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RESEARCH ARTICLE

ADSORPTION THERMODYNAMICS OF PHENOBARBITAL SODIUM ON POWDERED *GARCINIA KOLA* SEEDS

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ABSTRACT

Effective remedy for common ailments associated with poisoning from environment, foods, drugs and cosmetics has gone beyond total dependence on orthodox medicines. Such ailments could require immediate attention which orthodox medicines (if available) might not provide before irreversible damages are done. The people of South Eastern Nigeria have been using *Garcinia kola* seeds as an antidote for the management of poison-related ailments. This research investigated the adsorptivity potential of the *Garcinia kola* seeds for weakly acidic antidepressant- phenobarbital sodium. Adsorption experiments were carried out by standard methods. The adsorption data were fitted to different isotherm models (Freundlich, Langmuir and Dubinin-Radushkevich) and the thermodynamic parameters (ΔHº, ΔGº and ΔSº) of adsorption were determined. The parameters were compared to those obtained with a standard adsorbent- activated charcoal. The adsorption parameters (Q_{max}, R_L, E and pH_{ZPC}) for *Garcinia kola* seed were 5.67 mg/g, 0.098, 2.26 KJ/mol and 7.12 respectively. The R^2 values of the linear plots were>0.9 while n constant of Freundlich isotherm was >1. The thermodynamic parameters, ΔGº, ΔHº, and ΔSº at 298 K were 1.165 KJ/mol, 18.308 KJ/mol and -0.058 KJ/mol.K respectively. The results show that maximum adsorption of *Garina kola* occurred below pH of 7.12. The adsorption and thermodynamics parameters showed that the adsorption processes of phenobarbital sodium onto *Garcinia kola* and charcoal were physisorption, favourable and non spontaneous at temperatures 298-318 K. *Garcinia kola* is a powerful adsorbent for phenobarbital and could be useful as an antidote for systemic barbiturate overdose.

INTRODUCTION

Adsorption is described as the spontaneous accumulation of the adsorbate (gases, liquid or vapour) on the surface of an adsorbent by chemical or physical process, thereby forming a surface or interface (Duraje and Madan, 2007). The process is governed by two important physicochemical aspects- adsorption equilibrium and adsorption kinetics; the former being established when the concentration of adsorbate is in dynamic balance with the concentration at the interface (Song *et al.*, 2009) while the latter describes the adsorption reaction with time and accompany diffusion process (Hui *et al*., 2009). The thermodynamics of adsorption parameters can be estimated from adsorption equilibrium constants with temperatures (Ho *et al.*, 2005; Ho and Ofomaja, 2005). Irrespective of adsorption mechanism-physisorption or chemisorptions-the process has been harnessed to purify the environment or detoxify biological systems by sequestration of toxic materials. To achieve this purpose, the uses of cheap, harmless and readily available adsorbents have been reported (Pavan *et al*., 2008; Han *et al*., 2006; Bulut and Aydin, 2006; Banat *et al.*, 2007; Ferrero, 2007; Ncibi *et al.*, 2007; Chakrabarti and Dutta, 2005; Hameed *et al.*, 2008). Seeds of *Garcinia kola* (Family-*Guittiferae*), popularly called bitter kola, have been utilized in folklore remedies by the Igbo people of the Southern Nigerian to treat ailments associated with poisoning, liver disorders, hepatitis, diarrhoea, laryngitis, bronchitis and gonorrhea (Adesina *et al.*, 1995; Iwu, 1993). The plant has been described as a “wonder plant” because every part of it has one or more medicinal value (Adegboye *et al*., 2008). Some of these uses depend on principles of adsorption. Extensive research findings on nutritional and phytochemical compositions of *Garcinia kola* have been reported (Adegboye *et al*., 2008; Afolabi *et al*., 2006; Adesuyi *et al*., 2012; Odebunmi *et al*., 2009). Phenobarbital sodium, PBT (Figure 1), chemically designated as 5-ethyl-5-phenylbarbituric acid or 5-ethyl-5-phenylhexahy dropyrimin din-2,4,6-trione is a long acting barbiturate that binds to gamma-aminobutyric acid A ($GABA_A$)-sensitive ion channels found in the central nervous system (CNS), where they allow an influx of chloride into cell membranes and, subsequently, hyperpolarize the postsynaptic neuron (Cami and Farre, 2003). The drug is a first-line agent of choice for treatment of neonatal seizures (Gokhale *et al*., 1997). It has a narrow therapeutic

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index (window), low V_d, pKa 7.4 (weakly acidic), duration of action 6-12 h, plasma half-life 48-144 h, urinary excretion 20-30%, 90% orally bioavailable and 20-30% protein bound. Drugs with a narrow therapeutic index (NTI-drugs) are drugs with small differences between their therapeutic and toxic doses, implying that small changes in dosage or interactions with other drugs could cause adverse effects; hence its dose must be titrated carefully and tight monitoring is required. Hemodynamic instability and pulmonary, cardiovascular and CNS depression have been associated with PBT overdose which can be eliminated through multiple-dose activated charcoal, MDAC (1 g/kg in children or 50-60 g in adults), urine alkalinization, extracorporeal (hemodialysis or hemoperfusion) and gastric lavage (Frenia *et al*., 1996). While MDAC accelerates PBT elimination, its clinical value in the treatment of barbiturate overdose has been questioned (Mohammed *et al*., 2001) and urine alkalinization is rarely achieved in clinical practice without unwanted effects of metabolic alkalosis or hypernatremia (Proudfoot *et al*., 2004); other approaches are, however, not cost beneficial. Therefore, we report an investigation on alternative antidote for PBT overdose using cheap, locally available and safe adsorbent, *Garcinia kola* for the management of drug related problems of barbiturates by testing the adsorption data on different isotherm equations.

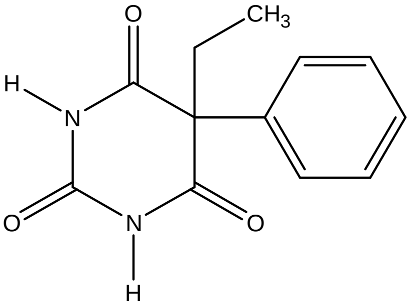

Figure 1. Structure of Phenobarbital

MATERIALS AND METHODS

Apparatus, Chemicals and Reagents

SHZ-88 Thermostatic water bath shaker, 0-100 ºC temperature controlled, 30-360 rpm, 0-120 minutes timing (Jintan Medical Instrument, China), magnetic stirrer with 200 ºC maximum heating chamber and 0-1000 rpm stirring speed (Remi PVT, India), pH meter (Eutech, Japan), UV/VIS spectrophotometer (Jeenway 6405, England), laboratory water bath (Uniscope Sm801A Surgifriend medicals, England), electronic weighing balance (Adventure^{TM}, capacity 310g, Ohaus corporation USA), vacuum pump B-42, 220V-/50-50 Hz, 5 Pa, single ¼ HP (Sigma, England) PBT sodium (Vitabiotics Pharma., Nigeria), methanol, hydrochloric acid (Sigma-Aldrich, USA), double distilled water (Lion waters, Nigeria), *Garcinia kola* seeds were locally sourced from Nsukka, Nigeria,

METHODS

Preparation of Adsorbent

The freshly harvested *Garcinia kola* seeds (GKS) used for the studies were randomly purchased from a local market in Nsukka. The seeds were manually dehulled and thoroughly washed with double distilled water (DDW) to remove all traces of the hulls. It was sliced and oven dried at 50 ºC for 24 h. The slices were ground, further oven dried at 70 ºC for 48 h and sieved to obtain a particle size range of 1-2 mm. The powdered GKS was stored in an air tight container and no further chemical or physical modification was given prior to adsorption studies.

Adsorption Studies

PBT sodium (10 mg/mL) solution was prepared by accurately weighing appropriate quantity of the drug and dissolving in DDW. From the stock solution, 8- 2 mg/mL solutions were prepared by dilution with appropriate volume of DDW. The solutions were labeled and kept for the batch adsorption studies. 50 mL of each solution was added separately to 2 g of activated charcoal in a stoppered flask and later to 2 g of GKS powder and mixed thoroughly. The mixture was agitated on mechanical thermostatic shaker (100 rpm) maintained at 25 ºC for 30 mins and the set up allowed to stand for 5 mins to attain equilibrium. The mixture was filtered using a vacuum pump and the filtrate assayed spectrophotometrically at ʎmax of 284 nm against a blank (filterate) prepared from mixture of adsorbent (activated charcoal or GKS) and DDW.

Effects of Temperature (Thermodynamic Studies)

The batch adsorption studies were repeated at 35 ºC and 45 ºC in order to determine the influence of temperature on adsorption efficiency

Effects of pH on Adsorption

The zero point charges (pH_{ZPC}) of the adsorbents were determined by adding 1-5 g of each adsorbent into a series of sodium chloride solutions (10 mL, 0.1 M) and agitating on a mechanical thermostatic shaker (100 rpm, 25 ºC, 1 h). The mixtures were filtered through a vacuum pump and the pH measured for each solution. The equilibrium pH was considered as the zero point charge of the adsorbent (Maji *et al*., 2001). The effect of pH on adsorption of PBT was determined by carrying out the batch adsorption studies at different pH (two pH values below and above pH_{ZPC}) at 25 ºC. The adjustment in pH was made by adding either 0.1 M NaOH or 0.1 M HCl.

Spectrophotometric Assay

The concentrations of PBT sodium adsorbed onto GKS or charcoal powder were quantitatively determined using UV/VIS spectrophotometer (Jeenway 6405, England) against the appropriate blanks (filtrate) prepared by mixing the adsorbent with DDW. The samples were analyzed at maximum wavelength of 284 nm. The calibration curve (absorbance versus drug concentration) was constructed by measuring standard solutions of the drug in DDW for every series of samples. Validation of the method was performed to ensure that the calibration curve at concentration 1-25 µg/mL was in the linearity range of the analysis and the coefficients of variation were less than 2 % both intra-day and inter-day.

Analysis of Adsorption Data

The amount of PBT sodium adsorbed onto the adsorbents at equilibrium, q_e (mg/g) was calculated by:

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

Where C_o and C_e (mg/mL) are the liquid-phase concentrations of PBT at initial and equilibrium respectively, V is the volume of the solution (mL) and W is the mass of dry adsorbent used (g). In order to investigate the adsorption isotherms, the adsorption data were fitted into three equilibrium isotherms: Langmuir, Freundlich and Dubinin-Radushkevich (D-R). The Langmiur adsorption is the most common of all isotherms describing monolayer adsorption and is often used to describe sorption of a solute from a liquid solution thus (Ho *et al*., 2005; Langmuir, 1918):

$$\frac{1}{q_e} = \frac{1}{Q_{max}} + \left(\frac{1}{bQ_{max}}\right)\left(\frac{1}{C_e}\right) \qquad (2)$$

While the Freundlich adsorption isotherm is the earliest known relationship describing adsorption, though from dilute solution, is empirical and can be expressed thus (Freundlich, 1906):

$$Log\ q_e = Log\ K_f + \left(\frac{1}{n}\right) Log\ C_e \qquad (3)$$

Where q_e is the equilibrium adsorption capacity (mg/g), C_e the equilibrium liquid phase concentration (mg/mL), Q_{max} the maximum adsorption capacity (mg/g), b is the adsorption equilibrium constant (L/mg), and K_f and n are empirical constants.

In order to understand the adsorption type, mechanism and efficiency of adsorption processes, the equilibrium data was applied to D-R isotherm model (equations 4-7) thus (Freundlich, 1906):

$$In\ Q = In\ Q_m - K\varepsilon^2 \qquad (4)$$

$$\mathcal{E} = RT\ In\left[1 + \left(\frac{1}{C_e}\right)\right] \qquad (5)$$

$$E = -(2K)^{-\frac{1}{2}} \quad (6), \qquad R_L = \frac{1}{1+bC_o} \quad (7)$$

Where Q is the amount of PBT adsorbed per unit weight of adsorbent (mg/g), Q_m is the adsorption capacity (mg/g), K is a constant related to adsorption energy, R is the universal gas constant (8.3145 J/mol.K), T absolute temperature, $\mathcal{E}$ polanyi constant, E the mean free energy of adsorption, R_L dimensionless equilibrium parameter and b is the Langmuir isotherm constant. The thermodynamic parameters of adsorption were estimated from Van't Hoff equations (8-9) in order to explain the nature of adsorption (Ho *et al*., 2005; Ho, 2003):

$$\Delta G^o = -RT\ In\ b \qquad (8)$$

$$In\left(\frac{1}{b}\right) = \frac{\Delta S^o}{R} - \frac{\Delta H^o}{RT} \qquad (9)$$

Where ΔG^o, ΔH^o and ΔS^o represent changes in free energy, changes in enthalpy and changes in entropy respectively and adsorption equilibrium constant, b is Langmiur constant.

RESULTS AND DISCUSSION

Adsorption Equilibrium Isotherms

The adsorption equilibrium isotherm was carried out to demonstrate the relationship between the concentration of PBT sodium in bulk solution and that adsorbed to the interface or removed from the bulk solution. Freundlich, Langmuir and D-R equilibrium isotherm models were applied to investigate the adsorption isotherm. The Langmuir model assumes that maximum adsorption corresponds to a saturated monlayer of solute molecules on the adsorbent surface with no lateral interaction between the sorbed molecules (Eastoe and Dalton, 2000). The linear plot of ($1/q_e$) verses ($1/C_e$) shows that the adsorption process obeys the Langmuir model, however, this model do not suggest anything about the adsorption mechanism (Maji *et al*., 2001). The Langmuir constants, Q_{max} and b were determined from the intercept and slope of the plot respectively and are presented in Table 1.

Another significance of Langmuir isotherm is the expression in terms of dimensionless constant equilibrium parameter R_L (equation 7) which indicates whether the isotherm is favourable ($0<R_L<1$), unfavourable ($R_L>1$), linear ($R_L=1$) or reversible ($R_L=0$). This studies show that the R_L lies between 0 and 1 indicating that adsorption of PBT sodium on charcoal and GKS is favorable at all the temperatures studied. Freundlich

Table 1. Adsorption Isotherm Constants for PBT Sodium Sorption on GKS and Charcoal

Adsorbents/Isotherms	Parameters	Charcoal			GKS		
		Temperature (K)			Temperature (K)		
Langmuir constants		298	308	318	298	308	318
	Q_{max}(mg/g)	3.864	3.023	2.180	5.674	4.093	3.118
	b (L/mg)	0.723	0.842	1.020	0.625	0.862	0.993
	R^2	0.996	0.991	0.982	0.999	0.995	0.994
Freudlich constants	n	1.002	1.006	2.518	1.268	1.873	2.864
	K_f	0.723	0.525	0.462	0.625	0.426	0.440
	R^2	0.925	0.923	0.910	0.939	0.932	0.920
D-R constants	E (KJ/mol)	3.580	3.657	5.893	2.259	4.976	5.143
	Q_m (mg/g)	-3.023	-2.982	-2.992	-0.581	-0.452	-0.285
	R^2	0.984	0.980	0.972	0.989	0.996	0.991
	R_L	0.122	0.106	0.090	0.098	0.094	0.051

isotherm, though empirical, is employed to describe heterogenous systems and adsorption from dilute solutions. The linear plot of Log q_e against Log C_e shows that the adsorption process obeyed Freundlich model, however the plot in the present study was linear but has poor correlation values and so did not fit well to the model when compared with other models. The constant, n gives an indication of favourability of adsorption; values of n>1 represent favourable adsorption process (Treybal, 1968; Poots *et al*., 1978; Ho and McKay, 1998). The empirical constants, K_f and n are calculated from the intercept and slope of the plot (equation 3). The findings here support earlier observation that adsorption of PBT sodium is favourable at all temperatures. Like Langmuir isotherm, Freundlich isotherm constants do not suggest anything about the adsorption mechanism; but to understand the mechanism, the equilibrium data was applied to Dubinin-Radushkevich (D-R) isotherm model (equation 4). Figure 2 shows the plot of In Q against ε^2 for both adsorbents and K and Q_m were calculated from the slope and intercept of the plot and presented in Table 1. The free energy change (E) when one mole of PBT sodium is transferred to the surface of GKS or charcoal from infinity in solution was estimated from equation 6. The value of E is significant because it explains the type of adsorption: ion exchange controlled adsorption (8<E<16), adsorption by physisorption (E<8), or chemisorptions (E>16). The present studies show that value of E is 3.58 for charcoal and 2.259 for GKS at 298 K. Other values were < 8 indicting that the adsorption does not involve chemical reaction.

Figure 2. Dubinin-Radushkevich Adsorption Isotherm for PBT at 298 K

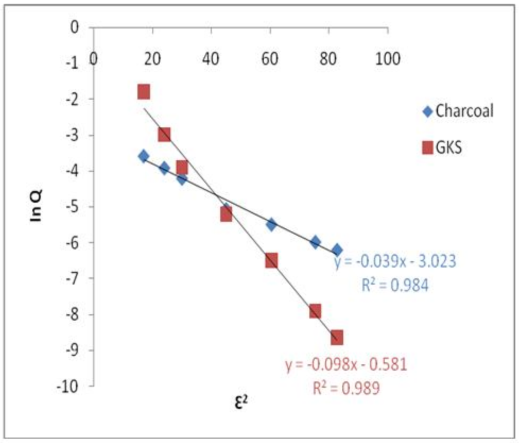

Table 2. Thermodynamic Parameters of Adsorption of PBT

Adsorbents	Temp. (K)	b (L/mg)	ΔG^o (KJ/mol)	ΔH^o (KJ/mol)	ΔS^o (KJ/mol.K)
Charcoal	298	1.020	-0.04906		
	308	0.842	0.44040	13.536	-0.04265
	318	0.723	0.85758		
GKS	298	0.625	1.16454		
	308	0.862	0.38028	18.308	-0.05775
	318	0.993	0.01857		

Thermodynamics of Adsorption

Thermodynamic studies were conducted to ascertain the spontaneity or otherwise of the adsorption processes. The Gibbs free energy, ΔG^o change suggest the spontaneity of the process (-ve value indicates the feasibility and spontaneity of the process); the enthalpy change, ΔH^o indicate the exothermic or endothermic changes of the process while the entropy change, ΔS^o indicate the randomness of the process (+ve value reflects the affinity of the PBT on adsorbent and any structural changes accompanying the adsorption) (Gupta, 1998). This studies obtained ΔH^o and ΔS^o from slope and intercept of linear plot of (equation 8) In (1/b) against (1/T). Table 2 shows that ΔH^o and ΔS^o were positive and negative respectively for charcoal and GKS. The implication is that adsorption of PBT sodium is non spontaneous regardless of temperature with no structural change(s) on the adsorbents used.

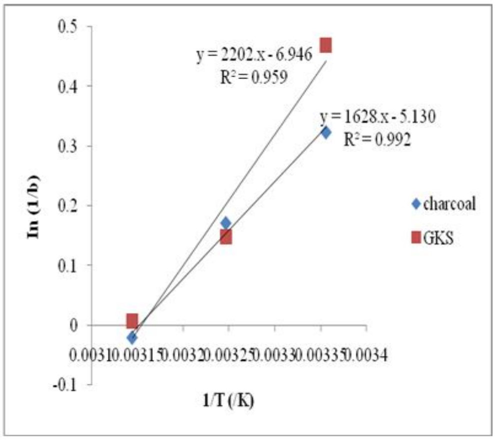

Figure 3. Plot of In b vs (1/T) for PBT

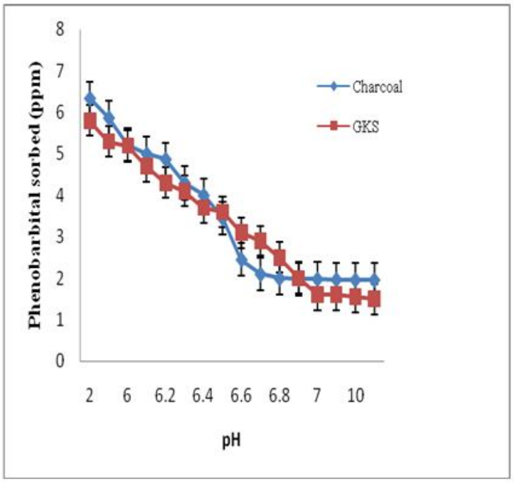

Figure 4. Effects of pH on sorption of PBT on Adsorbents

Effects of pH on Adsorption Isotherm

The adsorption of PBT sodium on the adsorbents is governed primarily by the pH of the bulk solution and the surface charge of the adsorbent. The pH_{ZPC} of GKS and charcoal were determined as 7.12 and 6.98 respectively. The surface of the adsorbents is positively charged below the pH_{ZPC} and negative above the point. The results show that adsorption of PBT sodium is highest below this point (Figure 4) due the neutrality of the drug which adsorbs via an attraction of the positively charged surface sites at lower pH by weak van der Waals forces (Maji *et al*., 2001). The decreases in adsorption above pH_{ZPC} could be attributed to gradual ionization of PBT sodium in alkaline medium as a result of lactam-lactim tautomerism at higher pH which is as a result of active methylene group (upon tautomerization) between two carbonyl groups of PBT (Figure 1) and the presence of a diiminocarbonyl system in the tautomeric forms (Olaniyi, 2005).

Conclusion

Basic findings revealed that GKS has powerful adsorption capacity for the weakly acidic antidepressant, phenobarbital sodium compared to the universally accepted antidote for poisoning, charcoal. This is evident in the maximum adsorption capacity of GKS which is twice that of charcoal. The adsorption was also found to be favourable at all temperatures which were supported by n value of Langmiur isotherm. The adsorption process was by physisorption and non spontaneous at all temperatures as confirmed by the thermodynamic studies. The studies, therefore, confirms the folkloric use of *Garcinia kola* seed for treatment of systemic poisoning, especially due to drug overdose or poisonous insect bites.

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