemicals were of analytical reagent grade and purchased from Sigma Aldrich, while all the experiments were conducted using double-distilled deionized water.

Chlorpheniramine:A stock solution containing 50mg/L chlorpheniramine in maleate form, was prepared by dissolving 50mg of chlorpheniramine in deionized water in a 1000mL volumetric flask.

Glipizide: An initialdiluent was prepared through a mixture of water, acetonitrile, and methanol (3:1:1) and a mobile phase consisting of acetonitrile: 0.01M potassium di-hydrogen phosphate buffer (pH 3.5) in a ratio of 35:65, which was degassed by sonification.

A stock solution containing 50mg/L glipizide was prepared by accurately weighing about 50mg of glipizide and transferring the same into a 1000mL volumetric flask. Adding 50mL of diluent and keeping it in an ultrasonic bath until it dissolved completely. Make it up to the mark with the mobile phase and mix.

Ibuprofen: In a 1000mL volumetric flask, a stock solution containing 50mg/L ibuprofen was prepared by dissolving 50mg of ibuprofen in some 20% methanol to achieve complete solubility with deionized water. Adsorption experiments involving temperature, concentration, pH, and contact time variations will be carried out after serial dilution of standard solutions.

Drug analysis

High performance liquid chromatography (HPLC) equipped with a diode array detector (Agilent technologies, 1260 Infinity Series, USA) was used for the analysis of chlorpheniramine, ibuprofen, and Glipizide, at λmax 260 nm. The drugs were separated using a C18 analytical column and a mobile phase consisting of methanol and 20mm ammonium format buffer (pH 4.8) in a gradient elution mode with a flow rate of 45 μL/min and a column temperature of 40 °C. Calibration standards of the three drugs (1–20 mg/L) were prepared and standard curves were obtained by linear regression of the mean values of peak areas. Retention times for Chlorpheniramine, Ibuprofen, and Glipizide were found to be 2, 6.5, and 7 minutes, respectively. For chlorpheniramine, the linear range was found to be between 1–20 mg/L (R2: 0.9995). For Ibuprofen, the linear range was found to be between 1–20 mg/L (R2: 0.9996). For Glipizide, the linear range was found to be between 1–20 mg/L (R2: 0.9994). The accuracy of the method of analysis shows more than 98.2% recovery for both drugs [21].

Sorption Studies

The effect of initial pH on chlorpheniramine, ibuprofen, and glipizide adsorption was carried out by mixing 0.06 g of each of the carbons, OACs, HACs, and BACs, with 25 mL of drug (50 mg/L) solution in a glass vial. The initial pH was pre-adjusted to be between 3–11 for chlorpheniramine and 5–11 for Ibuprofen and Glipizide using 0.1M NaOH and/or 0.1M HCl prior to carbon mixing. After carbon mixing, the solution was kept under mechanical agitation until equilibrium was reached at 25 °C. The final pH was recorded and the residual drug concentration was analyzed. Initial pH 7.0 was found optimal for chlorpheniramine, ibuprofen, and glipizide adsorption and was selected as the initial pH for the kinetic and equilibrium studies. The effects of pH (3 to 11), contact time (30 to 180 min), adsorbent dose (0.1 to 0.5g) and concentrations of the drugs (50 to 250mg/L) were investigated. In each case, the quantities adsorbed and percentages removed by the adsorbent were calculated using the equation:

$$qe=(Co-Ce)V/m \quad (i)$$

$$qt=(Co-Ce)V/m \quad (ii)$$

%rem = (Co – Ce) 100/Co (iii)

Kinetic Experiment

The kinetic experiment of each of the drugs' adsorption was studied by mixing 0.1g of carbons from mango kernel seed (OACs, HACs, and BACs) with 50 mL (50mg/L) at an initial pH of 7.0. The adsorption mixtures were kept at 25°C under mechanical agitation for 180 min, during which the equilibrium was reached. At different time intervals, samples were separated for analysis. The filtrate obtained was then analyzed for chlorpheniramine, ibuprofen, and glipizide concentrations. Results obtained were analyzed using pseudo first-order, pseudo second-order and Intra-particle diffusion kinetic models.

Pseudo-first order; $In(q_e - q_t) = Inq_e - k_1t$ (iv)

Where,

q_t = the amount of drug adsorbed at any time t in mg/g

q_e = the amount of drug adsorbed at equilibrium time in mg/g

k_1 = pseudo first order rate constant in min^{-1}

Then a plot of $In(q_e - q_t)$ against t gives a negative slope, -k1 with intercept, Inq_e.

Pseudo-second order; $t/q_t = 1/k_2q_e^2 + t/q_e$ (v)

Where

t = time in minutes

k_2 = second order rate constant in $gmg^{-1}min^{-1}$

q_t = amount adsorbed at a given time t in mg/g

A plot of t/q_t against t enables the calculation of q_e from the slope and the rate constant k_2 is then evaluated from the intercept.

Intra-particle diffusion

$Qt = kit^{0.5} + C$ (vi)

ki = intra-particle diffusion rate constant

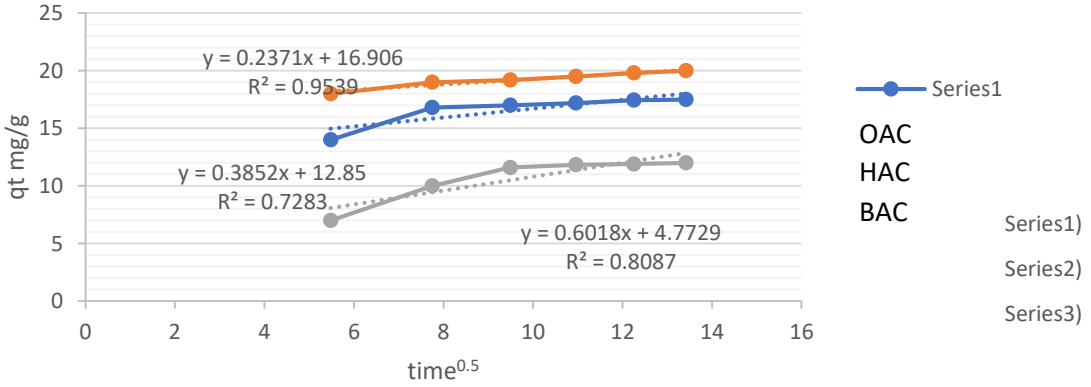
C = intercept related to the thickness of the boundary layer

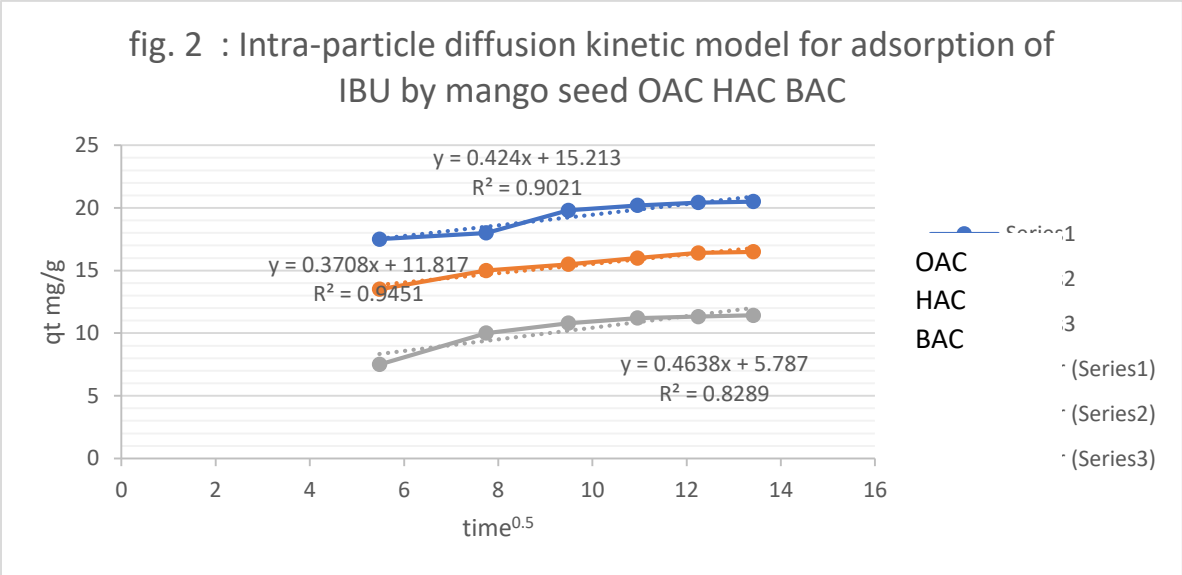
RESULTS AND DISCUSSION

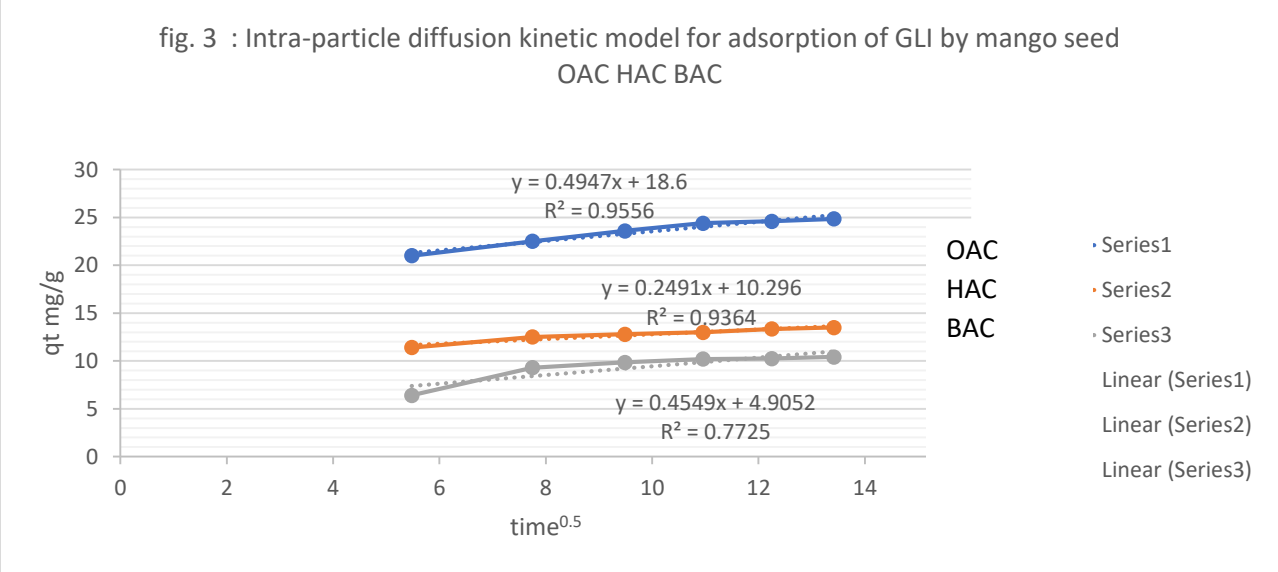
Intra-particle diffusion kinetic model for adsorption of Chlorpheniramine, Ibuprofen and Glipizide using OAC, HAC and BAC of mango kernel seed are shown in figures 1-3.

Adsorption of CHP was found fast reaching equilibrium in 120–150min for OAC, HAC and BAC. Similarly, IBU and GLI adsorption was found faster reaching equilibrium in 150min for OAC HAC and BAC. Drug uptake varies almost linearly with the half power of time in the early stages of drug adsorption. ki for CHP, IBU and GLI diffusion on BAC of almost all the adsorbent, show high values indicating faster diffusion mostly due to the electrostatic attraction between opposing charges of the drugs and BAC surfaces, but low for OAC and HAC.

fig. 1 : Intra-particle diffusion kinetic model for adsorption of CHP using mango seed OAC, HAC, and BAC







Drug uptake varies almost linearly with the half power of time in the early stages of drug adsorption. ki for CHP, IBU and GLI diffusion on BAC of mango kernel seed, show high values indicating faster diffusion mostly due to the electrostatic attraction between opposing charges of the drugs and BAC surfaces, but low for OAC and HAC.

CONCLUSION

Drug uptake varies almost linearly with the half power of time in the early stages of drug adsorption. ki for CHP, IBU and GLI diffusion on BAC of almost all the adsorbent, show high values indicating faster diffusion this could be attributed to the electrostatic attraction between opposing charges of the drugs and BAC surfaces, but low for OAC and HAC.

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