Production of activated carbon from apple waste prepared under N$_2$/microwave radiations

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ABSTRACT

Activated carbons are produced from Algerian apple waste (peel and pulp) by microwave activation under N$_2$. The effect of activation method on textural and chemical surface properties of carbon materials and activated carbons produced are studied. The best prepared activated carbon was utilized for the removal of cadmium from wastewater and the adsorption data was correlated to Langmuir and Freundlich models. Experimental results showed that microwave radiation time and microwave power have significant effects on the activated carbons properties. The percentage yield decreases with increase of carbonization temperature and microwave power. The best microporous activated carbon (surface area of 443 m^2/g, micropore area of 339 m^2/g and microporous volume of 0.175 cm^3/g) was obtained by carbonization at 800 °C and microwave activation under microwave radiation time of 10 min and microwave power of 400W. Characterization results by N$_2$ adsorption-desorption at -196°C show the predominance of a microporous character of the obtained activated carbons. FTIR results shows that different oxygen-containing functional groups are found in the raw material while aromatic structures are developed after carbonisation and activation. This activated carbon has been found to be an efficient material for cadmium removal from wastewater and the adsorption data fitted better to the Langmuir isotherm model.

Keywords: Apple waste, Activated carbon, Microwave activation, Adsorption process, Cadmium.
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INTRODUCTION

In view of the considerable degradation of water quality, a number of water technologies have been developed. Some of them are coagulation and flocculation, advanced oxidation processes, solvent extraction, aerobic and anaerobic treatment, ion exchange, electrolysis, and adsorption. However, most of them require substantial financial input and their use is restricted because of cost factors overriding the importance of pollution control. Adsorption process is widely used with success to control wastewater pollution because of simplicity of process equipment and operation and the large variety of pollutants to remove. Many materials have been investigated as adsorbent in wastewater treatment. Activated carbon has been the most popular adsorbent usually used worldwide for wastewater reclamation, gas purification and also as catalyst support [1]. Activated carbon is produced by a process consisting of raw material dehydration and carbonization followed by physical [2] or chemical activation [3]. AL thought his big efficiency; this material is expensive. The production of alternative sorbents to replace the costly activated carbon has intensified in recent years [4-5]. Attention has focused on various natural solid supports, which are able to remove pollutants from contaminated water at low cost. The by-products from the agricultural and industrial

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industries could be assumed to be low-cost adsorbents since they are abundant in nature, inexpensive, require little processing and are effective materials. Several agricultural wastes have been explored as low-cost adsorbent. Some of them include the shells [3-6-7], the stones of fruits [1-2-8-9] and wastes resulting from the production of cereals [10-11]. In the recent year, adsorbents from peels and pulp of different agricultural waste like banana [12-13], pomegranate peel [14], yellow passion fruit and mandarin peels [15], beet pulp [16], grape seed [17], coffee husks [18], and apple [19] have been also used. Apples constitute one of the most abundant fruits, with a world production of 68.3 million metric tons for 2005. Although, about 12% of the production is destined to the manufacture of apples juice and cider. In turn, the solid residue from pressing apples (apple pulp) represents more than 12 wt.% of the fruit. Therefore, great amounts of about 0.84 Mt of apple pulp are generated yearly worldwide [5]. This by-product have many uses like production of antioxidants [20-22], hydrogen production [23], extraction of lactic acid [24] and pectin [25], animal feed [26], and activated carbons [19]. In this way, many studies have been done by Suarez-Garcia et al. for the feasibility of production of activated carbon from apple peel by using the chemical activation with phosphoric acid [19,27,28], but the preparation of activated carbon apple waste by microwave has not been studied. In recent years, the number of processes that combine the use of carbons and microwave heating, instead of other methods based on conventional heating has increased. The main advantage of using microwave heating is that the treatment time can be considerably reduced; in addition, the consumption of gases used in the treatment can also be reduced. In addition, microwave heating is both internal and volumetric heating. Therefore, the tremendous thermal gradient from the interior of the char particle to its cool surface allows the microwave-induced reaction to proceed more quickly and effectively at a lower bulk temperature, resulting in energy savings and shortening the processing time [29]. So, it seems to us relevant to study this activation procedure in more details.

The aim of this study is then to prepare an activated carbon from apple waste by using microwave activation process under azote gas. A particular attention has been paid to the effects of activation time and microwave power on porosity and chemical properties of carbon materials obtained by this way in order to determine the optimal conditions leading to the activated carbon having the best active surface area and a highly-developed porosity. To investigate the effects of the modification treatment on the adsorption performance of the prepared activated carbons, the removal of cadmium from aqueous solution on the low-cost adsorbents were studied. Also the equilibrium of the adsorption was described by the Langmuir and Freundlich models.

EXPERIMENTAL SECTION

2.1. Starting material
The wastes of different Apple varieties were provided from Algerian juice manufactories. The raw material was first air-dried at room temperature for about one week, then dried at 110 °C for about 48 h. Proximate analysis of apple wastes: pH (4.18), apparent density (0.60 g/cm^3), moisture (5.6 %), ash (3.8%) and volatile matter (79%), were carried out, however inorganic elements was determined by Suarez-Garcia et al. (3.3% in dry weight) [30]. Suarez-Garcia et al. also studied the elemental and the biopolymer analysis (wt.%, db.) of apple wastes. The results showed that it is composed of 49.56% carbon, 8.43% hydrogen, 38.85% oxygen and 0.97% nitrogen. The value for hollocellulose and lignin was 44% and 17.3% respectively, 6.7% soluble in organic solvents and 31.3% soluble in water [19,30]. Having examined the proximate and chemical analysis of apple wastes, we can deduce that their lignocellulosic composition promotes the preparation of activated carbon.

2.2. Adsorbents preparation
Activated carbons were prepared from apple waste by carbonization and microwave activation under nitrogen flow. Carbonization of the raw material was carried out with a horizontal furnace.

For the carbonization step, about 10 g of dried apple waste were placed in the middle of the furnace. Different carbonization temperatures of 500, 600, 700, 800 and 900 °C were used. Once the carbonization temperature was reached, sample was maintained at this one for 1 h. The resulting chars were introduced in a modified commercial microwave oven (Procombi Whirlpool MOD. AVM 840/WP/GR) with frequency of 2.45 GHz and subjected to microwave (MW) radiation first, at different power levels (200, 400 and 900 W) and then, for various exposure times (1, 10 and 20 min). These conditions were chosen to study the modification effects. After activation, the sample was cooled to ambient temperature under N$_2$ flow rate. The obtained activated carbons are denoted MWAA 1, MWAA 10 and MWAA 20.

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2.3. Characterization
The raw apple waste, carbonised and activated carbons produced from apple waste were examined using nitrogen adsorption-desorption at - 196 °C and FTIR spectroscopy.

The indicators used for determining the optimum microwave activation time were the surface area and the porous volume. These values were determined by adsorption of nitrogen at -196 °C by means of a commercial manometric sorptometer (micrometrics ASAP 2020 Surface Area and Porosity Analyser). Prior to adsorption, the samples were out-gassed under vacuum at 200 °C for 12 h. Adsorption isotherms were analyzed by applying the Brunauer–Emmett–Teller equation (BET) to calculate the specific surface area (S_{BET}). The micropore volume ($V_{DR-\mu}$) was determined from the Dubinin–Radushkevich equation (DR) [31]. The pore size distribution: BJH adsorption average pore diameter (Apd_{BJH}), and BJH Adsorption cumulative surface area of pores (S_{BJH-cp}) between 1.7 nm and 300 nm diameter was determined using the Barrett-Joyner-Halenda (BJH) model. The external surface area (S_{t-ext}), micropore area ($S_{t-\mu}$) and the micropore volume ($V_{t-\mu}$) were calculated using the t-method. The cross-sectional area of nitrogen molecule was taken equal to 0.162 nm^2 and the nitrogen adsorbed was considered as a liquid with a density equal to 0.8081 g/cm^3 at -196 °C.

Chemical characterization was carried out by FTIR spectroscopy in order to identify the functional groups at the surface of raw apple waste and carbon materials. The infrared transmission spectra were recorded with a Brucker Equinox 55 spectrometer, from 400 to 4000 cm^{-1}, using the KBr wafer technique. Five hundred scans were taken with a 4 cm^{-1} resolution. Wafers were prepared from the mixture of 0.5 mg of the sample and 200 mg of KBr. This mixture was compacted in a manual hydraulic press at 59 MPa.

2.4. Adsorption studies
Adsorption of cadmium has been one of the most important means of assessing removal capacity from the aqueous phase. The efficiency of the removal of heavy metal: Cd^{2+} from aqueous solutions by MWAA 10 (prepared under the conditions of 800 °C carbonisation temperature, 400 W microwave power, 10 min microwave exposure time and nitrogen flow rate of 100 cm^3 min^{-1}) was experimentally studied by recording the equilibrium experiments and adsorption isotherms.

2.4.1. Equilibrium studies
For the equilibrium study, about 0.1 g of MWAA 10 activated carbon was thoroughly mixed with 1000 ml of cadmium (Cd^{2+}) solution and shaken in a mechanical shaker at 200 rpm. For the determination of equilibrium time, the aqueous samples were taken at preset time intervals, and the concentration C_e (mg/l) of metal ions remaining in the aqueous phase were measured using a double beam UV–VIS spectrophotometer (1605 SHIMADZU) at λ_{max} 518 nm.

2.4.2. Adsorption isotherm
Batch adsorption experiments were carried out in 500 ml glass-stoppered flask at a constant temperature (25 °C). About 0.1 g of samples was thoroughly mixed with 100 ml of cadmium solution. The isotherms studies were performed by varying the initial (Cd^{2+}) concentrations from 0.9 to 240 mg/L. The mixtures were continuously stirred (200 rpm), for 180 minutes. This equilibrium time has been previously determined from equilibrium experiments.
After such agitation, samples of 5 ml were taken for analysis using UV-Visible spectrophotometer (1605 SHIMADZU) at λ_{max} 518 nm to determine the residual concentration of metallic ion in the aqueous phase. The adsorption capacity at time *t*, q_t (mg/g), was calculated using equation (1).

$$q_t = \frac{(C_0 - C_e)V}{m} \tag{1}$$

where C_0 and C_e (mg/L) are the liquid-phase concentrations of Cd^{2+} ions at initial and any time t, respectively. *V* is the volume of the solutions (L), and *m* is the mass of adsorbent used (g).

Two isothermal models were applied to the experimental data [32]. The adsorption isotherm indicates how the adsorption molecules distribute between the liquid phase and the solid phase when the adsorption process reaches an equilibrium state. The analysis of the isotherm data by fitting them to different isotherm models is an important step to find the suitable model that can be used for design purpose.

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Langmuir model was applied to the experimental data. The Langmuir isotherm is based on the assumption that the adsorption process takes place on sites having the same energy and each site can be occupied by only one metallic ion. Moreover the interactions between adsorbed ions are neglected. The linear expression for the Langmuir isotherm is:

$$\frac{C_e}{q_e} = \frac{C_e}{q_m} + \frac{1}{K_L q_m}$$

(2)

where C_e is the equilibrium concentration of ions (mg/L) and q_e is the amount of the Cd^{2+} molecules adsorbed (mg/L). q_m and K_L are the maximal adsorption capacity (mg/g) and the Langmuir equilibrium constant (L/g), respectively.

The Freundlich model is an empirical equation assuming that the adsorption process takes place on a heterogeneous surface through a multilayer adsorption mechanism and adsorption capacity is related to the concentration of metallic ion at equilibrium. The Freundlich model is given by the linear equation:

$$\log q_e = \log K_F + \frac{1}{n}\log C_e$$

(3)

where q_e is the amount adsorbed (mg/g), and C_e is the equilibrium concentration of the adsorbate (mg/L). K_F is the Freundlich adsorption constant related to adsorption capacity of the adsorbent (mg/g) and $1/n$ is the adsorption intensity. Values of $n > 1$ represent favourable adsorption condition.

RESULTS AND DISCUSSION

3.1. Determination of the optimal carbonisation temperature
The yield of carbonized or/and activated apple waste can be defined as the ratio of the mass of carbonized or/and activated apple waste upon the mass of the raw material used.

Carbonization experiments at different temperature have been performed in order to determine the temperature at which the yield is the lowest i.e. the loss of mass after carbonization is maximal.

Table 1. Effect of carbonization temperatures and microwave power levels on the yield of carbonized and microwave activated apple waste

Parameters	Yield (wt.%)
Carbonization temperature (°C)	
500	48
600	47
700	46
800	43
900	43
Microwave power levels	
200	44
400	39
900	39

Table 1 show that the yield of carbonized apple waste decreases as the temperature increases from 500 to 800 °C. This is the result of the partial decomposition of apple waste. Adapted from a number of literature references, apple waste is composed basically of cellulose, hemicellulose, lignin and pectin, the TG analysis of this material indicate that four weight loss steps can be identified in the TG/DTG curves of apple pulp [19], the first step occurs at 120 °C, and can be attributed to moisture release. A second step occurs at 233 °C, and is attributable to degradation of hemicellulose and organic and/or aqueous extractives. The third step, at 328 °C, would correspond to thermal degradation of cellulose. The last step overlaps with the two previous ones and its characteristic temperatures cannot be distinguished so clearly. This weight loss step, ascribable to lignin degradation, appears with maximal weight loss rate at 406 °C. The lowest yield is obtained from 800 °C. The optimal carbonization temperature is then fixed at 800 °C. In the following, all the samples are carbonized at this temperature.

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Table 1, also reports the results obtained for samples carbonized at 800 °C and activated under microwave radiation and steam at different microwave power levels. Results showed that the yield decreases after activation from 200 to 400 W. This is attributed to the removal of volatile matters resulting from the decomposition of major compounds of apple waste i.e. cellulose and hemicellulose.

Above 400 W, the yield becomes constant because all cellulose and hemicellulose are decomposed. However, the decomposition of cellulose and hemicellulose creates porosity in apple waste that allows a better diffusion of oxygen into the particles. Thus, lignin, the third component of apple waste, which the decomposition is more difficult, can better decompose under microwave radiations. These results suggest that the higher the contents of cellulose and hemicellulose in the raw material are, the faster the decomposition of lignin is.

3.2. General features of the N_2 adsorption-desorption isotherms
Figures 1-4 give the shape and behavior of the N_2 adsorption-desorption isotherms, of the t- and DR-plots, and the micropore size distribution from BJH model, for the series of apple waste activated carbons prepared under microwave radiation at different exposure times. Table 2 summarizes the values of the structural parameters that characterize the porous structure of the samples, derived from the N_2 adsorption-desorption isotherms at -196 °C.
Figure 1 shows the N_2 adsorption-desorption isotherms at -196 °C, on apple waste activated carbons obtained at different microwave exposure times. All the adsorption isotherms have the type I shape typical of microporous solids. However, a small upward bending at high relative pressure indicates that some meso- and/or macropores are present in the prepared samples.
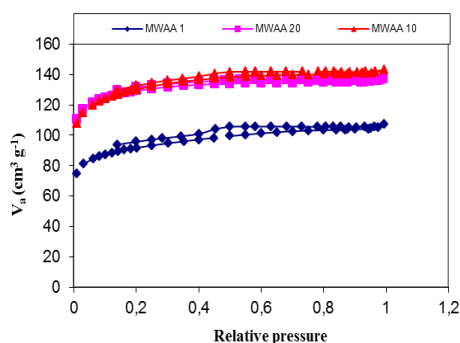

Fig. 1. N_2 adsorption-desorption isotherms at -196 °C of apple waste activated carbons obtained at different microwave exposure times
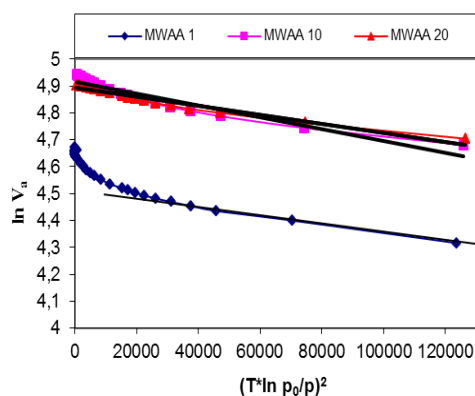

Fig. 2. DR-linear plots for N_2 adsorption-desorption isotherms at -196 °C for apple waste activated carbons obtained at different microwave exposure times
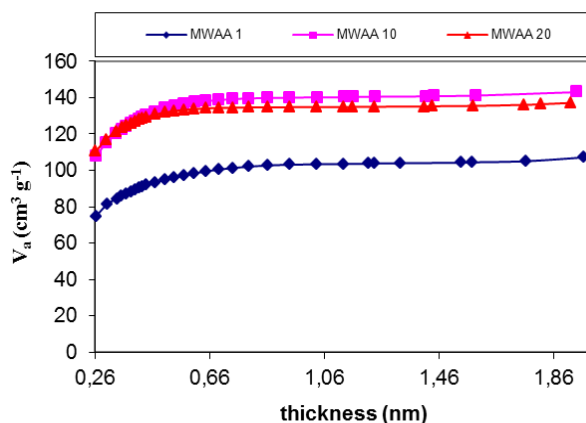
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Fig. 3. Curve transformed "t" obtained with Harkins and Jura equation
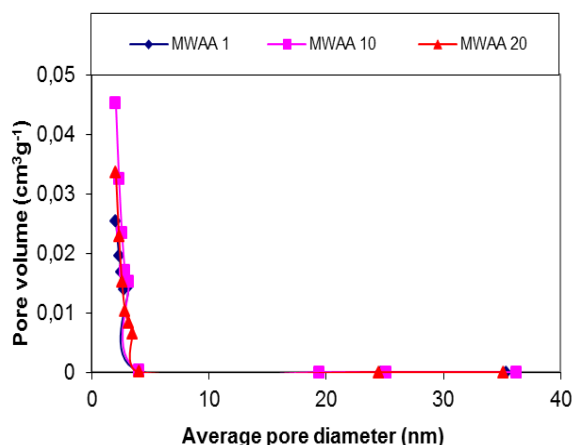

Fig. 4.Pore size distribution for the apple waste activated carbons obtained at different microwave exposure times

On the other hand, the DR-plots (Figure 2) indicate a type C behavior, with a small upward bending at high pressures, corresponding to low values of $(T*\ln p_0/p)^2$ which results from adsorption in meso and/or macropores.

The t-plots (Figure 3) show that from a thickness (calculated by Harkins and Jura equation) equal to 0.7 nm, we can plot a straight line which a slop corresponding to the specific external area (S_{t-ext}) responsible of multilayer adsorption and characteristic of type II isotherm in addition to type I isotherm.

Figure 4 shows the pore size distributions of activated carbons from apple waste obtained at different microwave exposure times. The important increase of all pore size distribution curves for pore diameters of about 2 (nm) indicated the formation of micropores in majority of the structure of the activated materials in accordance with the classification adopted by the International Union of Pure AND Applied Chemistry (IUPAC). This increase became significant in the activated carbon prepared at 10 min. In fact, the values of $(V_{DR-\mu})$, $(V_{t-\mu})$ and $(S_{t-\mu})$ presented in Table 2 are higher for MWAA 10, and the BJH average pore diameters (Apd_{BJH}) are around 2 nm.

From the derived textural data (see Table 2) it follows that the increase in microwave exposure times from 1 to 10 min lead to the development of surface area and porosity in the prepared samples. This is attributed to the removal of volatile matters and the decomposition of major compounds of apple waste (cellulose and hemicellulose) under the activating action of high microwave energy in presence of N_2. However, between 10 and 20 min, the values of these parameters decreases a little, because at this temperature all cellulose and hemicellulose are decomposed, it remains only lignin, the decomposition of which is slow, resulting in the shrinkage of porous volume of the samples.

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Table 2. Textural parameters deduced from N₂ adsorption at -196 °C on apple waste activated carbons prepared at different microwave exposure times

| Samples	MWAA 1	MWAA 10	MWAA 20
S_{BET} (m² g⁻¹)	312	443	437
$V_{DR-\mu}$ (cm³ g⁻¹)	0.10	0.175	0.171
S_{t-ext} (m² g⁻¹)	98	132	98
$S_{t-\mu}$ (m² g⁻¹)	214	339	311
$V_{t-\mu}$ (cm³ g⁻¹)	0.098	0.157	0.143
S_{BJH-cp} (m² g⁻¹)	64	75	50
Apd_{BJH} (nm)	2.87	2.64	2.50

The exposed values of the specific area (S_{BET}) are closer and lower to the values obtained in the literature from other biomasses, the S_{BET} of activated carbons prepared from orange peels, coconut shell, cotton stalk, bamboo, and waste tea were 379.63, 891, 795, 1335, and 928.8 m²/g respectively [31-36].

For the three prepared activated carbons, the values of the micropore area ($S_{t-\mu}$) are greater than the values of the external area (S_{t-ext}) because these activated carbons exhibited type I adsorption isotherms typical of predominant microporous. However, the obtained surfaces are almost exclusively within the micropores, which once filled with adsorbate, leave little external surface for additional adsorption.

These results indicate that 10 min microwave exposure times is sufficient to create the best textural properties.

3.3. FTIR analysis
The FTIR spectra of natural (AW), carbonized (CAW) and microwave activated apple wastes (MWAA 1, MWAA 10 and MWAA 20) are shown in Figure 5 and the assignments of IR absorption bands are collected in Table 3.
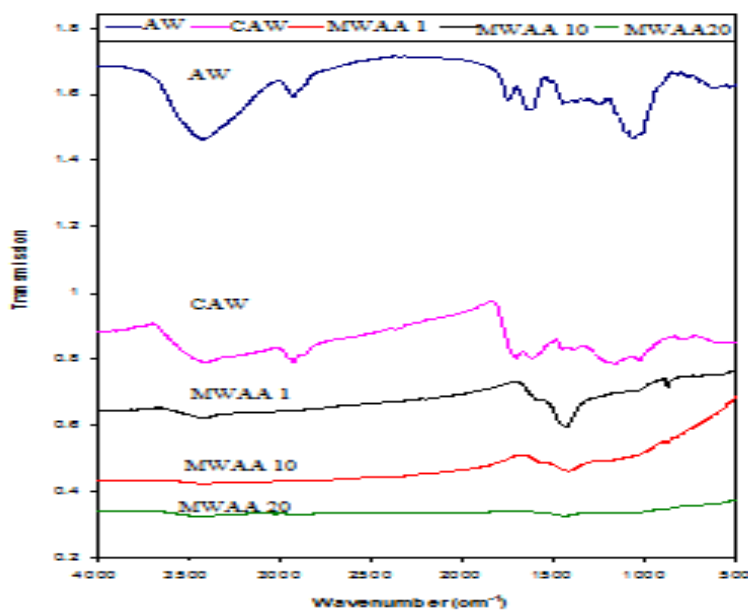
Fig. 5. FTIR spectra of natural (AW), carbonised (CAW) and activated apple waste (MWAA 1, MWAA 10 and MWAA 20)

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Table 3. Assignments of IR absorption bands for AW, CAW, MWAA 1, MWAA 10 and MWAA 20

σ (cm^{-1})	Assignment	Comments
3400	ν (O-H)	Stretching in hydroxyl groups
2910	ν (C–H)	Symmetric or asymmetric C–H stretching vibration of aliphatic acids
1744	ν (C=C)	Carboxyl stretching vibration of the carboxyl groups of pectin, hemicellulose and lignin
1612	C=C	Stretching vibration that can be attributed to the aromatic C-C bonds and to COO$^-$ asymetric stretchings
1445	C=C	Stretching vibration in aromatic skeletal and ester
1420	ν (C–H) and -CH$_3$	Symmetrical vibration of ionic carboxylic groups and CH$_3$ bending
1066	ν (C–O–C) and ν (C-O-P)	Stretching vibrations of C-O-C, C-O-P, and O-H of polysacharides.
610	ν (O–H)	Stretching in OH groups

σ is the wavenumber.

The IR spectrum of natural apple waste is in good agreement with the results of Suarez-Garcia et al. [37] who used infrared spectroscopy to compare the behaviour of apple pulp, alone and impregnated with 60 wt.% H$_3$PO$_4$. The assignment of absorption bands shows that the functional groups carboxyl, ester, aromatic, alcohol, alkene, hydroxyl, ether and carboxyl are present in the raw material. This is in accordance with the composition of apple wastes, which are essentially composed of cellulose, hemicellulose and lignin.

The FTIR spectrum of apple waste exhibits a broad peak at 3400 cm^{-1}, which corresponds to the O–H stretching vibrations of cellulose, pectin, absorbed water, hemicellulose, and lignin, the main compounds of apple waste. The peak observed at 2910 cm^{-1} can be assigned to the symmetric or asymmetric C–H stretching vibration of aliphatic acids. The peak observed at 1744 is due to the carboxyl stretching vibration of the carboxyl groups of pectin, hemicellulose and lignin. C=C stretching vibration that can be attributed to the aromatic C-C bonds and to COO$^-$ asymmetric stretching is observed at 1612 cm^{-1}. Symmetrical vibration of ionic carboxylic groups and CH$_3$ bending at variable wave number around 1420 cm^{-1} are observed. The peak at 1066 cm^{-1} is assigned to vibrations of C-O-C, C-O-P, and O-H of polysacharides. The peak at 610 cm^{-1} is assigned to stretching vibration in OH groups.

After carbonization, the IR absorption bands exhibit a similar shape, which shows that the same functional groups are present in the material, and a lower intensity than the raw material indicating a decrease of water and aliphatic compound contents. After microwave activation, the IR absorption bands between 2800 and 3500 cm^{-1} exhibit a lower intensity than after pyrolysis. This change in intensity is the result of the activating action of microwave heating/N$_2$. Oxygen and hydrogen groups are decomposed and extracted from the surface [38].

After microwave activation of raw apple waste during 10 min under nitrogen flow, the band at 3400, 2910, 1744, 1612 and 610 cm^{-1} disappear. New band appears at 1445 cm^{-1}. This band is assigned to C=C stretching vibration in aromatic skeletal and ester. In addition, the disappearance of bands and the emergence of others suggest that the aromaticity of the material increases during activation. Basically, FTIR results show that microwave activation under microwave radiation time of 10 min and microwave power of 400 W are sufficient to perform a complete activation of apple waste.

3.4. Adsorption capacity from cadmium
3.4.1. Equilibrium studies
Figure 6 shows the effect of contact time on batch adsorption of Cd^{2+} on MWAA 10. Adsorption of the studied ion can be described by a two stage kinetic behaviour, first with a rapid initial ions adsorption between 1 and 180 minutes followed afterwards by a much slower rate. A further increase in contact time has a negligible effect on the amount of adsorption. This phenomenon can be explained like this: during adsorption of metallic ions, initially they reached the boundary layer, then they had to diffuse into the adsorbent surface, and finally, they had to diffuse into the porous structure of adsorbent. Hence, this phenomenon will take a relatively longer contact time. According to these results, the contact time was fixed at 180 minutes.
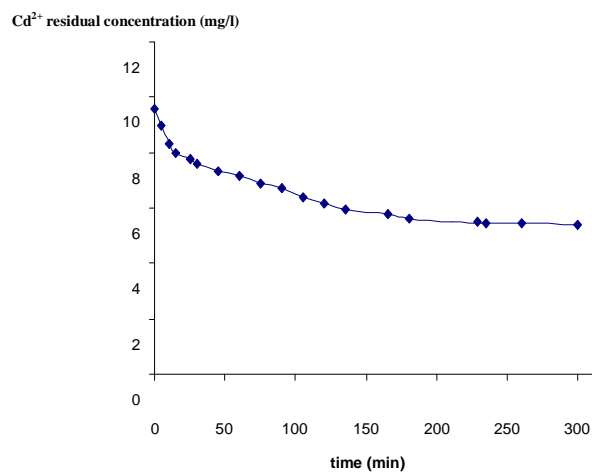
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Cd²⁺ residual concentration (mg/l)

Fig. 6. Effects of contact time on adsorption of Cd²⁺ on MWAA 10

3.4.2. Adsorption isotherms
Adsorption isotherm of Cd²⁺ on MWAA 10 is reported in Figure 7. The isotherm in Figure 7 was of type I, wich is given by microporous adsorbents with a relatively small external surface. Maximal Cd²⁺ adsorption capacity determined at the plateau of the isotherm is 33 mg/g.
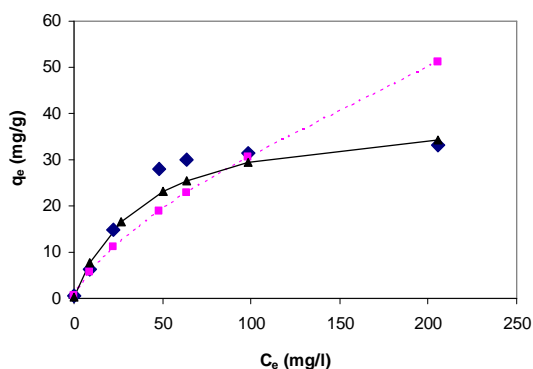

Fig. 7. Modeling of adsorption isotherm of Cd²⁺ on MWAA 10. [symbols: experiments; solid line: Langmuir model; broken line: Freundlich model]

The equilibrium adsorption data were interpreted using Langmuir and Freundlich models (Figure 7).

Values of Langmuir and Freundlich parameters are given in Table 4.

Table 4. Langmuir and Freundlich parameters for the adsorption of Cd²⁺ on MWAA 10

Langmuir isotherm model			Freundlich isotherm model		
q_m (mg/g)	K_L (L/mg)	R^2	K_F (mg/g)	n	R^2
41	0.026	0.97	1.29	1.45	0.94

Figure 7 shows that the fit between experiments and Langmuir model is acceptable. The comparison of correlation coefficients (R^2) of the linearized form of both equations indicates that the Langmuir model yield a better fit for the experimental equilibrium adsorption data than the Freundlich model. This suggests the monolayer coverage of the surface of the studied activated carbons. The *n* value in Freundlich model were superior to 1 (*n* > 1), indicating favourable adsorption of Cd²⁺ on the prepared activated carbon.

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CONCLUSION

This work showed that activated carbon with well-developed porosity (high specific surface area and micropore volume) can be prepared from apple wastes by carbonization and microwave activation processes. The best activated carbon (BET surface area of 443 m^2/g) prepared from apple wastes was obtained at a carbonization temperature of 800 °C and microwave power of 400 W for 10 min, under 100 cm^3/min nitrogen flow rate. The yield of activated carbon is conversely related to carbonization temperatures and microwave power. Nitrogen adsorption shows that the activated carbons obtained are essentially microporous. As expected, FTIR spectroscopy shows that different oxygen-containing functional groups are found in the raw material while aromatic structures are developed after carbonization and microwave activation. Activated carbon prepared from apple wastes under optimum conditions (MWAA 10) was employed as an adsorbent for the quantitative removal of cadmium from aqueous solution. The maximum adsorption capacity for Cd^{2+} ions on the prepared activated carbon was reached after 180 min and was 33.00 mg/g. The equilibrium data fitted well in the Langmuir model of adsorption, indicating homogeneous and monolayer adsorption.

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