

Sorption of Pb^{2+} Ions on to Activated Carbons Prepared from Olive Stones

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Abstract

The carbon sample "O", phosphoric acid-activated carbon "OP", zinc chloride-activated carbon "OZ", and two steam activated carbons "OS" and "OS2" with different burn-off of 25% and 58% respectively, were prepared from olive stones. The textural properties were determined from the results of nitrogen adsorption at 77 K and by analyzing these results through the application of different adsorption models. The chemistry of the carbon surfaces was determined from the base neutralization capacities, acid neutralization capacity and surface pH. The sorption of Pb^{2+} ions on to the carbons prepared was followed under dynamic and equilibrium conditions. The differences between the values of the textural parameters were attributed to the inapplicability of some adsorption models and to the heterogeneity of the microporous carbons. The sorption of Pb^{2+} ions is favored on carbon and activated carbons. However, chemically activated carbons are more effective compared with steam-activated ones. The sorption of Pb^{2+} ions were related to the chemistry of the surface rather than to the textural properties.

Keywords: Active carbons, Adsorption, Removal of heavy metals

1. Introduction

The term "activated carbon" relates to a group of materials with highly developed surface area and porosity and hence a large adsorption capacity for various adsorbates both from solutions and from gaseous phases [1-3]. Activated carbons are extremely versatile adsorbents of major industrial importance and are used in a wide range of applications concerned principally with the removal of species of toxic or hazardous nature [4, 5]. Activated carbons also find a use in catalysis where they may be used either as catalysts [6] or as catalyst supports [7]. The treatment of surface and waste water is a new important field in which activated carbons are effective [8].

Activated carbons can be produced from virtually and carbonaceous material precursor, both naturally occurring and synthetic. Coals of different rank are important precursor for the production of activated carbons. Common examples of commercial feedstocks are materials of botanical origin (e.g. wood, coconut shell and nut kernels) and degraded or coalified plant materials. Activated carbons are obtained by following one of two procedures: Chemical or physical activation. In chemical activation, the precursor in a divided form is mixed with an activating agent such as phosphoric acid or zinc chloride and the mixture is then carbonized in a limited supply of air or in an inert atmosphere at an intermediate temperature not exceeding 1000°K [9]. Physical activation is more frequently used relative to the chemical activation and is performed by gasifying non-activated

carbon with a stream of oxidizing gas to a certain degree of burn-off. The conditions under which physical activation is conducted depend on the precursor but more on the gasifying agent and temperature. Activation with carbon dioxide or steam is usually carried out at temperatures between 1200 and 1400 K, while activation with oxygen or air is made at ca. 700~800 K [10].

Several processes have been developed for removal of metals from waste discharges. These unit operations include chemical precipitation, coagulation/flocculation, ion exchange/solvent extraction cementation, complexation, adsorption, evaporation, filtration, electrochemical operations and membrane processes. Adsorption of heavy metals from waste discharges is a current trend. Many adsorbents such as silica, clay, cellulose and its derivatives and metal oxides are reported to show high capacity for the removal of heavy metals [11, 12]. However, activated carbons are by far more effective in this application due to some specific characteristics that enhance the use of activated carbons for the removal of contaminants including heavy metals from water supplies [8, 13].

The present investigation is devoted to prepare different activated carbons from one of the major agricultural wastes, namely olive stones. To determine their textural characteristics (surface area and porosity) and the chemistry of their surfaces (the surface carbon-oxygen groups), the study concentrates on the factors affecting the activity of the investigated carbon for the adsorption of $Pb(II)$ ions from aqueous solution.

2. Experimental

2.1. Materials

The carbon sample "O" obtained from carbonizing dry clean and crushed olive stones at 873 K, in a limited air supply. Phosphoric acid-activated carbon "OP" was obtained by impregnating dry crushed olive stones in 50 wt% phosphoric acid solution. The resulting material was heated gradually in absence of air at 873 K, over a period of 2 h and then maintained at the maximum exposure temperature for a further 3 h. After cooling the carbonized mass, it was washed thoroughly with distilled water until the washing attained a pH value of 6.0 when the washed material was dried. Further details have been given elsewhere [11]. Zinc chloride-activated carbon (OZ) was prepared by impregnating dry, crushed olive stones in an aqueous solution containing twice the weight of the olive stone, of anhydrous zinc chloride. The resulting mass was heated gradually in absence of air at 873 K over a period of 2 h and then maintained at 873 K for a further 3 h. The carbonized product was washed thoroughly with distilled water until the washings were free from chloride ions then the washed material was dried. More details have been published elsewhere [12]. Two steam-activated carbons (OS1 and OS2) were prepared by gasifying the activated carbon O with steam at 1173 K to burn-off's equal 25% and 58%, respectively. All the carbon samples have been treated for several times with 10% HCl and then with 5% HF to reduce the inorganic content to the least possible amount. This has been followed by determining the ash content. The ash content of the carbon samples was determined to be 0.08%.

2.2. Methods

The adsorption of nitrogen at 77 K was measured using a conventional volumetric apparatus. Prior to all measurements, the carbon samples were heated at 523 K for 6 h under a reduced pressure of 10^{-5} Torr. The pH of the aqueous solution of Pb(II) nitrate and the aqueous suspensions of carbons are measured using a digital (Pope model No.1501).

Carbon exchange capacities (CEC) were determined by following the standard ASTM method [14]. The quantity is expressed in meq/g. Base neutralization capacities were determined according to the Boehm titration [15]. These were carried out by neutralization of $0.1 \text{ mol/dm}^3 \text{ NaHCO}_3$, Na_2CO_3 , NaOH and NaOC_2H_5 by the carbon sample.

The adsorption of Pb(II) was carried out as follows: Defined amount of the carbon sample were shaken for different periods of time (Kinetic experiments) or for 6 h (equilibrium experiments) at 298 K. Before the concentration of Pb(II) ions present in the solution was measured, the carbon was filtered from the mixture. The concentration of Pb(II) was measured using a Varian Spectra AA-200

Atomic Absorption Spectrophotometer (AAS) in flame mode with an air-acetylene flame.

3. Results and Discussion

3.1. Textural properties

The adsorption of nitrogen at 77 K on all the carbons investigated proved to be rapid with the equilibrium attained within 30 min., indicating that all the existing pores are accessible to nitrogen molecules at 77 K. Fig. 1 are of type I according to the BDPT classification. This was true for carbons O, OP, OZ and OS1 and indicated the predominance of microporosity. Nitrogen adsorption at 77 K on OS2 exhibited an isotherm laying between types I and type II, indicating a different pore structure than that predominated in the other investigated carbons. Another evidence for the different pore structure of OS2 is the presence of a closed hysteresis loop of H3 type according to IUPAC classification [16]. OS2 is a steam activated carbon with a high percentage of burn-off (58%) that might lead to pore widening.

Different adsorption models were considered in analyzing the nitrogen adsorption results. The Langmuir equation was applied to determine the maximum adsorption capacity and consequently the equivalent surface area S^L (m^2/g), column 2 of Table 1. The conventional BET equation was also applied to calculate the surface areas of the investigated carbons S^{BET} (m^2/g), column 3 of Table 1. The total pore volume V_t (ml/g), expressed as the volume of liquid nitrogen adsorbed per 1 g was determined by converting the amount of nitrogen gas adsorbed at a relative pressure of ca. 0.95 P/P^0 , is listed in column 4 of Table 1.

Based on the assumption that the space in the micropores is similar to the space between two parallel plates, the average pore radius r_p (nm) could be calculated from the relationship

$$r_p = 2 V_t \times 10^3 / S^{\text{BET}} \quad (1)$$

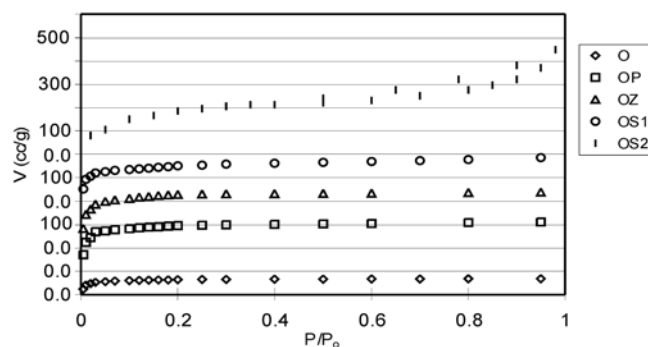
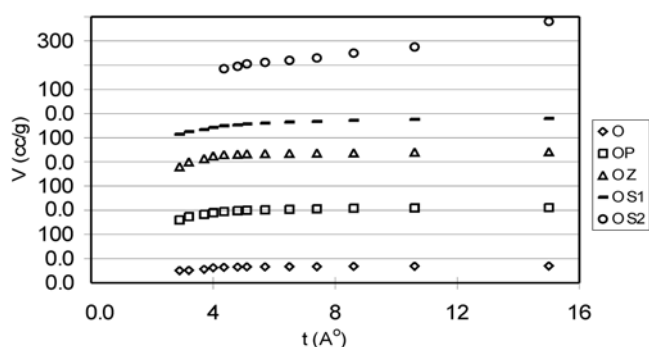


Fig. 1. Nitrogen adsorption isotherms at 77 K.

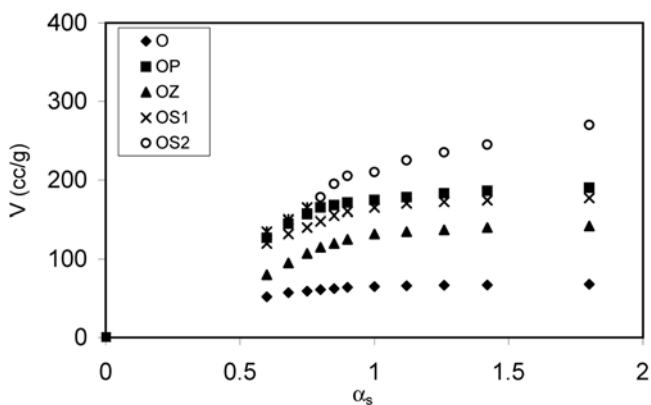
Table 1. Textural properties of carbons studied obtained from nitrogen adsorption at 77 K

Sample	S m ² /g	S ^{BET} m ² /g	V _t ml/g	r _p nm	S ^t m ² /g	S ^α m ² /g	S ^{DR} m ² /g	S _n ^t m ² /g	S _n ^α m ² /g	S _n ^α × 100
										S ^α
O	302	226	0.107	0.95	248	246	295	8.0	8.4	3.3
OP	922	728	0.329	0.90	750	756	892	28.0	26.5	3.5
OZ	1057	799	0.372	0.93	823	858	969	32.4	32.2	3.7
OS1	728	524	0.287	1.10	540	560	642	78.6	80.0	14.3
OS2	–	725	0.574	1.58	636	674	–	412	398.5	61.1

**Fig. 2.** V-t plots nitrogen adsorption at 77 K.

The values of r_p as calculated for the carbon investigated are given in column 5 of Table 1.

Two other independent methods were also applied to analyze the nitrogen adsorption isotherms, i.e. the t-method [17] and the α_s -method [18]. In the first method, the volume of gas adsorbed is plotted versus the multilayer thickness t in (Å) as measured on a non-porous sorbent of comparable BET-C constant Fig. 2. The second method plots the volume of the gas adsorbed versus the reduced isotherm (α_s) determined on a standard non-porous carbon. The adsorption data reported by [18] were used for such plots which are depicted in Fig. 3.

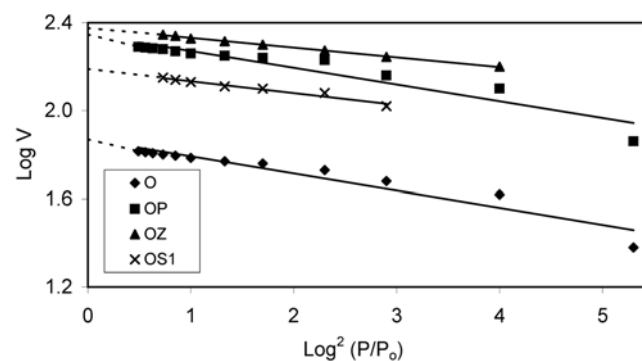
**Fig. 3.** α_s plots nitrogen adsorption at 77 K.

The t-method allowed the determination of the specific surface area S^t , the micropore volume V_{mic}^t and the non-microporous area S_n^t . S^t values are given in column 6 of Table 1 and S_n^t values are given in column 9 of this table. Similarly, the α_s -method allowed the determination of the same parameters but with notations S^α , V_{mic}^α and S_n^α . Columns 7 and 10 of Table 1 show, S^α and S_n^α , respectively. The Langmuir model and the BET model are both based on the concept of surface coverage, although the first considers monolayer adsorption in micropores while the latter considers multilayer adsorption. The physical adsorption of gases and vapors by microporous solids, in general, and by active carbons, in particular, may also be described by Dubinin's theory as developed in successive stages since 1991 [19]. The DR equation postulated in 1991 as

$$V = V^\circ \exp [-B (T/\alpha)^2] \log^2 (P^\circ/P) \quad (2)$$

where V represents the volume filled at temperature T at relative pressure P/P° , V° is the total volume of micropores, B is a parameter with the dimension K^{-2} and is called the structural parameter being related to the energy of adsorption E° by the relationship $B = 2.303 (R/E^\circ)^2$, β is another parameter and is called affinity coefficient.

The DR equation is based on the observation that a plot of $\log V$ versus $\log^2 P/P^\circ$, Fig. 4, leads to a straight line covering the adsorption at very low relative pressure in

**Fig. 4.** DR plots nitrogen adsorption at 77 K in the carbons investigated.

which the micropore are completely filled, usually between 0.02 and 0.20 P/P° . This range of applicability has been verified for many reported adsorption measurements [9, 20]. The micropore volume V° can be converted into an equivalent surface area S^{DR} . The DR method allowed also the determination of some adsorption parameters, i.e. the pore radius $X = K/E^\circ$ where E° is the adsorption energy. The equivalent surface area S^{DR} (m^2/g), of the carbons investigated is listed in column 8 of Table 1.

Inspection of Table 1 reveals the following:

1. Activation with phosphoric acid at 873 K is associated with about 3.2 fold increase in S^{BET} as compared with the carbon sample (O). The activation with zinc chloride brought also a considerable increase in the surface area S^{BET} of (OZ) is 3.54 times S^{BET} of (O). However, activation with phosphoric acid or with zinc chloride was found to be associated with a slight decrease in the average pore radius r_p . This indicates that activation with this activating agents proceeds via creation of micropores.

2. Activation with steam to 25.0% burn-off (OS1) resulted in about 2.3 fold increase in the surface area determined by the BET-method when compared with S^{BET} of carbon sample (O). Steam activation to 25% burn-off was also associated with a slight increase in r_p . Further gasification of carbon sample (O) with steam to 58% burn-off (OS2) was found to be associated with about 3.2 fold increase in the S^{BET} and with a considerable pore widening. The average pore radius of (OS2) was calculated to be 1.58 nm, i.e. lying in the mesoporous range.

3. The surface areas calculated through application of the t-method and α -method are comparable. These two methods are based on a standard non-porous material and each method can be used to compliment the other. The data listed in Table 1 show that with the exception of (OS2), the S^{BET} values were lower than the S^t and S^α values. However, the difference was not high and may be attributed to the BET-model based on multilayer coverage, which is not precisely the case in adsorption of activated carbons where most of the pores accommodate only on a limited number of layers as indicated by the values of their average radii (column 5, Table 1). It should be noted that the data in Table 1 of the calculated S^L values were very high compared with the S^{BET} , S^t and S^α values, an unsurprising fact since the Langmuir

model is based on a monolayer adsorption and in most cases monolayer capacities as determined by the application of the Langmuir model lie beyond the equilibrium pressure employed. Moreover, the Langmuir model was found to be in applicable to the adsorption results of (OS2) because this particular carbon sample is mostly mesoporous and can accommodate multilayer coverage.

4. The surface areas located in the micropore region represent a large fraction of the total surface area of carbon sample and chemically activated carbons and consequently the surface located in non-microporous region would be only a small fraction of the total surface area. This was found to be the same with (OS1) which is a physically activated carbon in which gasification with steam was limited to low percentage of burn-off (25%). For highly steam-activated carbon (OS2) with 58% burn-off, the surface located in non-micropores amounted to 61%, column 11 of Table 1.

5. Fair agreement exists between the comparable values of S^{DR} and S^L determined for carbon sample and chemically-activated carbons, i.e. O, OP, and OZ despite the fact that these values are based on two different models, S^{DR} is based on a model that considers the filling of small pores while S^L is based on a model that considers a surface coverage with a monomolecular layer. This is confirmed with previously reported results [21] which were explained on the basis that more than one mechanism of adsorption could be expected in the micropores with diameters less than 2.0 nm. In mesoporous sorbents, one mechanism is predominating, namely the multilayer surface coverage. The adsorption results obtained for (OS2) supported this point of view. Thus, the Langmuir model based on monomolecular coverage and the DR model based on micropore filling were found to be inapplicable to these results.

Table 2 lists some of the adsorption parameters from the DR equation and also includes parameters determined in other ways for comparison. It will be seen that the micropores volumes of carbon sample and chemically activated carbon, as determined from the DR model are comparable with the volumes of the nitrogen adsorbed at $P/P^\circ = 0.1$. For steam-activated carbons, there is no agreement between the values of these parameters. For carbon sample and chemically activated carbons, both the values of x (column 7, Table 2) and (column 5, Table 1) indicated microporous

Table 2. Application of the DR equation to nitrogen adsorption at 77 K

Sample	V_t ml/g	$V_{0.1}$ ml/g	V_m^{DR} ml/g	K kJ/mol	E° kJ/mol	x nm	$V_m^{D2} \times 100$	$V_{0.1} \times 100$
							V_t	V_t
O	0.107	0.094	0.105	12.82	14.6	0.89	98	88
OP	0.329	0.284	0.316	12.95	13.2	0.97	96	86
OZ	0.372	0.330	0.344	12.77	16.2	0.78	92	89
OS1	0.287	0.208	0.228	12.90	13.6	0.95	79	72
OS2	0.574	0.233	—	—	—	—	—	41

type. For OS1, x indicated microporosity, while r_p indicated the existence of a small fraction of mesoporosity which shifted the value of r_p to the border between micro- and meso-type pores.

It is also seen from Table 2, that the characteristic energies for adsorption ranged between 13.6 and 6.2 kJ/mol, i.e. they all lie in the range characterizing physical adsorption. This is not surprising for nitrogen in particular, since this molecule seldom goes into specific interaction with any adsorbent surface at 77 K [12]. Once again, columns 8 and 9 of Table 2 predict that micropores represent a very high fraction of the total pore volumes of chemically-activated carbons and consequently the volume on non-micropores represent very small fraction of the total porosities. For steam-activated carbons, the fraction of non-microporosity is considerable and increases with the increase of the percentage of burn-off.

3.2. The chemistry of the surface

The chemistry of the surface of a carbon is equally important to its textural properties in determining its adsorption capacity particularly from solution. The chemistry of the carbon surface is due to the existence of carbon-oxygen groups of acidic and / or basic nature. The chemistry of the carbon surface is determined from the base neutralization capacities (BNC) expressed in meq/g. A series of basis of increasing strength are used namely, NaHCO₃, Na₂CO₃, NaOH and NaOC₂H₅. NaHCO₃ neutralizes carboxylic groups whereas these neutralized by Na₂CO₃ but not by NaHCO₃ were believed to be lactones. Phenols are neutralized by NaOH but not by Na₂CO₃. The reaction with NaOC₂H₅ was not considered as a true neutralization since it did not involve exchange by H⁺ or Na⁺ ions. The groups reacting with NaOC₂H₅ but not with NaOH were suggested to be carbonyl groups. The acidic groups on the surface, expressed in meq/g are listed in Table 2 together with the cation exchange capacity (CEC) expressed in the same units. Included also in this table are the total amounts of basic groups on the carbon surface as determined by neutralization with 0.1 M HCl. The surface pH's of the investigated carbons are also given in Table 3.

The results given in Table 3 indicate: 1) The carbon sample and chemically-activated carbons contain considerable concentrations of surface carbon-oxygen groups with

their type in the order; carboxylic > phenolic > lactonic > carbonyl. These carbons contain very low concentration of surface carbon-oxygen groups of the basic nature. 2) Steam-activated carbons contain lower surface acid groups and higher surface basic groups compared with the carbon sample and chemically-activated carbons. The cation exchange capacity gas parallel with the total amount of surface acidity, both expressed in meq/g. 3) The surface pH's of carbon sample and chemically-activated carbons lie on the acidic side and continuously shifts to the lower pH's values with the increase of the amount of surface acidity. The pH's of the steam-activated carbons, on the other hand, lie on the basic side with the extent of gasification with steam, i.e. with the percentage of burn-off.

3.3. Adsorption of Pb(II)

Preliminary experiments have been carried out to determine the time required to attain equilibrium and also to determine the pH at which maximum adsorption of Pb(II) was measured. These experiments predicted that more than 90% of the adsorption was completed within 3h and that the adsorption of Pb(II) increased with the increase of pH from 2 to 6 and drastically decreased with the further increase in pH to 7.0. Based on these preliminary experiments, the kinetic measurements were followed under the same temperature and pH but 24 h were allowed to ensure equilibrium conditions.

Fig. 5 depicts plots of the experimental data points for the sorption of Pb²⁺ ions on the carbons investigated as

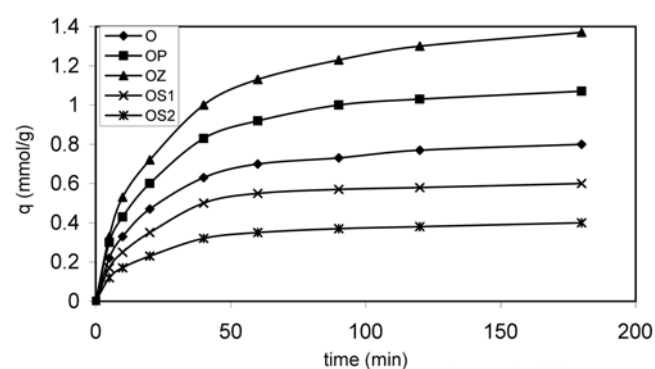


Fig. 5. Kinetic curves of Pb²⁺ adsorption at 298 K.

Table 3. The carbon-oxygen groups on the surfaces of the carbons investigated

Sample	Carboxylic meq/g	Lactonic meq/g	Phenolic meq/g	Carbonyl meq/g	CEC meq/g	Basic meq/g	pH
O	0.80	0.32	0.48	0.18	1.98	0.08	5.8
OP	1.05	0.45	0.70	0.20	2.72	0.08	4.6
OZ	1.20	0.50	0.80	0.23	3.24	0.12	4.1
OS1	0.36	0.16	0.24	0.10	1.10	0.28	8.2
OS2	0.14	0.20	0.18	0.08	0.72	0.42	9.2

determined at various time intervals. It will be seen that in all cases, the sorption rate was initially rapid which may be attributed to ion exchange with surface cations on the carbon surface. The gradual uptake shown as a plateau could be due to cation exchange at the inner surface, thereby involving a diffusion step [22].

The carbon sample and activated carbons contain polar surface groups responsible for cation exchange with Pb^{2+} ion as follows:



where O^- and HO are polar sites on the surface.

Pseudo-second order kinetic expression for sorption systems of divalent metal atoms has been proposed [23] and was applied to the sorption of Pb^{2+} on to peat [24]. The kinetic rate equation of pseudo-second order can be written as follows:

$$dq_t / dt = k (q_e - q_t)^2 \quad (3)$$

where k is the rate constant for sorption [$g/(mmol \cdot min)$], q_e is the amount of Pb^{2+} adsorbed ($mmol/g$) at equilibrium and q_t the amount of Pb^{2+} adsorbed ($mmol/g$) at any time t . Separating the variables in equation (3) and integrating for the boundary conditions $t = 0$ and $t = t$ and $q_t = 0$ to $q_t = q_t$ gives:

$$\frac{1}{(q_e - q_t)} = \frac{1}{q_e} + k_t \quad (4)$$

equation (4) can be rearranged to

$$q_t = \frac{t}{1/q_e^2 + 1/q_e} \quad (5)$$

If the initial sorption rate is $h = k q_e^2$ (6)

Then equations (4) and (5) become:

$$q_t = \frac{1}{1/h + 1/q_e} \quad (7)$$

and $t / q_t = 1/h + (1/q_e) t$ (8)

Equation (8) allowed the determination of the initial sorption h , the equilibrium sorption capacity q_e and the rate constant k from the slope and intercept of a plot of t / q_t versus t .

Fig. 6 shows the variation of t / q_e with time for the sorption of Pb^{2+} on to the investigated carbons. Linear plots over considerable proportions of the sorption period were achieved in all cases. The excellent fit of the experimental data to the theoretical plots supports the suggestion that the chemisorption of metal ions on the carbon surface is the rate determining step and that the process as a whole follows

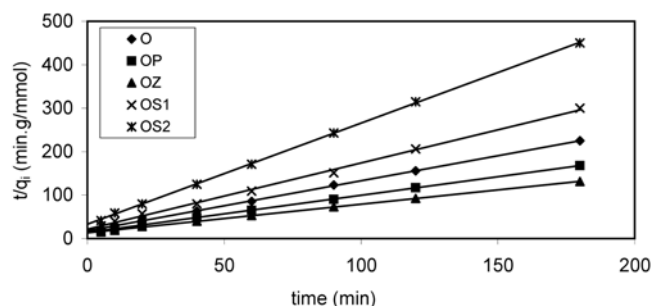


Fig. 6. Pseudo-second order sorption kinetic of Pb^{2+} at 298 K.

Table 4. The kinetic parameters of Pb^{2+} sorption on to the carbons investigated

Sample	Total acidity (meqv/g)	k (g/mmol min)	q_e (mmol/g)	h (mmol/g min)
O	1.78	0.075	0.855	0.059
OP	2.40	0.063	1.060	0.071
OZ	2.73	0.033	1.550	0.080
OS1	0.86	0.114	0.670	0.050
OS2	0.60	0.149	0.426	0.0286

pseudo-second order kinetics.

Table 4 lists the rate constant (k), the equilibrium capacity (q_e) and the initial sorption rate (h) for Pb^{2+} sorption on to the carbons investigated. Table 4 revealed: 1) The equilibrium adsorption capacity increased with the increase of total surface acidity supporting thus the chemisorption of Pb^{2+} on to the investigated carbon. Fig. 7 shows a straight line which could be obtained when q_e was plotted versus the amount of total surface acidity. It is also evident that the initial rate of Pb^{2+} adsorption increased with the increase of the concentration of the surface acid groups indicating that the high concentration of these groups enhances the Pb^{2+} adsorption. 2) Considering the rate constant k for Pb^{2+} sorption, it could be observed that it is inversely proportional to the total amount of surface acidity. This may be attributed to the difference between the strength of the sorption sites and their distribution on the surface.

3.4. Equilibrium measurements

The sorption of Pb^{2+} ions on to the carbons investigated was followed under equilibrium conditions, the sorption isotherms being determined by following the amount adsorbed (q_e mmol/g) at different equilibrium concentrations (C_e mmol/l) at 298 K by allowing sufficient time (24 h) to enable the system to reach equilibrium conditions.

Fig. 8 shows these isotherms which are typical to those obtained for adsorption from solution. Two equations are conventionally used for the interpretation of sorption from solution. These are the Langmuir equation and the Freund-

Table 5. Values of q_{\max} , K_F and $1/n$ for the sorption of Pb²⁺ on to the carbons investigated

Sample	q_{\max} (mmol/g)	K_F	$1/n$
O	1.45	0.20	0.53
OP	1.93	0.28	0.49
OZ	2.20	0.36	0.45
OS1	0.47	0.18	0.33
OS2	0.39	0.08	0.33

lich equation. These two equations have been applied to the equilibrium isotherms determined for Pb²⁺ ions in the present study. The most important information which can be obtained from the Langmuir equation is the maximum sorption capacity q_{\max} (mmol/g), while application of the Freundlich equation enables two parameters to be obtained, K_F which is the measure of the sorption strength and $1/n$ which provides an idea of the intensity of sorption, which varies with the nature of a given sorbate/sorbent system.

Table 5 lists the values of these three sorption parameters. The data clearly indicate that the sequence of K_F values listed seems to follow the same order as q_{\max} values, i.e. OZ > OP > O > OS1 > OS2.

All the Freundlich exponents n were greater than unity, indicating that sorption of Pb²⁺ ions on all the investigated carbons was favorable [25].

4. Conclusions

1. Microporous active carbons are obtained from olive stones by activation with phosphoric acid or zinc chloride with the latter more efficient as an activating agent. Steam activation of carbonized olive stone with burn-off of 25% gave activated carbon in which micropores are predominating while steam activation with burn-off of 58% gave active carbon with a considerable fraction of the surface area located in non – microporous range.

2. The surface areas calculated depend on the adopted adsorption model but the t -method and the α -s method gave comparable surface areas indicating that adsorption results should be explained considering standard non-porous sorbents as a reference.

3. Chemically activated carbons having acid functional groups on their surface while steam-activated carbons has basic functional groups which were found to be of lower surface density compared with the acidic groups on the surface of chemically-activated carbons.

4. Chemically activated carbons exhibited higher adsorption capacity toward Pb²⁺ compared to steam-activated carbons indicating that the chemistry of the surface is the

most predominant factor for Pb²⁺ adsorption which proceeds via ion exchange mechanism and follows pseudo-second order kinetics.

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