

Adsorption of Heavy Materials to Activated Carbon from Waste Plastics

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Abstract: This study demonstrated that activated carbon from waste PET bottle, could be used as an effective adsorbent for the removal of Cu(II) and Pb(II). Four adsorbents from waste PET bottle were experimented to remove Cu(II) and Pb(II). The adsorption performance study of the four adsorbents used revealed a different behavior with Cu(II) and Pb(II) depending on the experimental conditions. Many experiments were carried out to study the adsorption capacity of certain parameters such as effect of concentration, effect of pH, effect of temperature and contact time. The initial of Cu(II) and Pb(II) concentration used is 100 mg/L while maintaining the adsorbent dosage at 0.150 g for each of 4 activated carbons used. The highest adsorption capacities for the removal of Cu(II) and Pb(II) were found with the activated carbon 1/4 with composite with (Coal=1 and KOH=4) which gave (7.27 mg/g and 17.74 mg/g for Cu and Pb, respectively) followed by activated carbon 2/4 with composite with (Coal=2 and KOH=4) gave (6.35 mg/g and 14.78 mg/g for Cu and Pb, respectively). On the other side the lowest adsorption capacity of 4/4 gave (5.97 mg/g and 10.28 mg/g for Cu and Pb, respectively) were recorded for (Coal=4 and KOH=4). The equilibrium time for adsorption of Cu(II) and Pb(II) from aqueous solutions by using activated 1/4 was achieved within 6 hours of contact time. Kinetics studies showed better applicability for pseudo-second-order model for copper and lead. The isotherm study indicated that adsorption data correlated well with Langmuir isotherm model than Freundlich isotherm model.

Key words: copper, lead, adsorption, waste PET bottle, activated carbon.

1. Introduction

Heavy metal pollution has been one of the most challenging environmental problems due to its toxicity, persistence, and bioaccumulation tendencies [1]. They are toxic, resistant and non-biodegradable pollutants. They generally come from activities including mining, industry and agriculture. In developing countries, these pollutants are directly discharged into watercourses without prior treatment and have negative consequences on aquatic ecosystems. They are toxic to humans, animals, soil and the aquatic environment [2]. The impact of heavy metals on human health include cancers, dermatitis and muscular impairments, reproductive system damage, low infant birth weight, lactation problems, gastrointestinal, lungs and kidney diseases, immune and nervous system dysfunction. Their discharge into the

natural environment requires taking into account certain measures, including discharge standards, compliance with the limits and restrictions imposed by international organizations. Copper is a heavy metal that is very dangerous for health and for the environment at high concentrations. It has an aptitude for the organism when it is present at too high level and much more toxic in the form of the divalent metal Cu(II). Once in the human body, it can cause many diseases such as widespread capillary damage and central nervous system damage, hemolysis problems, hepatotoxic and nephrotoxic effects and Wilson's disease. It is often found in wastewater and industrial effluents [3]. Lead is one of the most toxic heavy metals in the world. It can cause acute and chronic effects on human health even at very low levels of exposure. It comes from different sectors of activity such as industry, mining,

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agriculture and is easily found in raw water. Once in the human body, lead can cause nervous system disorders, severe abdominal pain, cardiovascular problems and kidney problems [4]. The development of various traditional techniques for the depollution of domestic and industrial wastewater containing heavy metals and the strengthening of more efficient methods continue to be extended in order to be able to effectively treat wastewater containing heavy metals. There are several techniques for wastewater treatment; the most important and widely used include ion exchange, adsorption, membrane treatment, precipitation and dialysis. For implementation, some of these methods are expensive and difficult to achieve technically and economically in developing countries. Adsorption with activated carbon is the simplest and least expensive method with a heavy metal removal efficiency is up to 99%. Research then turned to adsorption processes using less expensive materials. Among these less expensive adsorbents, there is PET waste bottle, which can be recycled into activated carbon and be used to eliminate hazardous materials from effluents. In South Korea, these waste PET bottles are generated in large quantities each year and ends up free of charge in garbage cans. The most common way to recycle waste PET is production of activated carbon and it is one of the most environmentally friendly solutions.

2. Materials and Methods

2.1 Experimental procedure

2.1.1 Adsorbent and characteristics

The activated carbon used in this adsorption study

was prepared in our Laboratory. It was obtained from waste PET bottle, which were cut into small fine pieces, introduced and then carbonized at 450 °C for 4 hours in Electrical Tube Furnaces. The nitrogen flow and the nitrogen pressure used are 100 cc/min and 80 bars, respectively. The coal obtained was mixed with potassium hydroxide and activated again in Electrical tube furnaces at 800 °C for 6 hours. The nitrogen flow and the nitrogen pressure used are the same like previously step. The activated carbon obtained is dissolved in 250 ml of HCl solution at 1.0 M and continually washed with distilled water. The target pH of the activated carbon found is between 6.5 to 7.5 and then dried at 110 °C. in an oven for 3 nights. Different masses ratios of coal to potassium hydroxide $1/4 = 1:4$, $2/4=1:2$, $3/4 = 1:1.33$ and $4/4 = 1:1$ g/g and took to prepare composite of coal –KOH.

2.1.2 Chemical reagents

All the chemical reagents used were of analytic grade, except as noted and solutions were prepared using deionized (DI) water. Copper sulphate pentahydrate $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$, lead (II) nitrate $\text{Pb}(\text{NO}_3)_2$, Potassium hydroxide KOH, sodium hydroxide NaOH and hydrochloric acid HCl purchased and used for this work.

2.1.3 Preparation of Cu(II) and Pb(II) stock solutions

Stock solutions of copper (II) ions and lead (II) ions at 1,000 ppm were prepared by dissolving respectively 3.929 g of copper sulphate pentahydrate ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$) and 1.598 g of lead (II) nitrate $\text{Pb}(\text{NO}_3)_2$, in 1000 ml of DI water. Samples of different concentrations were prepared from the stock solution by appropriate dilutions.

Table 1 Chemical properties of the target compounds.

Compounds	Molecular Formula	Molecular Weight	Chemical structure
Copper sulphate pentahydrate	$\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$	249.68 g/mol	
Lead (II) nitrate	$\text{Pb}(\text{NO}_3)_2$	331.2 g/mol	

a) Impact of variable factors

- Contact time

Adsorption equilibrium studies are performed with an adsorbent quantity of 0.5 g by 500 ml of heavy metals with 100, 200 and 300 ppm from 10 to 360 min at 25 °C.

b) Effect of initial concentration

To study the influence of the variation of the initial concentration of Cu (II) ions and Pb (II) on the adsorption efficiency, we used 0.150 g of each adsorbent, the initial concentration of Cu (II) ions and Pb(II) ions was 100 ppm. Rotation time used is 48h.

- Effect of temperature

The adsorption equilibrium studies are carried out with 0.150 g of adsorbent, 40 ml of volume of Cu(II) and Pb(II) with 20, 50, 100, 200, 400, 600 ppm. at various system temperatures: 15 °C, 25 °C and 35 °C.

- Effect of pH

The effect of pH on adsorption of Cu(II) and Pb (II) was investigated by varying the solution pH from 4 to 10 (pH=4, pH=5.5, pH=7, pH=8.5 and pH=10). The solution pH was adjusted by using 1.0 M HCl and 1.0 M NaOH and recorded in a Hanna pH meter. The initial concentration of copper (II) and lead (II) ions used was 50 mg/L, adsorbent quantity was 0.2 g and volume of solution was 40 ml. Rotation time, rotation speed and temperature were 48 hours, 200 rpm and 25 °C respectively.

- Determination of wavelengths

All samples of Cu(II) and Pb(II) used were analyzed by ICP-OES. The wavelengths of copper (II) ions and lead (II) ions obtained are: 327.393 nm and 220.353 nm respectively.

2.2 Experimentation

The experimental studies of sulfamethoxazole and carbamazepine on the activated carbons used in this study were carried out by studying several possible scenarios: the variation of the initial concentration, the variation of the experiment temperature and the contact time. The equilibrium quantity and the removal

efficiency of the compounds used were determined by the following relationships:

$$q_e = \frac{(C_o - C_e) * V}{m} \quad (1)$$

And by calculating the removal percentage

$$R(\%) = \frac{(C_o - C_e)}{C_o} * 100 \quad (2)$$

Are: C_o —initial concentration (mg/l), C_e —equilibrium concentration (mg/l), m —mass of the adsorbent (g), V —volume of the solution (l).

3. Results and Discussion

3.1 Activated Carbon Characteristics

Knowledge of the textural properties of an adsorbent is a fundamental step in adsorption. They are always carried out by N_2 adsorption/desorption. Its main objective is to determine the specific surface area of materials by multilayer nitrogen adsorption, the pore area and the specific pore volume. It also makes it possible to evaluate the external surface and the surface of the pores to determine the total specific surface. It also makes it possible to interpret in advance the adsorption capacity between the adsorbent and the molecules [5]. BET analysis determines the specific surface area of materials by multi-layer nitrogen adsorption using relative pressure using an automated analyzer while the

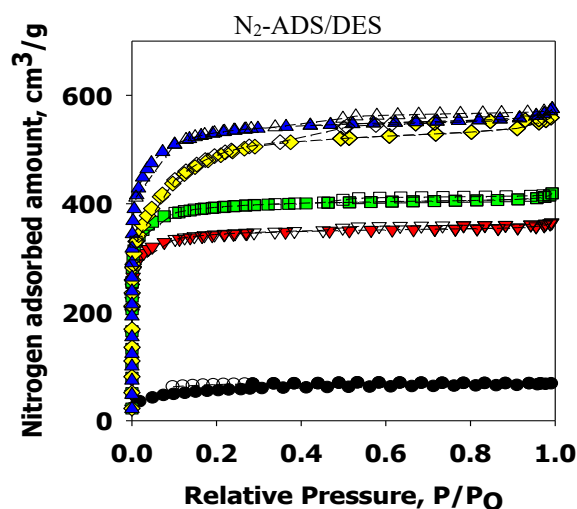


Fig. 1a N_2 adsorption-desorption isotherms of various PET Acs.

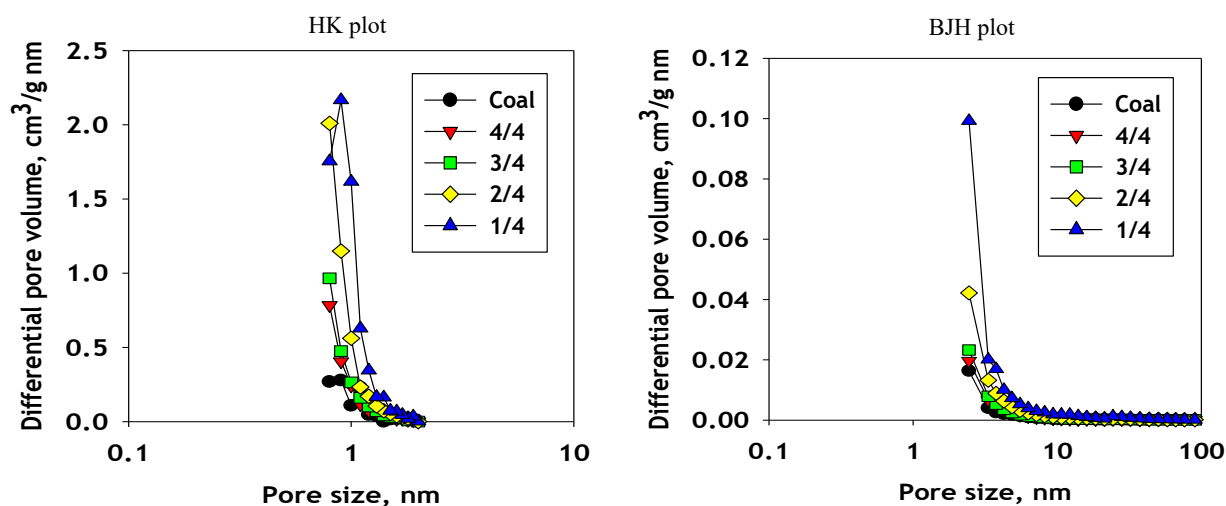


Fig. 1b and 1c Pore size distributions obtained from HK methods and BJH methods.

Table 2 The parameters of porous structure for the initial carbons calculated from nitrogen adsorption isotherms.

Adsorbents	BET surface area (m ² /g)	Pore volume (cm ³ /g)	Diameter (nm)
1/4	2720.90	1.2914	1.8985
2/4	2022.50	0.8848	1.7499
3/4	1530.80	0.6454	1.6864
4/4	1348.00	0.5636	1.6724
Coal	199.33	0.1051	2.0555

BJH and HK methods determine the surface area and specific pore volume using adsorption and desorption techniques. The experimental results show that the increase in the porosity of the adsorbent depends on the increase in the rate of interpretation [6]. The BET specific surface and the pore volume of 1/4 activated carbon are 2,720.98 m²/g and 1.2914 cm³/g, respectively.

3.2 Effect of pH

The study of the pH of the solution of a metal is an important factor in adsorption. It makes it possible to determine the charge of the surface and the degree of ionization and speciation of the adsorbent. In this study, the pH of the solution of copper and lead were studied in the range of 4 to 10. The pHs of the solution were adjusted using solutions of HCl and NaOH at 1.0 M. the initial concentration of each of the solutions studied was equal to 50 mg/l and the quantity of the adsorbent is equal to 0.2 g.

The pH solution study of a metal is an important factor in adsorption. In this study, the pH of the solution of copper and lead was study in an interval of 4 to 10 by using 50 mg/l initial concentration of each pH solutions. Seeing the results in the figure above, we can conclude that the pH positively influences the adsorbed amount of Cu(II) and Pb(II). From pH=7 to pH=10, the adsorbed quantity of Cu(II) and Pb(II) is very low. The highest quantity adsorbed can be obtained between pH=4 and pH=6 for both Cu(II) and Pb(II). From pH 4 to 6, the concentration of H⁺ is high and the adsorbent surface becomes much more positively charged so the active sites of the adsorbent surface become available for attraction with copper and lead ions. At pH greater than 6, the H⁺ concentration decreases and the OH⁻ concentration increases such that the active sites of the of adsorbent surface become negatively charged and the adsorption between the metal ions and the adsorbent could not be available. Similar results have been reported by [7].

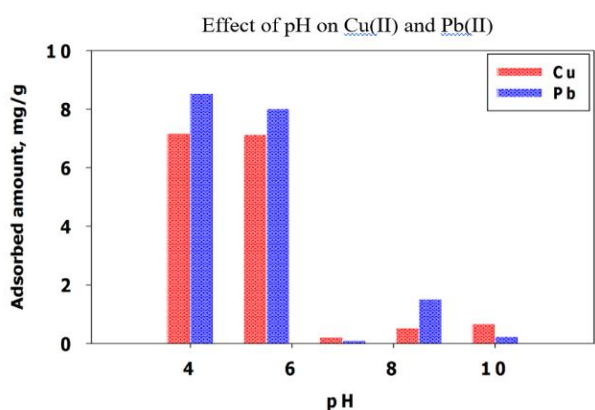


Fig. 2 Effect of pH on Cu and Pb, initial concentration (Co=50 mg/l), 40 ml of each of the solution, adsorbent amount 0.200 g, rotation speed 200 rpm, rotation time 48 hours and temperature 25°C.

3.3 Effect of Activation Agent Contents on Cu(II) and Pb(II) Adsorption

The experiments on impact of initial Cu(II) and Pb (II) concentration were carried out at pH 5.0 for 48h at 25 °C. Cu(II) and Pb (II) adsorption are significantly influenced by the initial concentration of Cu(II) and Pb (II) ions in aqueous solutions. In the present study, the initial of Cu(II) and Pb (II) concentration used is 100 mg/L while maintaining the adsorbent dosage at 0.150 g for the 4 activated carbons used.

The results of the histogram representation show that the adsorption capacity of activated carbon 1/4 =

1:4 g/g with composite of Coal and KOH (Coal=1 and KOH=4) was high than those obtained with less KOH. This result can be explained by the high amount of KOH it contains compared to other activated carbons used. From the adsorption test results of the 4 activated carbons used on Cu and Pb by using 100 ppm initial concentration of adsorbates, it seems that the activated carbon 1/4 with composite with (Coal=1 and KOH=4) gave the highest adsorption quantity (7.27 mg/g and 17.74 mg/g for Cu and Pb, respectively) followed by activated carbon 2/4 with composite with (Coal=2 and KOH=4) gave (6.35 mg.g⁻¹ and 14.78 mg.g⁻¹ for Cu and Pb, respectively). Unlike, the lowest adsorption capacity belongs to activated carbon (5.97 mg.g⁻¹ and 10.28 mg.g⁻¹ for Cu and Pb, respectively) which were recorded for (Coal=4 and KOH=4). Our results are similar to those found by [8].

3.4 Langmuir Isotherm of Cu and Pb at Various System Temperature

The Langmuir isotherm [9] describes monolayer adsorption onto a homogeneous surface of the adsorbent. The assumptions of the Langmuir model are [10]: The adsorption energy is constant on all sites and each site can accommodate a single molecule or an atom.

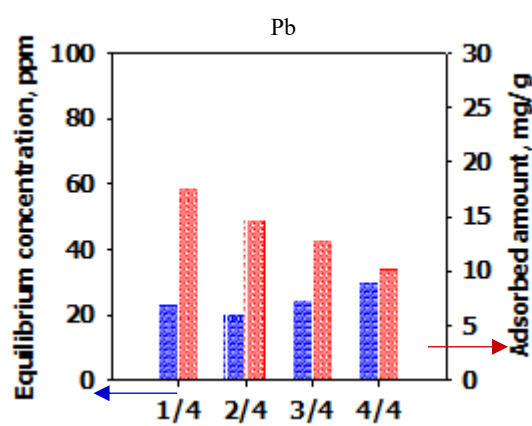
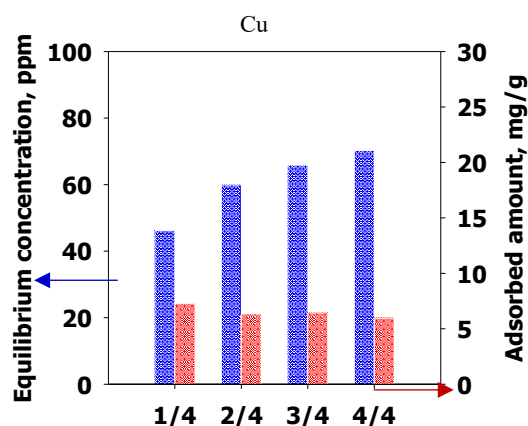


Fig. 3a and 3b Effect of initial concentration of Cu and Pb, initial concentration 100 ppm, 40 ml of each of the solution, adsorbent quantity 0.150 g, rotation speed 200 rpm, pH=5 and temperature 25 °C.

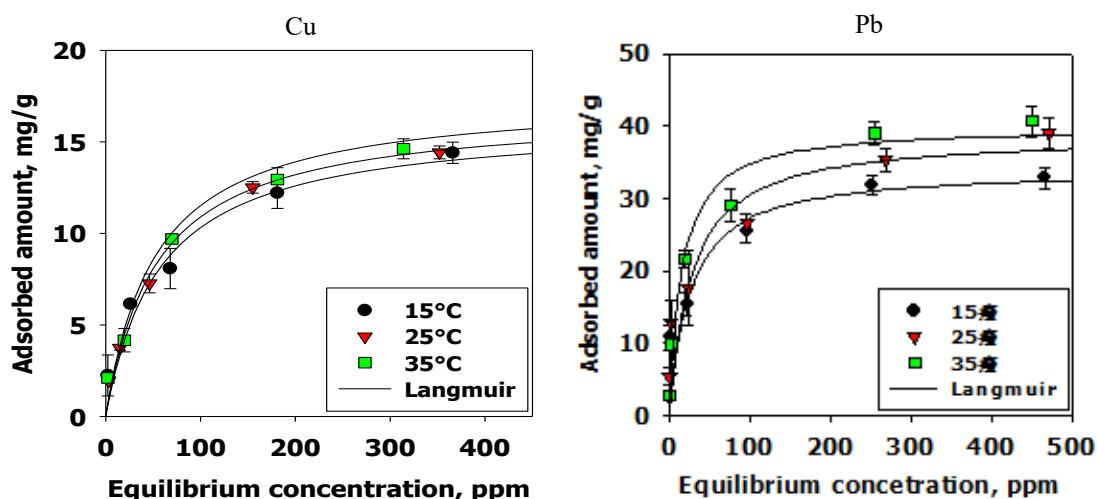


Fig. 4a and 4b Langmuir isotherm at various temperature on copper and lead, initial concentrations ($C_0=20, 50, 100, 200, 400$ and 600 ppm), 40 ml of each of the solution, adsorbent quantity 0.150 g, agitation speed 200 rpm, shaking time 48 hours and $pH=5$.

The expression of Langmuir's law is given by the following equation:

$$q_e = \frac{q_m * b * C_e}{1 + bC_e} \quad (3)$$

With: q_e —equilibrium quantity by the adsorbent (mg. g^{-1}), C_e —equilibrium concentration of the adsorbate (mg. L^{-1}), q_{max} —maximum adsorption capacity of Langmuir (mg. g^{-1}) and b —Langmuir adsorption equilibrium constant (L.mg^{-1}).

Temperature is a very important parameter in the adsorption process. Experimental Cu(II) and Pb(II) adsorption tests were evaluated at different temperatures ($15, 25$ and 35 °C). The adsorption test results of Cu(II) and Pb(II) revealed that the adsorption capacity of Cu(II) and Pb(II) increases when the temperature increases, i.e. when one increases, the second also increases indicates that the adsorption process is endothermic and the highest adsorption capacity of Cu(II) and Pb(II) was obtained at 35 °C using $15, 25$ and 35 °C. This may be due at to high temperature; the increase in kinetic energy of adsorbent particles and indicates that the adsorption between adsorbent and metal ions was an endothermic process [11]. Moreover, we notice that the adsorption capacity of Cu(II) and Pb(II) increased when the initial concentration of Cu(II) and Pb(II) increased. This

phenomenon can be explained by the fact that at high initial concentration, there are many molecules of copper and lead available in the solution to be adsorbed in the active sites of the activated carbon. According to the isotherm study, we can conclude that Langmuir isotherm describes well the experimental adsorption test of Cu(II) and Pb(II) on the activated carbon used, which indicated a reduction of active sites on the adsorbents at a high residual Cu(II) and Pb(II) concentration in the solution phase [12]. As shown in Table 6.3, with increasing temperature, the Langmuir adsorption equilibrium constant b (l/mg) of Cu(II) and Pb(II) increases also, indicating the bond energy between active sites of adsorbents and metal ions is favorable at high temperature [13]. Additionally, the largest maximum adsorption capacities of the Langmuir isotherm are obtained at high temperature, which is consistent with the experimental data. From Langmuir equation, the values of q_m were calculated to be $16.174, 16.751, 17.547$ mg/g at 15 °C, 25 °C and 35 °C, respectively for Cu(II) and $34.162, 38.811, 40.001$ mg/g at 15 °C, 25 °C and 35 °C, respectively for Pb(II). Similar results have been reported by [14]. The values of correlation coefficients obtained for Langmuir model of Cu(II) and Pb (II) model ($R^2 > 0.9724$) showed that Langmuir model is suitable to describe the

adsorption of Cu(II) and Pb (II) ions on activated carbon.

3.5 Freundlich Isotherm of Cu and Pb at Various System Temperature

The Freundlich isotherm [15] is frequently used to describe the adsorption on heterogeneous surfaces. The Freundlich equation is well suited to describe the aqueous phase equilibrium. Its empirical formula is:

$$qe = Kf * ce^{\frac{1}{n}} \quad (4)$$

With: q_e —The equilibrium concentration of the adsorbent (mg. g^{-1}), C_e —The equilibrium concentration of the adsorbate (mg. L^{-1}), KF and $1/n$ —Freundlich constants related to adsorption and affinity

The analysis of Figs. 5a and 5b and the obtained Freundlich isotherm parameters from Cu(II) and Pb(II) experimental tests make it possible to conclude the behavior of the Freundlich isotherm with the experimental data. It was found that the highest adsorption capacities K of Freundlich isotherm are obtained at high temperature. The calculated Freundlich isotherm K values were 2.1227, 2.6965 and 3.0994 by using 15 °C, 25 °C and 35 °C, respectively for Cu(II) and 9.8569, 9.9849, 10.7331 by 15 °C, 25 °C

and 35 °C, respectively for Pb(II) which is consistent with experimental data and also shows that the adsorption capacities increases with increasing temperature, indicating at high temperature the interaction between metal ion and adsorbent become more available [16]. The Freundlich isotherm is frequently used to describe the adsorption on heterogeneous surfaces. The n parameter, known as the heterogeneity factor, can be used to indicate whether the adsorption is linear ($n=1$), whether it is a chemical process ($n<1$), or whether a physical process is favorable ($n>1$). When ($n=1$), the adsorption is linear; when ($n<1$), the adsorption process is a chemical process; when ($n>1$), physical process is favorable. On the other hand, values of $1/n<1$ and $1/n>1$ indicate a normal Langmuir isotherm and cooperative adsorption, respectively [17]. In this study, the values ($n>1$) and the $1/n$ values are less than 1 indicate that the physical process and the normal Langmuir isotherm are favorable. The correlation coefficients obtained from Freundlich model of Cu(II) and Pb (II) model ($R^2>0.9528$) showed that Freundlich model is suitable to describe the adsorption of Cu(II) and Pb (II) ions on activated carbon with the lowest correlation coefficients.

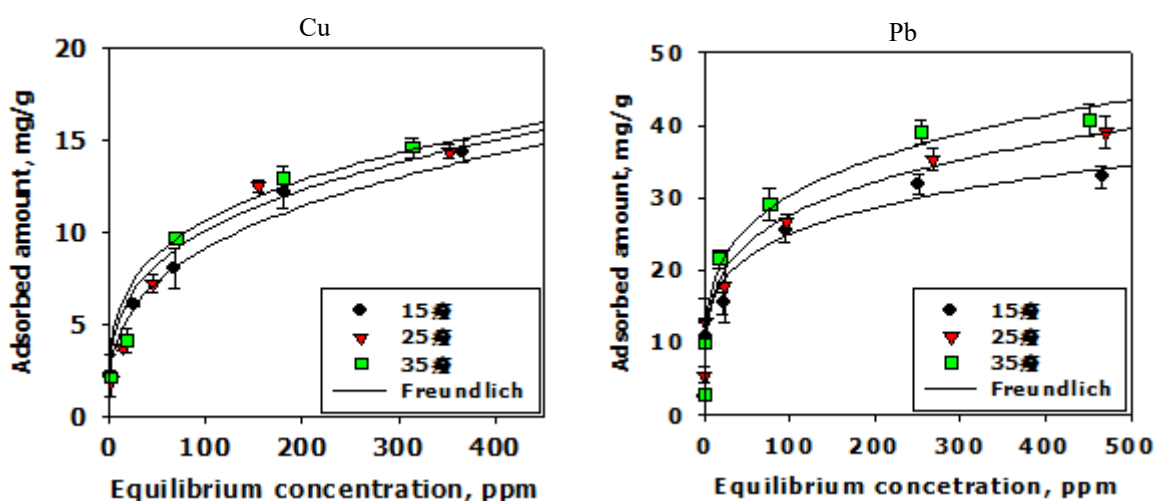


Fig. 5a and 5b Freundlich isotherm at various temperature on copper and lead, initial concentrations ($C_0=20$, to 600 ppm), $v=40$ ml, $AC=0.150$ g, rotation speed 200 rpm, rotation time 48hours and $pH=5$.

Table 3 Adsorption isotherms parameters.

Adsorbates	Temperature (°C)	Langmuir isotherm model			Freundlich isotherm model		
		q_m	b	R^2	K	$1/n$	R^2
Cu	15	16.174	0.0176	0.9724	2.1227	0.376	0.9614
	25	16.751	0.0186	0.9842	2.6965	0.286	0.9741
	35	17.547	0.0191	0.9841	3.0994	0.268	0.9605
Pb	15	34.162	0.0395	0.9813	9.8569	0.2012	0.9708
	25	38.811	0.0368	0.9816	9.9849	0.2234	0.9528
	35	40.001	0.0658	0.9795	10.7331	0.2251	0.9612

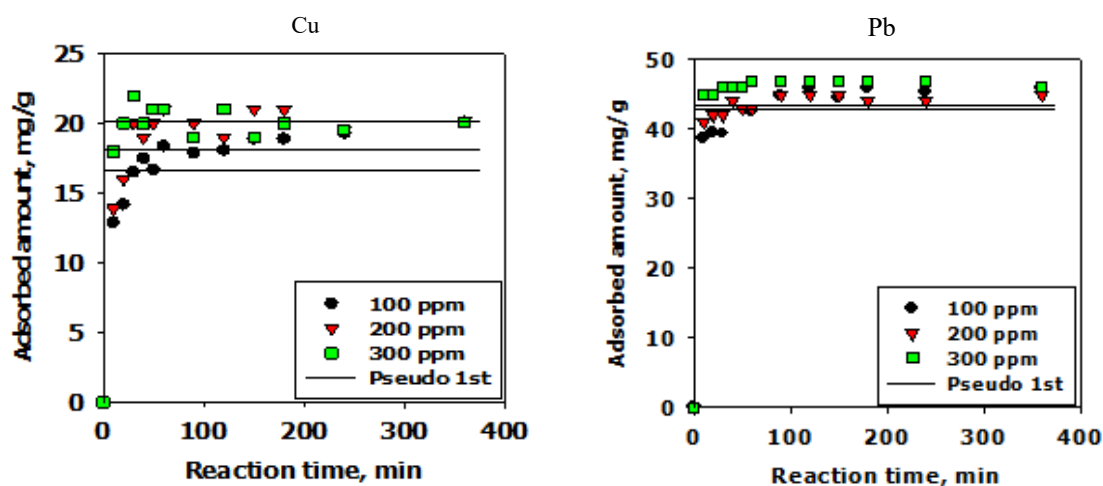


Fig. 6a and 6b Pseudo-first order model of copper and lead at various initial concentration 100, 200 and 300mg/l and various contact time

3.6 Adsorption Kinetics

Kinetic studies are carried out to better understand the dynamics of adsorption reactions on the studied pollutants. They are also used to determine the rate constant of the kinetics model. The most important information for the design and modeling of the adsorption process is provided by the kinetic parameters of the model. In our study, the adsorption tests for the kinetic study were carried out using 100, 200 and 300 mg/l initial concentrations for copper and lead with 0.5 g of adsorbent for a contact time ranging from from 10 to 360 minutes.

4.6.1 Pseudo first order kinetics

Lagergren first order equation is tested to fit the experimental data obtained from the experiments test. The equation is based on the adsorption of an adsorbate from solution onto solid adsorbent, so it is usually referred as pseudo-first order kinetic model [18]. The

pseudo-first order equation is given as follows:

$$q = q_e (1 - e^{-k_1 t}) \quad (5)$$

Where: k_1 is the rate constant for pseudo first order kinetics (min^{-1}), q_e is the equilibrium adsorption capacity (mg/g) and q the adsorption capacity at time t (mg/g).

Analysis of Figs. 5a and 5b showed that the copper and lead adsorption capacity increased rapidly during the first 30 minutes with a very high copper and lead removal rate and reached equilibrium after 60 minutes. This adsorption rate was probably due to the number of active sites of the adsorbent surface available to receive the molecules of the adsorbate in solution on its surface. Then after 30 minutes of contact, the adsorption rate decreased as the contact time progressed until equilibrium. This can be explained by the fact that after equilibrium, the active sites of the activated carbon were saturated and the mass transfer of the adsorbate

molecules from the liquid to the adsorbent surface was limited [19]. The equilibrium quantities obtained from the experimental adsorption tests are (Q_{exp}) are 20.154, 20.441 and 20.181 respectively, for 100, 200 and 300 ppm for Cu(II) adsorption and 45.861, 46.014 and 45.912 mg/g respectively, for 100, 200 and 300 ppm for Pb(II) adsorption. The kinetic parameters obtained from pseudo-first-order model revealed that the pseudo-first order model does not describe the experimental data of Cu(II) and Pb(II). This can generally be explained by the low values of the correlation coefficients obtained from the first-order-model equation and the disagreement between the adsorbed quantity obtained by the experimental test and those obtained by using the first order model equation. In this present study, we notice that the correlation coefficients obtained for Cu(II) and Pb(II) are very low and very far from 1. Therefore, we can conclude that the pseudo-first order model does not describe the experimental test on Cu(II) and Pb(II). This can be confirmed by [20].

3.6.2 Pseudo second-order kinetics

The pseudo-second-order model is frequently used in adsorption. This model was applied in activated carbon adsorption, clays or other adsorbents. According to [21], this model is based on the following

assumptions:

$$q = \frac{K_2 q_e^2 t}{1 + K_2 q_e t} \quad (6)$$

K_2 is the rate constant for pseudo-second-order kinetics (min^{-1}); q_e is the equilibrium adsorption capacity (mg/g).

q —the adsorption capacity at time t (mg/g).

From the results obtained in the Figs. 7a and 7b, we can conclude that the adsorption capacity of Cu(II) and Pb(II) increases when the contact time increases and reaches equilibrium after 60 minutes. The kinetic parameters results of the model obtained revealed that pseudo-second-order model described well the experimental data of Cu(II) and Pb(II) as seen in the rate constant adsorption which increased with the increase of Cu(II) and Pb(II) initial concentrations and the correlation coefficients (R^2) values. Moreover, the equilibrium quantities obtained from the adsorption test of Cu(II) and Pb(II) coincide with those obtained from the pseudo-second order using 100, 200 and 300 mg/l. The rate constant k_2 values for de pseudo second-order kinetic equation adsorption were calculated to be 0.0094, 0.0130 and 0.0635 $\text{mg} \cdot \text{mg}^{-1} \cdot \text{min}^{-1}$ respectively, for 100, 200 and 300 ppm for Cu(II) adsorption and

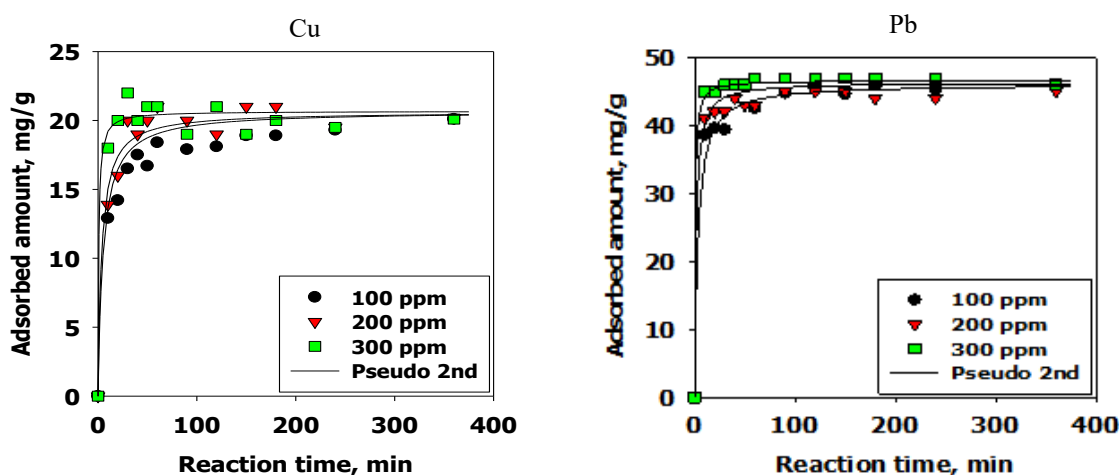


Fig. 7a and 7b Pseudo-second-order model of copper and lead at various initial concentration 100, 200 and 300mg/l and various contact time.

Table 4 Kinetic parameters of pseudo 1st and 2nd order models

Adsorbate	Initial concentration	q _e (Exp)	pseudo 1 st order			pseudo 2 nd order		
	ppm	mg · g ⁻¹	q _e (Pre)	K ₁	R ²	q _e (Pre)	K ₂	R ²
			mg · g ⁻¹	min ⁻¹		mg · g ⁻¹	g · mg ⁻¹ l · min ⁻¹	
Cu	100	20.154	16.566	141.717	0.851	19.189	0.0094	0.988
	200	20.441	18.1733	142.159	0.848	20.632	0.0130	0.960
	300	20.181	20.1809	141.159	0.957	20.673	0.0635	0.966
Pb	100	45.861	42.904	128.047	0.946	46.095	0.0065	0.983
	200	46.014	43.362	129.568	0.987	46.334	0.0142	0.996
	300	45.912	43.364	131.145	0.971	46.634	0.0385	0.996

0.0065, 0.0142 and 0.0385 mg/mg/min respectively, for 100, 200 and 300 ppm for Pb(II) adsorption [22]. Therefore, the perfect agreement between the values of (q_{e,exp.}) and (q_{e,cal.}) of Cu(II) and Pb(II) indicates that the pseudo-second-order kinetic model is appropriate to describe the adsorption behavior of the adsorbent selected so that the rate limiting factor could be a chemisorption process, where the interactions (chemical bonding) involved the sharing or exchange of electrons between the adsorbate and the adsorbent [23].

4. Conclusion

The experimental results of Cu and Pb adsorption tests revealed that the activated carbons used in this thesis are excellent adsorbents for the removal of heavy metals from aqueous solutions. They were made from plastic waste, activated by KOH with a very low cost and have a high adsorption capacity. They can be recommended for wastewater treatment containing hazardous materials. At the end of this study, we can conclude the following results:

The experimental tests results of PET activated carbons on copper and lead have shown the effectiveness of the activated carbons used for copper and lead elimination.

by carrying out the experimental study with different temperatures, the obtained results showed that the adsorption capacity of Cu and Pb increases when the temperature increases, i.e. when one increases, the

second also increases indicates that the adsorption process is endothermic and the highest adsorption capacity was obtained at 35 °C by using 15, 25 and 35 °C.

The highest adsorption capacity of Cu and Pb removal were found at pH 5.

The equilibrium time was reached at only 1h of Cu and Pb contact time on the activated carbon used

Langmuir's model described well the experimental adsorption of Cu and Pb than Freundlich's model.

Kinetic studies showed that the pseudo-second-order model better describes the adsorption of Cu and Pb on activated carbon used than the pseudo-first-order model.

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