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Sequestration of PCBs Congeners Present in Askarel Formulation by Adsorption on the Prepared Activated Carbons

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Abstract: The difficulties of managing polychlorinated biphenyls (PCBs), a persistent organic pollutant inherited from the last century, constitute a major environmental problem, due to the lack of efficient, low-cost and accessible techniques of its destruction. The options of adsorption on activated carbon, prepared from available local agroforestry by-product appear to be an effective method that reduces the bio-accumulation character of PCBs. The adsorption of PCBs molecules in aqueous solution (ethanol-water, 1:10) on chemically activated carbons with H_3PO_4 at different concentrations (5%, 10%, 20%, 30%) was investigated. An UV spectrophotometer is used to assess the adsorption. The adsorption rate (> 90%) and the adsorption capacity (170.24 mg/g) of the activated carbon showed the performance of the prepared activated carbon. All experiments were carried out at room temperature. The effects of contact time, absorbent masse, initial concentration, pH solution, were evaluated. The resulted adsorption data applied to four isotherm models (Freundlich (R^2 =0.90), Langmuir (R^2 =0.95), Tenkim (R^2 =0.96), and Dubinin-Radushkevich (R^2 =0.94)), lead to the interpretation of the observed adsorption phenomena. The calculated free energy E (5.06 Kj) indicated that the physio-sorption played a significant role in this adsorption mechanism. The adsorption process was entirely controlled by intra particle diffusion, and followed the pseudo-second order mechanism. These adsorption performances combined with a photo-radiation of contaminated PCBs solution could be an easier way to destroy PCB_S, that is an ecologically rational elimination of POPs.

Keywords: Askarel, *Hyphaene tabeika* Fruits, Adsorption, PCBs Persistence, Organic Pollutants

1. Introduction

The most dangerous hazardous pollutants, inherited from industrial waste of the 20th century, are classified as persistent organic pollutants (POPs) [1]. Earlier, in 2001, the international community decided to rid the environment from these substances. But some of them are still used or stored as waste; this is the case of polychlorinated biphenyls [2]. Polychlorinated biphenyls, commonly called PCBs, have been used mainly as dielectric fluids, in transformers, capacitors and radiators or as lubricants in turbines and pumps [3]. Despite the prohibition of their production since 1980, from 1.5 million tons of PCBs produced worldwide, between 1929 and 1989 its large amount is released into the environment (31%), or is still found in old electrical transformers in service or used (70%). Thus, they contaminate water, air and soil, thus to the foodstuffs of various origin [4].

Nowadays, the toxicity of PCBs and its harmful effect on human health are carcinogen potentially linked with the bioaccumulation factor [5]. It is in this context that United Nations Environment Program (UNEP) has fixed the complete removal of PCBs through 2028. However, available disposal technologies are very expensive, have high energy-consuming, often with health and environmental risks. The

PCBs combustion around 1100°C, releases carcinogenic substances (dioxins and furans); while their incineration is done at temperatures between 3000-15000°C, and their alkaline reduction is explosive [6]. Despite multiple efforts towards their elimination in 2028 (UNEP), there is still tons and tons of PCBs waste, stored often, under conditions that do not meet environmental standards. Therefore, by revisiting the principles of the adsorption process, the Activated Carbon appeared to be an alternative for reduce the environmental effect of PCBs. [7] The activated carbon used as adsorbent was prepared from waste derived from agroforestery (*Hyphaene tabeika* fruits shells). These shells, the byproducts that are poorly valorized despite their potential; constitute a complicated waste added to more problem to the urban waste management in Niger cities. Thus, it is a waste valued (used) to eliminate other wastes, what materializing an ecological management of POP_s. In fact, a sequestration of PCBs congeners in aqueous solution, reduces their ecotoxicity by decreasing their concentration in water [8]. Thus, if the adsorption of PCBs in organic phase increases their half life and persistence by reducing their biodegradability; however, their bioavailability is reduced once trapped in the pores of an adsorbent [9].

The analysis of the adsorption isotherm, the adsorption kinetics, and the intra-particular diffusion mechanism helped to explain the global adsorption mechanism, for the best application in the reduction of harmful effect of PCBs on the environment. Therefore, the purpose of the present work is to verify this sequestration through an adsorption of PCBs congeners presents in Askarel formulation, in aqueous solution. In addition, the effects of contact time, absorbent masse, initial concentration and pH solution, were investigated.

2. Materials and Methods

2.1. Chemical Reagents and Materials

The phosphoric acid (85% purity) used as an activating agent was purchased from Merck, Germany. The Askarel was gotten from an electrical transformer N°536 (as identified by TREDI®), stored at temporary PCBs waste storage site (Niamey, Niger). The chemically grade Iodine (I_2), potassium iodide (KI) and sodium thiosulfate ($Na_2S_2O_3.5H_2O$); and metylene blue (BM) was purchased Labtech. chemicals, China. he shells of *Hyphaene tabeika* fruits were carbonized using an electric incinerator (Heraeus KM 170, Germany). Askarel solution was prepared using 10% ethanol (≥99.8%, Sigma-Aldrich). The adsorption was measured using an UV spectrophotometer (Thermo Fisher Scientific, Evolution 300 UV-Vis, Madison, USA).

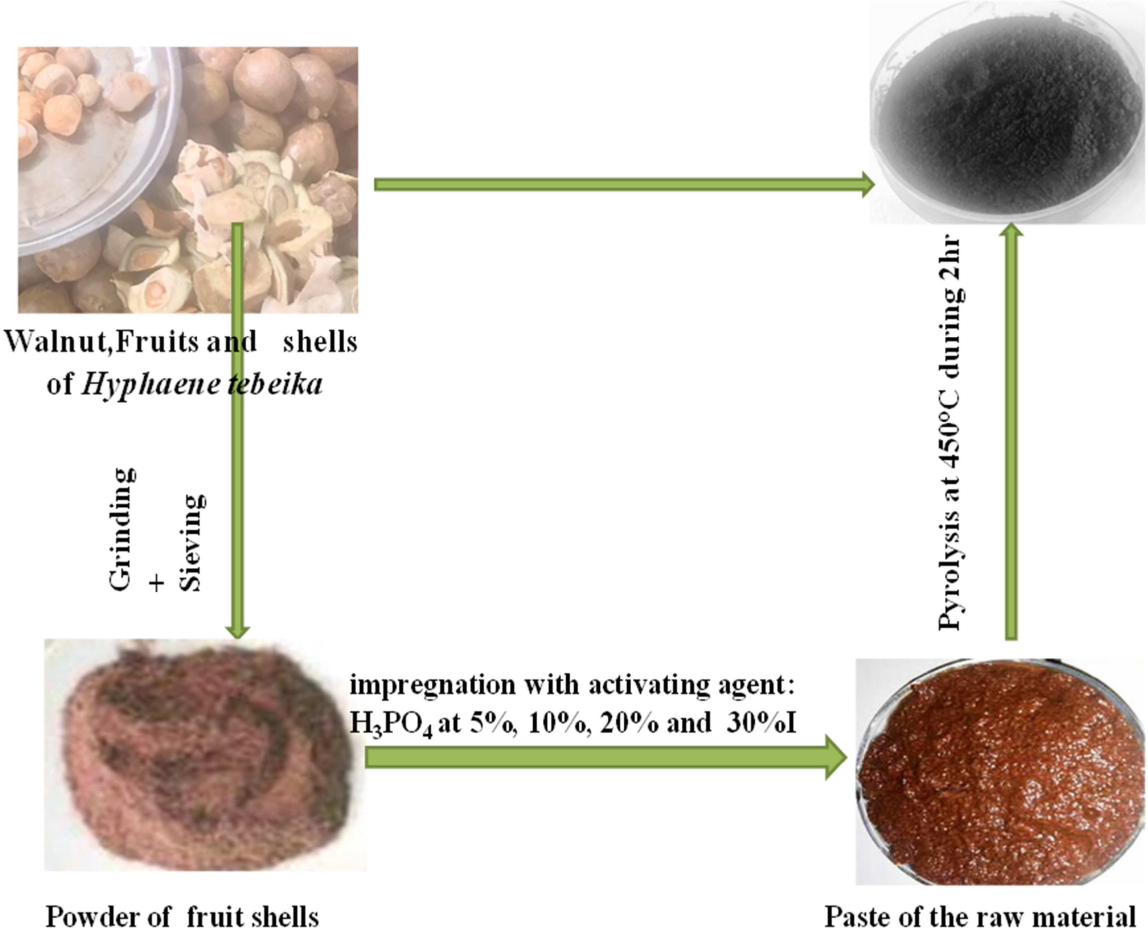


Figure 1. *Steps on the preparation of activated carbon.*

2.2. Preparation of Activated Carbons

The different steps of synthesis activated carbons are shown in Figure 1. The shells were collected from the seller of the palm nut. Then, they were washed and sun dried for two weeks followed grinding and sieved (0.4 mm). The impregnation was carried out as follow: 20 g of shells powder was mixed with 100 ml of phosphoric acid with different concentrations (5%; 10%; 20%; 30%). Each mixture was stirred at room temperature for 2 h and temperature increase to 60°C for the last 30 min. The retained after filtration (paste) was dried (100°C) overnight (12 hours). The pyrolysis was conducted in an incinerator at 450°C for 2 h, then, the obtained different activated carbons were washed with NaOH solution and distilled water until the pH of the filtrate stabilized to 7. The obtained activated carbons were Activated Carbon with 5% H_3PO_4 (AC5), AC10, AC20 and AC30 related to the respective H_3PO_4 concentrations (5%, 10%, 20% and 30%).

2.3. Askarel Solution Analysis

To prepare an aqueous Askarel solution, 0.5 ml of the concentrated sample was first dissolved in 50 ml of ethanol to obtain a stock solution, then the different concentrations of 50, 40, 30, 20, 10, 5 and 2.5 PPM were prepared using the aqueous solutions (1:10, ethanol: water). The absorption spectra of different solutions were obtained (UV spectrophotometer, Thermos Fisher Scientific, Evolution 300 UV-Vis, Madison, USA).

2.4. Adsorption of PCB Congeners

2.4.1. Equilibrium Time of Different Activated Carbons

A 100 ml of askarel aqueous solution with a given concentration was added to an aliquot mass of prepared adsorbent and the mixture (in 100 mL Erlenmeyer flask) was stirred until equilibrium. The adsorption rate was calculated following either of two equations:

$$T\% = \frac{(Ci - Ct)}{Ci} \quad (1)$$

$$A\% = \frac{(A_0 - A_t)}{A_0} \quad (2)$$

The effect of contact time was calculated as follow:

$$q_t = \frac{(Ci - Ct)}{mCA} \times V \quad (3)$$

Where:

q_t = amount of PCB_S adsorbed at time t

C_i = initial concentration

C_t = concentration at time t

V= volume of solution

m_{AC} = mass of activated carbon

The influence of adsorbent mass by varying the mass of activated carbon from 20 to 120 mg (20, 40, 60, 100 and 120 mg), the influence of initial concentration (10, 20, 40 and 50 PPM) and the effect of pHsolution by varying the pH from 2 to 11 (pH = 2, 7, 9 and 11) were investigated following the method Baccar et al. [10].

2.4.2. Determination of pH at Zero Charge, Iodine Number and Methylene Blue Adsorption

The pH at zero charge (pH_{PZC}) was determined using the Lopez method [11]. A 0.1 g of AC10 was mixed with 20 ml of 0.1 mol NaCl solutions repeatedly at different pH 2, 5, 7, 9 and 10. Each solution was then stirred for 72 h at room temperature prior to filter and the final pH was measured using pH meter (Multi 3430 SET).

The Iodine Number was determined using the ASTM method (Astm D4607-94 (2006)) with little modification and its calculated as follow:

$$I_2(mg/g) = \frac{25.4 \times (20 - Vn)}{mCA} \quad (4)$$

Where:

I_2 = iodine number mg/g

Vn = volume of thiosulfate added

mAC = mass of adsorbent (AC10)

The methylene blue (BM) number is determined using the method of Benadjemia et al [12]. The residual concentration of BM was measured by reading its absorbance at 660 nm using a UV spectrophotometer (Thermo Fisher Scientific, Evolution 300 UV-Vis, Madison, USA)

$Ci = \frac{Ai \times Co}{A0}$ derived from Beer-Lambert equation. And the adsorption index of BM was calculated as follow:

$$I_{BM}(mg/g) = \frac{(C_i - C_f) \times V}{m_{CA}} \quad (5)$$

Where I_{BM} is an adsorption of BM in mg/g, Ci is the initial concentration of BM; V the volume of BM solution and m_{CA} is the mass of activated carbon in gram (g)

2.4.3. Isotherms Adsorption Applied to Langmuir, Freundlich, Temkim and Dubinin-Radushkevich Models (D-R)

1 *Langmuir isotherm*

The Langmuir isotherm is described by equation 6:

$$q_e = \frac{q_{\max} k_l C_e}{1 + K_L C_e} \quad (6)$$

Where q_{max} (mg/g) and K_L (L mg) are constants related to the maximum adsorption capacity and the adsorption energy respectively. But the essential characteristics of this isotherm is expressed in terms of the dimensionless constants R_L as:

$$R_L = \frac{1}{1 + K_L C_e} \quad (7)$$

The value of R_L indicates the type of isotherm: unfavorable (0 >R_L); linear (R_L = 0) and irreversible (0 <RL<1). Out of the 5 linear form Langmuir equation the fifth $\frac{1}{C_e}$ versus $\frac{1}{q_e}$ one fit well this work.

2 *Freundlich isotherm*

The Freundlich model is expressed by equation (8):

$$q_e = K_F\, Ce^{\frac{1}{n}} \tag{8}$$

Where K_F and n are the Freundlich constants related to the adsorption capacity and the adsorption intensity, respectively. These parameters can be calculated from the intercept and the slope of the linear form of $\log q_e$ versus $\log c_e$. The magnitude of the exponent n indicates whether the adsorption is favorable or not.

3 *Temkim isotherm*

The isotherm of Temkim is expressed by:

$$q_e = \frac{RT}{b}\ln(AC_e) \tag{9}$$

Where the constant $= \frac{RT}{b} = \left(\frac{RT}{\Delta E}\right) q_{max}$, with R the universal constant of the gas (8, 314 J /mol K), T the temperature in Kelvin (K) and ΔE = (- ΔH) is the variation of the adsorption energy (J/mol). A is the Temkim equilibrium constant corresponding to the maximum binding energy and q_{max} the maximum adsorption capacity. If the adsorption obeys the Temkim equation, A and B can be obtained respectively from the slope and the intercept of the plot $\ln C_e$ against $q_e$rm.

4 *Dubinin−Radushkevich (D−R)*

The (D-R) model allows to distinguish the physical and chemical adsorption through the interpretation of the adsorption data with the (D-R) equations:

$$q_e = q_m e^{(-\beta\varepsilon^2)} \tag{10}$$

With

$$\varepsilon = RT\ln\left(1 + \frac{1}{C_e}\right) \tag{11}$$

where q_e is the maximum adsorption capacity, β is the constant related to the adsorption energy in (mol^2/KJ^2), ε is the surface potential energy, R is the universal constant gas (J/mol/K), T the absolute temperature (K). The constant B gives the free energy E (KJ/mol) for transfer of 1mole solute from infinity to the surface of adsorbent. It can be calculated using this relationship (12)

$$E = \frac{1}{\sqrt{2B}} \tag{12}$$

The (D-R) equation can be linearized by $\ln q_e = \ln q_m - \beta\varepsilon^2$, and the plot $\ln q_e$ vresus ε^2 gave straight lines. The values of q_m and B, thus the free energy E are obtained respectively from the intercept and the slop of the straight line. this shown slighter

Moreover, to compare the validity of each isotherm the normalized standard deviation Δq (%) was calculated as follow:

$$\Delta_q(\%) = 100\sqrt{\frac{\frac{\Sigma(q_{exp} - q_{cal})}{q_{exp}}}{N-1}} \tag{13}$$

Where q_{exp} and q_{cal} are the experimental and the calculated quantities of PCBs congeners adsorbed at equilibrium on the activated carbon, and N the number of measurements carried out.

2.4.4. Adsorption Kinetics and Intra-particle Diffusion

Kinetic adsorption models have been investigated with two classically kinetic models: pseudo-first-order and pseudo-second-order. The linear forms of the both models are expressed as follow:

$$\frac{1}{q_t} = \frac{1}{q_e} + \frac{K_1}{q_e \times t} \tag{14}$$

$$\frac{1}{q_t} = \frac{1}{K_2 \times q_2{}^2} + \frac{t}{q_2} \tag{15}$$

The terms q_e and q_t have the same meaning as previously mentioned; K_1 and K_2 are the pseudo first order and pseudo second order velocity constants and are expressed respectively in /min and /mg /min, where t is the duration of each interval in minutes. The diffusion study of the intra particle mechanism is carried out by modeling the data, using the equation (16).

$$q_t = K_{id} \times t^{\frac{1}{2}} + C \tag{16}$$

Where qt is the adsorption capacity at a given instant, and varies almost proportionally with the square root of contact time ($t^{\frac{1}{2}}$) than with time t. K_{id} is the particle intra particle diffusion constant (mg / g/ $min^{1/2}$) and C is the intercept.

3. Results and Discussion

3.1. Askarel Solution Analysis

The sample of Askarel has its commercial formulation corresponding to Aroclor 1260. The mixture contains 60% of chlorine in masse and it's composed essentially by 37% hexachloro-biphenyls, 47% heptachlorobiphenyls, 10% trichlobenzene as solvent and 6% of PCBs congeners with less than 3 chlorinated substituents. The density of Askarel is 5.45 kg / gallon or 1.438 kg/L. [13]. The PCBs molecules having an absorbance ranged between 195 and 300 nm, the adsorption spectra of these different solutions have realized. Then, it was carried out a reproducible spectral profile of PCBs congeners present in Askarel (Figure 2). These absorption spectra contain three bands: a main absorption band at 200 - 225 nm, *K*-band at 245–265 nm, and weak absorption band at 245-265 nm [14].

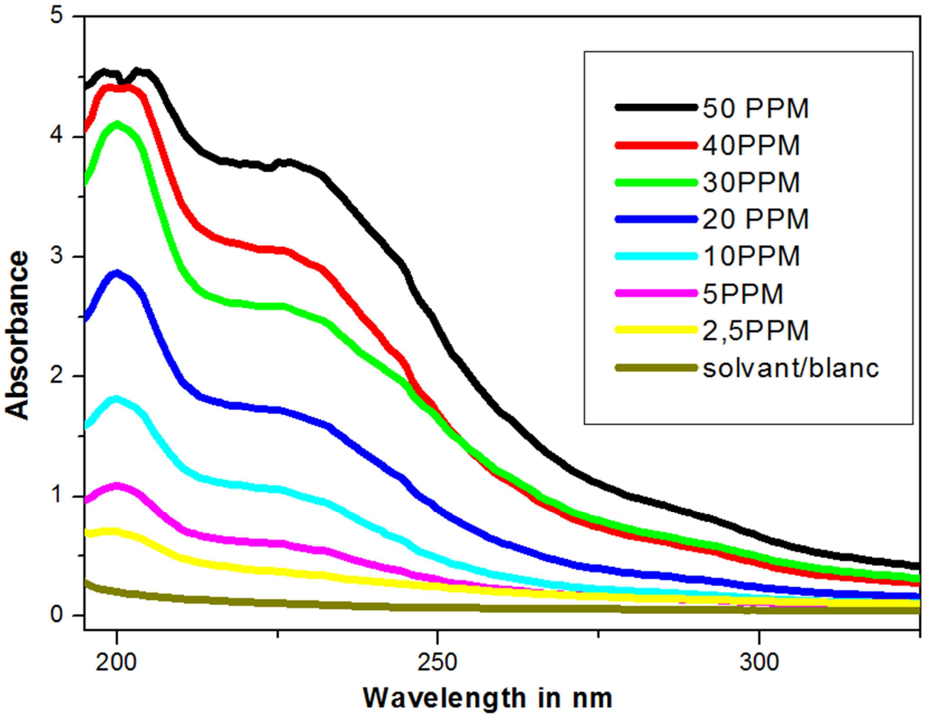


Figure 2. *Additive absorption spectra of PCBs congeners.*

3.2. pH at Zero Charge, Iodine Number and Methylene Blue Indicator

The pH_{PZC} is the point where the curve pH final versus pH initial intersects the line pH final = pH initial. The funding pH_{PZC} (6.9) showed that there is not predominance of acidic or basic functional groups on AC10 surface; thus, that all functional groups present appeared in equilibrium related to their acidity or basicity [15].

The result showed that the iodine value of activated carbon AC10 (I_2 = 889 ± 5.04 mg/g) was lower than that of KAG (I_2 = 952 ± 6.23 mg/g) a commercial activated carbon under the same conditions. The methylene blue number I_{BM} of the prepared AC10 was 168.63 ± 6.78 mg/g though the I_{BM} of KAG gotten under the same conditions was 167.8 ± 3. 84 mg/g this shown slighter. The data obtained corroborate with the work of Gueye et al. and Yangui [7, 12] on the jatropha shell, coco nut and olive waste cake; likely, the activated carbon AC10 performed good adsorption of molecules as well as PCB congeners [16, 17].

3.3. Adsorption of PCBs Congeners Present in Askarel Formulation

The pyrolysis yield and the adsorption performance of four different activated carbons showed that the AC10 recorded the highest value as seen in Figure 3a when compared to others activated carbon. It could be seen also that the AC30 used three times the concentration of phosphoric acid to reach approximatively similar value of the AC10 (Figure 3a); thus, the choice AC10 for further analysis.

To assess the other parameters, it's fundamental to determine the equilibrium time of their adsorption. The equilibrium time for the prepared activated carbons is shown in Figure 3b indicating that after 2 h of reactions it was observed a constant adsorption. For the whole activated carbons, the curve of adsorption kinetics has the same allure. In particular, it is noticed with a rapid adsorption during the first 30 min; furthermore, it was obvious in the first 5 min, indeed the 4 h was retained as contact time for the whole work. Similar phenomenon was observed in the work of Baccar et al.; Tchakala et al.; Gueye et al. [10, 11, 12] related to adsorption of organic molecules in aqueous solutions.

3.4. Influence of Adsorbent Mass and Effect of Time Contact

Globally, Figure 4a showed the quantity of substrate adsorbed ranging from 85 to 95% when related with the variation of adsorbent mass (20; 40; 60; 100; and 120 mg). Indeed, for an adsorbent mass of 20 mg, the amount of solute adsorbed was 85%; this quantity increased to 95% for 100 mg of mass adsorbent. However, when the AC10 mass increases up to 100 mg of mass adsorbent the quantity adsorbed decreased for 120 mg of adsorbent (Figure 4b). This result could be explained by the unsaturation pores for a mass of adsorbent lower than 100 mg. This suggested the increase of available adsorption sites until some of theme became unoccupied, when the mass of the adsorbent attended 120 mg as reported by Gao [18]. However, as this mass increased from 20 to 100 mg, the adsorption capacity per unit of adsorbent decreased from 110 to 25 mg/g. This phenomenon indicated that the adsorption capacity is inversely proportional to the amount of adsorbent [19, 20].

In the first 50 min (Figure 4b) the capacity of the activated carbon showed a rapid increase despite the amount of the adsorbent, this phase might be the adsorption on the external surface, similarly reported by Baccar et al.; Sharma et al. [10, 15]. After the first 50 min the adsorption increased less rapid than in the first ones. On the other, the increase of the adsorption was more related to the variation in the mass of activated carbon. Moreover, in this stage, as the mass of adsorbent increased its adsorption capacity decreased. For 100 mg of AC, the equilibrium was already reached. The equilibrium adsorption capacity for the other masses lower than 100 mg (10; 20; 40 and 60 mg) was reached at 180 min (Figure 4b).

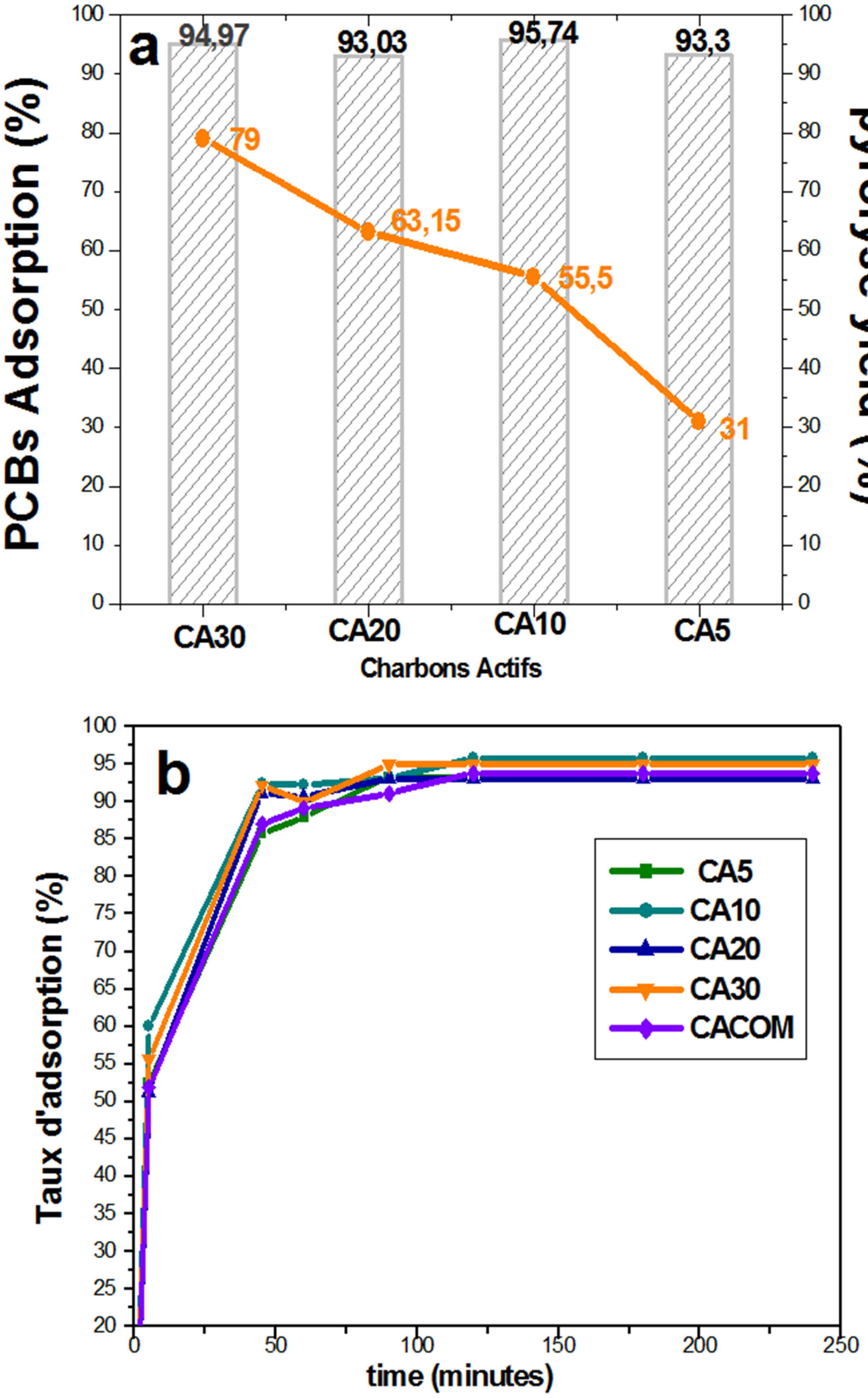


Figure 3. *(a) Comparison of pyrolisis rate and adsorption capacity of prepared activated carbons; (b) Determination of Equilibrium time for adsorption of PCBs in aqueous solution. (Ci=25PPM; pH=6.5; mAC= 100mg; at room temperature)*

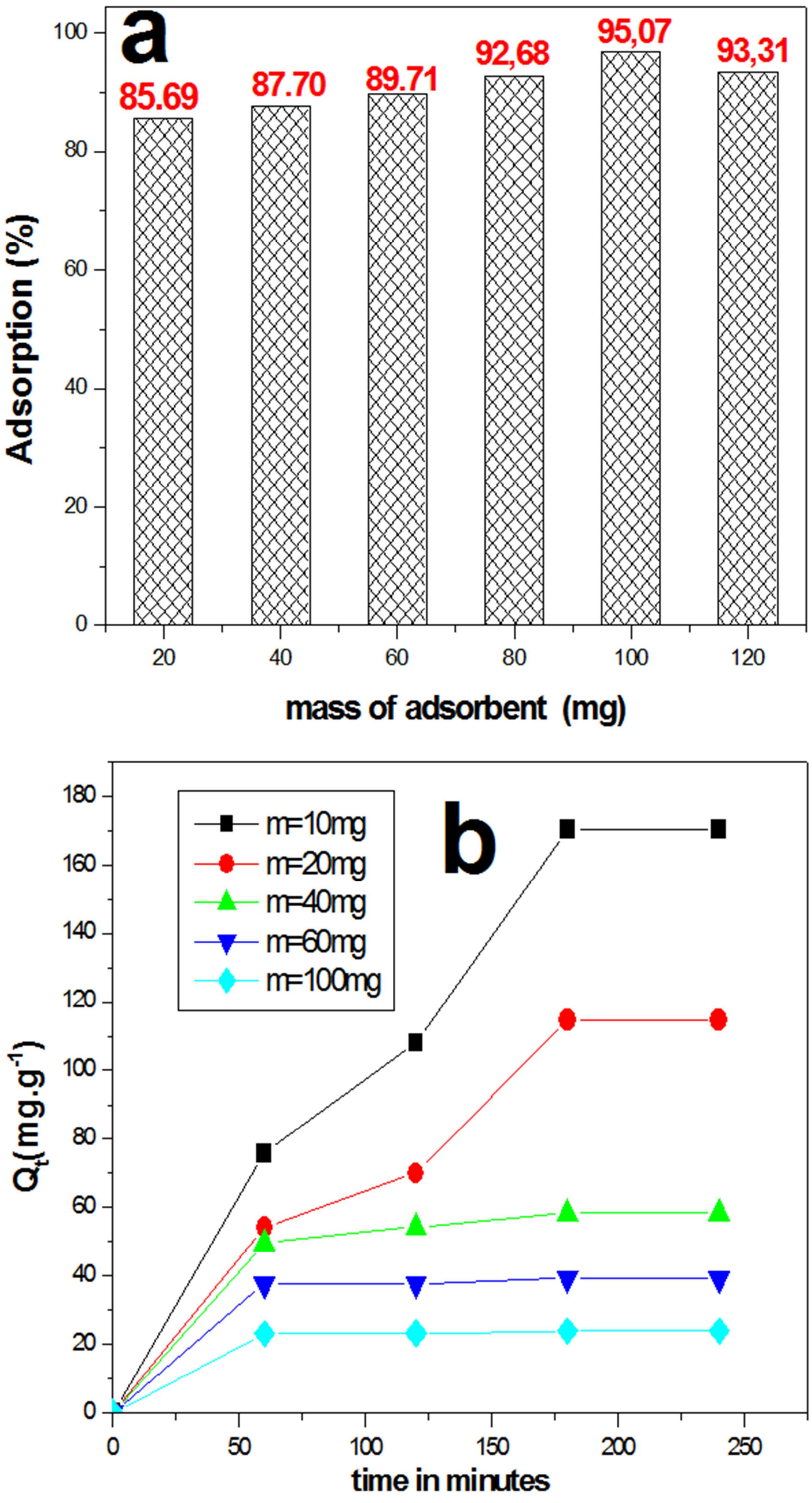


Figure 4. *Adsorbent mass effect on adsorption of PCBs congeners (a) and Contact time. effect for different masses of AC10 (Ci= 25PPM, pH=6.48 T=30°C) (b).*

3.5. Effect of Initial Concentration and pH on PCB$_S$ Adsorption

The phenomenon of adsorption involves number of molecules present against available sites; in addition, the initial concentration has been always decisive in the transfer of substrate in adsorption process [21, 22]. It observed in Figure 5a, that increasing the initial concentration from 10 to 70 PPM lead to decrease of the rate of adsorption. This could be explained by the fact that the increasing of the concentration of the substrate leads to the increasing of solute molecules while the free sites remain constant on the absorbent surface [23].

The pH of solution and the attraction between ions are factors that influence the process of adsorption [24]. In particular, the solution pH is one of the key factors that control the adsorption process of organic compounds with low electrolyte power on carbon material [25]. Thus, for a pH lower than pH_{PZN}, the charge on the surface of the adsorbent is positive while it becomes negative when the pH of the solution is greater than the pH_{PZN}. Figure 5b showed slight influence on the effect of pH on the PCBs congeners adsorption. Generally, the variation ranged from 90 to 80%, with the optimum rate at pH = 2 and pH = 7 (Figure 5b). On the other hand, at the given pH = 2 of the solution has a hypo chromic effect on the PCBs spectra, and the pH of Askarel solution without activated carbon near the pH 7; at the end the pH 6.5 was required for the consequent experiments. Also, the PCBs molecules having a slight solubility in water, the attachment of hydrophobic PCBs molecules to hydrophobic adsorbents in aqueous solution is mainly governed by their hydro phobia rather than by their attraction on adsorbent surfaces [26].

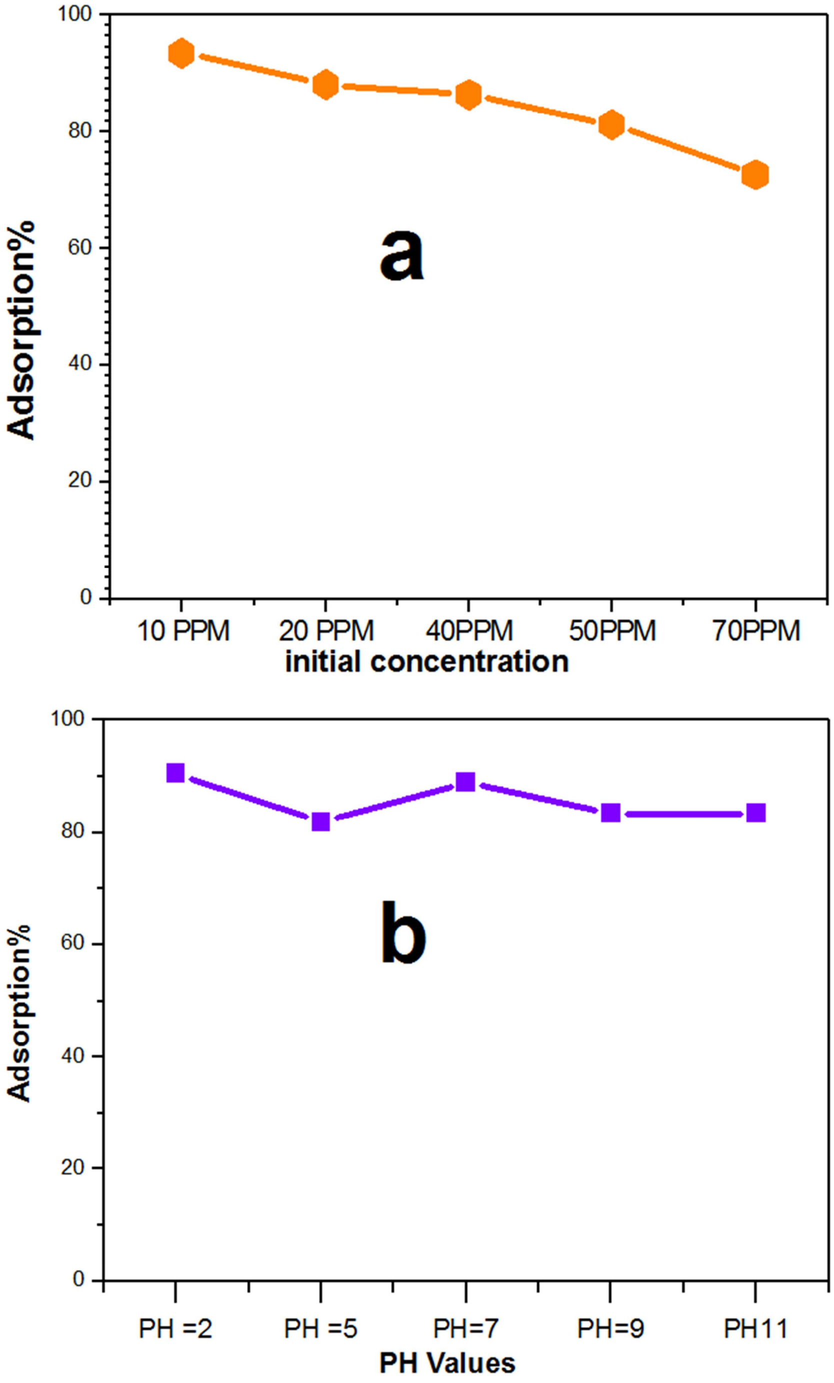


Figure 5. *Effect of initial concentration on PCBS adsorption (mAC=100mg, pH=6.48) (a) and Effect of PH on PCBs adsorption (mCA=100mg, Ci=25PPM, at room temperature,) (b).*

3.6. Modeling of Adsorption Isotherms and Adsorption Kinetics

3.6.1. Modeling of Adsorption Isotherm

The adsorption isotherm in Figure 6, showed the increase of the equilibrium adsorption capacity with increase of pollutant concentration. This trend is in line with the adsorption of organic contaminants in aqueous solution on adsorbents with similar properties such as activated carbon [7, 11, 27].

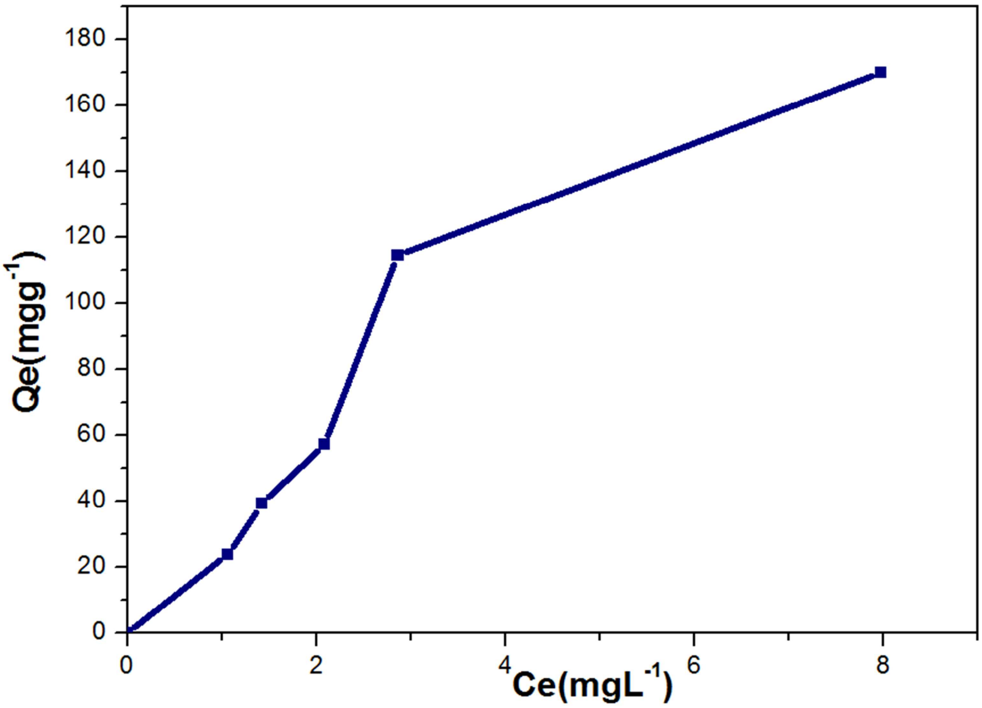


Figure 6. *Equilibrium Adsorption isotherm of PCBs on AC10 (mCA= 100mg, pH= 6.5 at room temperature).*

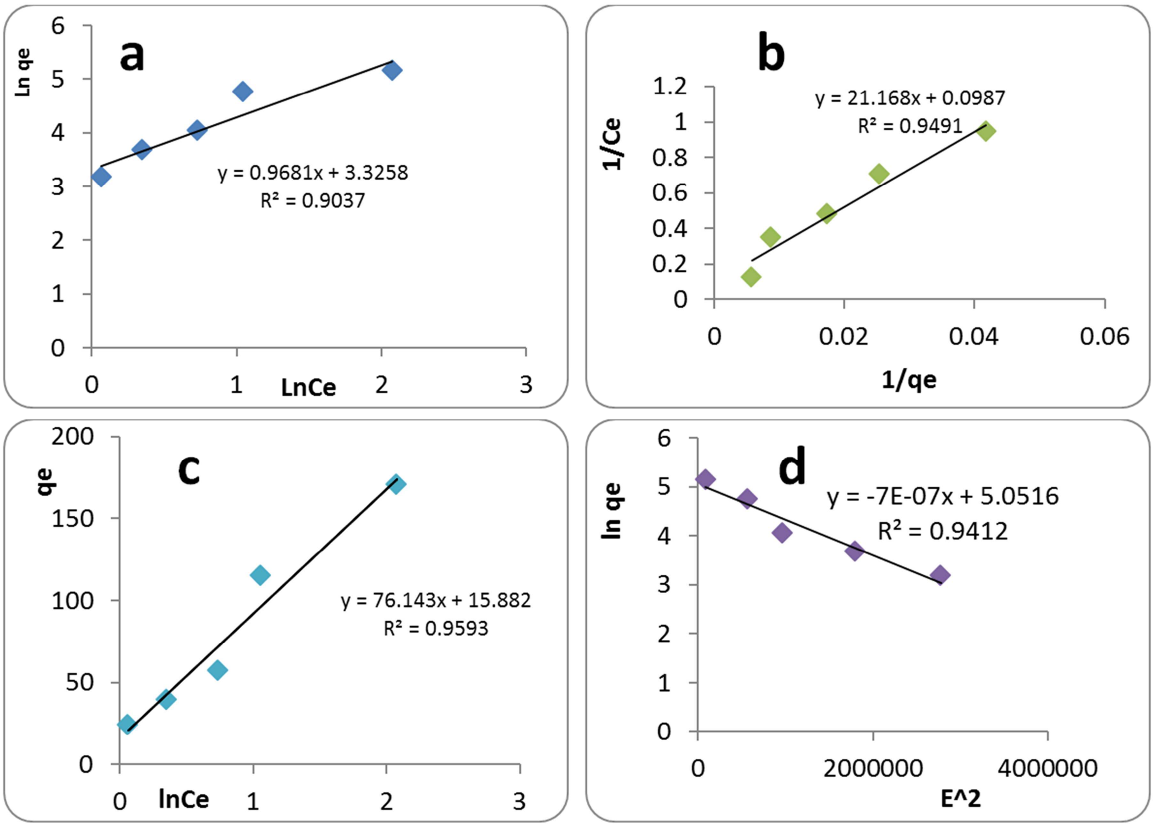


Figure 7. *Linear regression curves of Freundlich Isotherme (a), Langmuir-5 Isotherme (b), Temkim Isotherm (c) and Dubinin-Radushkevich (D-R) (d).*

In order to deduce an adapted model for this adsorption, 4 of the adsorption isotherms were used that is the Langmuir, Freundlich, Temkim and Dubinin-Radushkevich (D-R) models. Their linear forms allowed to determine the correlation coefficients and the other characteristic constants for every model. By comparing the correlation coefficient R^2 of the different models Figure 7. It appeared that the best fit was obtained using Temkim model ($R^2 = 0.96$). This could be due to a more pronounced adsorbent-adsorbent interaction that accompanied the adsorption phenomenon [28]. The Langmuir model, with its correlation coefficient ($R^2 = 0.95$), close to that of Temkim could be describe the adsorption results. The R_L dimensionless value (R_L=0.26) of Langmuir model indicated the favorable adsorption confirming the validity of this model. Moreover, the standard deviation represents the fit between the experimental and the predicted values of the adsorption capacity, whereas the linear correlation coefficient (R^2) represents the fit between the data and the linearized form of the isotherm equation. The four standard deviations related to the linearized forms of the tested models (Table 1), confirm that the Tenkim model described well the experimental data of adsorption with the smallest Δq (5.96%). The standard deviation value is more appropriate to design the fitness relating to the experimental and the calculated data for the adsorption process, than the correlation coefficients R^2.

The free energy E calculated from D-R model was found to be 5.06 Kj, which is lower than the range of typical bonding energy (8 - 16 Kj) for ion exchange mechanism, indicating that the physiosorption could play a significant role in this adsorption mechanism [29]. As The physical sorption processes have always energy ranged in (5 - 40 kj), this finding confirmed that physiosorption process governed the adsorption of PCBs congeners on this prepared activated carbon. The similar results were reported on the adsorption of organic molecules in aqueous solution [11, 13, 27].

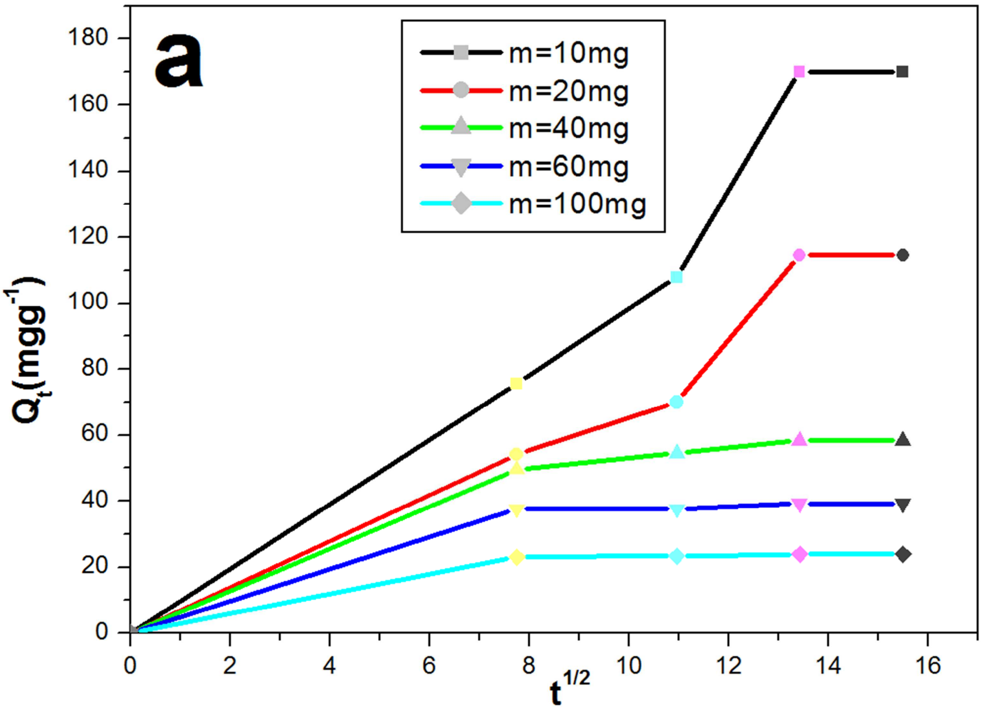
Table 1. *Langmuir, Freundlich, Temkim and Dubinin-Radushkevich (D-R) models Parameters, correlation coefficients and Δq (%) values for adsorptions of PCBs congeners at ambient temperature.*

Isotherms	Parameters
Langmiur	q_{max}= 181. 82 mg/g, RL = 0.68, R^2 = 0.9491, Δq(%) = 13.03
Freundlich	q_{max} =148.413 mg/g, n = 0.65, R^2 = 0.9037, Δq(%) = 18.01
Temkim	q_{max} = 168.15 mg/g, A = 1.384, B = 76.148, R^2 = 0.9593, Δq(%) = 5.69
Dubinin Radushkevich (D–R)	q_{max} =148.413 mg/g, ß = 3.47, R^2 = 0.9412, Δq(%) = 18.01

3.6.2. Adsorption Kinetics

(i). Pseudo First and Pseudo Second Order Kinetics Models

The values of K_1 and K_2 are obtained from the intercept of the linear regression forms, with their corresponding correlation coefficients R^2_1 et R^2_2. The finding values were K_1= 0.0413 /min and R^2_1 = 0.8219 for pseudo first order; while for pseudo second order, K_2= 0.1615 mg/g /min and R^2_2=0.9998. Knowing that $R^2_2 > R^2_1$ this imply that the second order mechanism was predominant on the adsorption process of PCBs on AC10. Similar works were reported by Oziolor et al., Baccar et al.; Gueye et al. [3, 10, 12] related to the adsorption of blue acid, black dye and methylene blue.



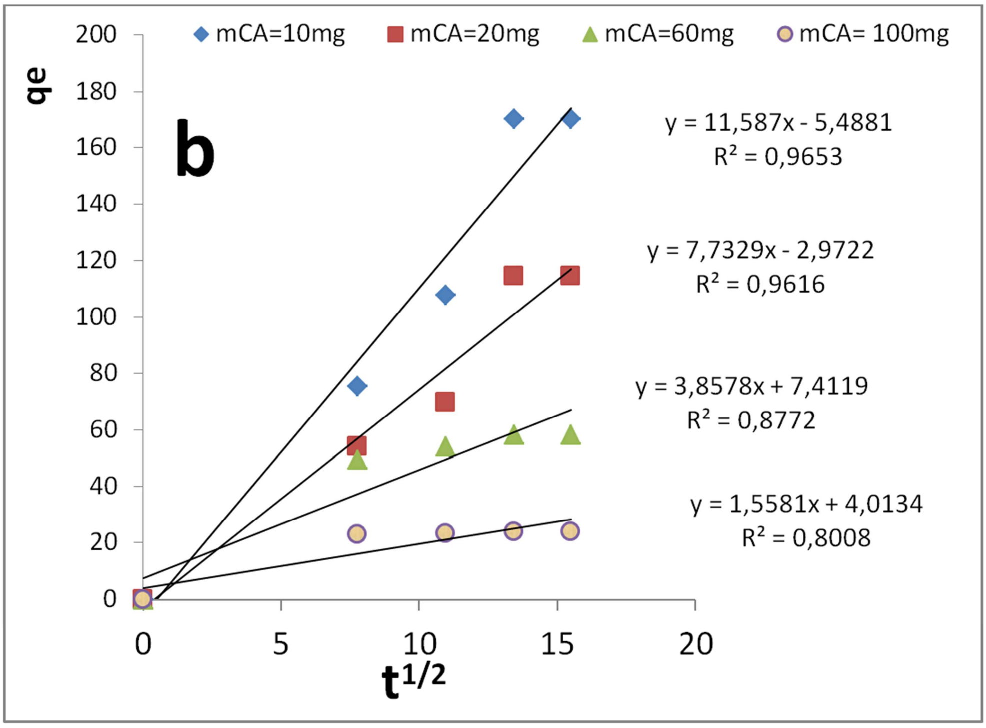


Figure 8. *(a) plots of PCBS congeners uptake against square root of contact time, and (b) Linear regression curves of intra particle diffusion on AC10.*

(ii). Intra Particle Diffusion

Figure 8a characterized the aspect at different points of q_t. The first stage ($t^{1/2}$ at 0 – 8 min) have the fastest adsorption followed by followed by an intermediate ($t^{1/2}$ at 8 – 11 min) then third one ($t^{1/2}$ = 11 - 16); whereby, slight differences toward the end point were observed relatively to different mass of AC. Thus, the third stage indicated the equilibrium stage where the intra-particle diffusion decreased; due to the low concentration of the substrate [26]. On the other hand, all the linear regression curves (Figure 8b) passed almost through the origin, that confirmed an adsorption process entirely that is controlled by intra particle diffusion. The correlation coefficients R^2 (0.965, 0.961, 0.877 and 0.800) related to the intra particle diffusion, varied respectively with adsorbent mass (10, 20, 60 and 100 mg). Surely, this variation indicates the existence of intra particle diffusion phenomenon in the adsorption process [29].

4. Conclusion

This work confirmed the liposolubility of the PCBs molecules through their adsorptions on the activated carbons produced from *Hyphaene tabeika* fruits waste, widely available and almost not cost. These sequestrations of volatile pollutants that reduced their bio-accumulation and bioavailable characteristics, is an alternative to the remediation of contaminated environmental matrix. This way proceeded to the revalorization of fruits waste, constitutes an ecological management of persistent organic pollutants reducing the effects of recalcitrant industrial waste. Optimization of performance of these activated carbons using combined photodegradation techniques and advanced oxidation processes likely more economical are needed.

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