

Determination of the surfaces functions and of the pH at the point of zero charges of powdered activated carbons produced from the shells of the nucleus of *Balanites aegyptiaca* and *Zizyphus mauritiana*

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Abstract

The objective of this study is to determine the surface functions and the pH at the point of zero charges (pH_{PCN}) of powdered activated carbons (PAC) produced from two biomasses (nucleus shell of *Balanites aegyptiaca* and nucleus shell of *Zizyphus mauritiana*) with a particle size between 60 and 80 μm . The methodology is based on immediate analyzes of the biomasses (ash rate, humidity rate, volatile matter rate and the actual density), the chemical activation of the biomasses by H_3PO_4 and KOH activating agents at concentrations of (5%, 15%, 25%) and (10%, 15%, 20%) respectively, followed by pyrolysis at 400 °C and 600 °C for 2 hours. The CAPs obtained were characterized for their surface chemistry, by Boehm titration and pH_{PCN} measurements and for their quantity, by yield calculation. The characterized PACs were compared to a commercial activated carbon. These analyzes reveal that the best PACs were obtained using a concentration of 25% H_3PO_4 and 10% KOH with a pyrolysis temperature of 400 °C. The surface functions of the PACs produced are acidic with a total absence of basic functions and exceed those of commercial activated carbon (CAC). The pH_{PCNs} of PACs resulting from acid activation are acidic and those resulting from basic activation are neutral and basic. Thus, the pH_{PCN} of the CAC is closer to the pH_{PCN} of the PACs resulting from the impregnation with KOH. These biomasses are potentially promising for the production of PACs.

Keywords: Powdered activated carbon; *Balanites aegyptiaca*; *Zizyphus mauritiana*; Surface functions; pH_{PCN}

1. Introduction

Presently, the growing demand for adsorbent materials for industrial processes and environmental protection is giving rise to additional research in the manufacture of activated carbons from materials that are not conventional, specifically from vegetable waste [1]. In Africa, the agri-food industry generates large quantities of waste, the recovery of which to produce energy or obtain materials is a promising way to make production sectors more profitable. Following the proliferation of gold mining industries in West Africa, the quantities of activated carbon imported into the continent have been multiplied by three or four [2]. These industries use activated carbons to adsorb cyanide gold complexes during the process. In Africa, there is little scientific information in the field of charcoal production on an industrial and laboratory scale. This continent is ranked last in terms of activated carbon production. Indeed, only Algeria, Egypt and Morocco are producers of activated carbon [3]. In recent years, several research works have been devoted to the recovery of agricultural waste and those from the food industries to reduce the rate of importation. For example, we can cite the recovery of agricultural waste for energy production, for composting, for the production of activated carbon [4]. From an economic point of view, the elaboration of activated carbons from local vegetable waste or biomass is

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however very interesting [1]. Activated carbons are very well known and inexpensive materials, which can be obtained by activation of precursors containing a high percentage of carbon and a low percentage of inorganic matter followed by carbonization [5]. The carbon activation process is done either physically or chemically. The characterization of activated carbons is a technique that gives the maximum information on the different properties of activated carbon. There is textural characterization and chemical characterization. Various studies have shown the production and characterization of activated carbons from several types of materials of plant origin such as rice straw [6-8], coconut shell [9-11], skin of cassava [12], sorghum grains [13], almond shell [14], date palm seed [15], bean husk [16], sugar cane bagasse [17], groundnuts [18,19], jatropha shells [20], olive pits [21], antlers [22], jujube pits [23], *Balanites aegyptiaca* and *Zizyphus mauritiana* [24, 25].... It is in this context that our work falls, the aim of which is to determine the surface functions and the pH at the point of zero charges of the PACs produced from the shells of the nuclei of *Balanites aegyptiaca* (CNBA) and the shells of the nucleus of *Zizyphus mauritiana* (CNZM) by the chemical activation process. Because it is very advantageous, it takes place at relatively lower pyrolysis temperatures and with a view to recovering this agricultural waste, that its usage stops only at consumption by the population.

2. Material and methods

2.1. Collection and preliminary processing of raw materials

In order to valorize local by-products in PAC, two raw materials were selected. These are the nucleus of *Balanites aegyptiaca* and the nucleus of *Zizyphus mauritiana* which are agri-food waste. Indeed, *Balanites aegyptiaca* and *Zizyphus mauritiana* are natural trees found in Niger and which produce fruits. These fruits were collected at the waste dump of a market (Katakou) in Niger. Figures 1 and 2 present the pictures of the raw materials used for the manufacture of PAC.



Figure 1 Kernels of *Balanites aegyptiaca*



Figure 2 Fruits of *Zizyphus mauritiana*

Regarding the preliminary treatment of raw materials, the fruits of *Zizyphus mauritiana* were immersed in water for 24 hours, then washed with plenty of water to retain only the pits. These were dried in the sun for 24 hours, then crushed in a secondary gyratory crusher to retain only the shells. While the cores of *Balanites aegyptiaca* were crushed using geologist's hammers to retain only the shells. Figures 3 and 4 show pictures of the shells used.



Figure 3 *Zizyphus mauritiana* shells



Figure 4 *Balanites aegyptiaca* shells

Thus, the retained shells of *Zizyphus mauritiana* and those of *Balanites aegyptiaca* were crushed in ball mills, then sieved by superimposing sieves of different mesh on a ShakerD406 brand automatic sieve to retain only particles with a diameter of between 60 and 80 μm . Then, the retained particles were dried in the oven at 105 °C for 24 h.

2.2. Immediate analysis

The immediate analysis of a biomass consists of determining the ash, moisture, volatile matter and fixed carbon content. As part of this work, the immediate analysis was carried out in accordance with the AFNOR XP CEN/TS 14774 (humidity), AFNOR XP CEN/TS 14775 (ash), and AFNOR XP CEN/TS 15148 (volatile materials) standards. The determination of the actual density was made by the test tube method.

2.2.1. Humidity rate

For the humidity rate, the porcelain crucibles were washed and then brought to a Volca MC18 muffle furnace at 1000 °C for 3 hours. Afterwards, these crucibles were cooled in a desiccator for 15 min and then weighed on a Mettler PM300 electric balance to obtain the weight P. Then, 2 g of each sample (*Balanites aegyptiaca* and *Zizyphus mauritiana*) were weighed in these crucibles to have the weight P_1 , then brought to an oven at 105 °C. for 24 h. After cooling in a desiccator for 15 min and weighing to obtain the weight P_2 , these crucibles were brought to a muffle furnace for 3 hours at 1000° C, then cooled and weighed to obtain the weight P_3 . The experiment was repeated three times. The humidity rates were calculated using the following formula:

$$H (\%) = \frac{P_1 - P_2}{P_1 - P} \times 100 \dots \dots \dots (1)$$

2.2.2. Volatile matter rate or loss on ignition

For the volatile matter rate, it is the same protocol as before, but the formula differs. The formula used is as follows:

$$LOI (\%) = \frac{P_2 - P_3}{P_2 - P} \times 100 \dots \dots \dots (2)$$

2.2.3. Ash rate

For the ash rate, the crucibles were weighed empty to have the mass m_1 , then with 1 g of each sample (*Balanites aegyptiaca* and *Zizyphus mauritiana*) to have the mass m_2 , then they were taken to a muffle furnace at 815 °C for 45 minutes until ash and blackheads disappear. Finally, these crucibles were cooled in a desiccator and then weighed to obtain the mass m_3 . This has been done three times. The ash rate was calculated by using the following formula:

$$C (\%) = \frac{m_3 - m_1}{m_2 - m_1} \times 100 \dots \dots \dots (3)$$

2.2.4. Actual density

For the determination of the actual density the test tube method was used. A test piece of volume $V = 50 \text{ cm}^3$ was weighed empty to have the mass m_1 , then particles of the different samples (*Balanites aegyptiaca* and *Zizyphus mauritiana*) with a diameter of between 60 and 80 μm were introduced into the test piece while pushing with a spatula to release the available air, then weighed to obtain the mass m_2 . This has been done three times. Actual densities were calculated from the following formula:

$$\rho = \frac{m_2 - m_1}{v} \dots \dots \dots (4)$$

2.3. Preparation of powdered activated carbons by activation with H_3PO_4 and KOH

The preparation of PACs by chemical activation with H_3PO_4 and KOH was carried out in two stages, namely: impregnation of the biomass, followed by pyrolysis of the impregnated biomass.

2.3.1. Biomass impregnation

The retained biomass with a diameter between 60 and 80 μm is impregnated in a solution of H_3PO_4 at different concentrations (5%, 15% and 25%), at the rate of 10 g of biomass per 100 ml of solution. The impregnation is carried out in beakers under magnetic stirring for 24 h. After filtration on Büchner with filter papers and washing with distilled water, the biomass is brought to an oven at 105 °C for 24 hours for drying. The protocol used is taken from Mbaye's thesis [20]. For impregnation with KOH, a mass of 10 g of biomass of the same diameter as before is placed in a beaker, then a mass of KOH crystals (5 g, 7.5 g and 10 g) was added, then 50 ml of distilled water. Everything is well mixed. The mixture is brought to an oven at 110 °C for 24 hours until complete evaporation of the water. The protocol used is taken from Drissa's thesis [26].

2.3.2. Pyrolysis of impregnated biomass

The impregnated biomasses were placed in porcelain crucibles, then the latter were closed with other porcelain crucibles, the whole is carried in a Volca MC18 brand muffle furnace and in a spotted brand tube furnace at the ambient temperature up to 400 or 600 °C with heating rates of 2.66 °C or 1.75 °C.min⁻¹ and a 2-hour time delay at the end of pyrolysis. After the 2-hour landing at the final pyrolysis temperature, the crucibles which are in the muffle furnace were removed with pliers to be placed in a desiccator for 20 min and the other crucibles which are in the tube furnace were left with a free temperature drop to room temperature. Figure 5 illustrates the picture of oven and desiccator used. After cooling, the carbons resulting from the impregnation with H_3PO_4 were washed abundantly with distilled water, then filtered on Buchner with a series of pH measurements with a pH meter brand ANNAH HI991001 until the pH of the filtered solution is between 6.5 and 7. Thus those resulting from the impregnation with KOH were washed with hot distilled water, then abundantly with distilled water until the pH of the solution filtered is between 6.5 and 7. At the end, the coals were brought to the oven at 105 °C for 24 hours, then weighed with a KERN572 brand balance.



Figure 5 Muffle Furnace and Desiccator

2.4. Characterization of powdered activated carbons

PACs have been characterized overall in terms of pyrolysis efficiency, pH at the point of zero charges, and surface functions.

2.4.1. Determination of pyrolysis yield

Determining the yield of PACs after pyrolysis is a very important quantitative characterization because it reflects the mass loss during pyrolysis. The following formula gives the expression of the mass yield.

$$\text{yield (\%)} = \frac{\text{mass}_{\text{initial}}}{\text{mass}_{\text{final}}} \times 100 \dots \dots (5)$$

2.4.2. Determination of pH at the Point of Zero Charges (pH_{PCN})

The pH_{PCN} is defined as being the pH for which the overall electrical charge of the carbon is zero. The method used and inspired by the work of Lopez Ramon et al. [27]. The pH_{PCN} was determined for all the CAPs developed and the CAC. Solutions of NaCl (Kermel) at 0.1 mol.L^{-1} and with a pH between 2 and 10 adjusted by adding a solution of NaOH or HCl at 0.1 mol.L^{-1} were first prepared using a HANNA HI991001 pH meter. Then, masses of 0.1 g of PAC were weighed on a precision balance of the Précisa 205A brand. These masses were brought into contact with 20 ml of each of these solutions in 100 ml and 200 ml plastic volumetric flasks with hermetically sealed magnetic bars. The solutions are kept stirring at ambient temperature for 48 hours until the stabilization of the pH of the final solutions. Then each sample is filtered on Büchner and a new pH measurement is carried out using a pH meter. A curve of final pH as a function of initial pH has been plotted and the zero charge point is determined from the value for which this curve crosses the first bisector. This was done for all twenty-five samples including twelve from *Zizyphus mauritiana*, twelve from *Balanites aegyptiaca* and one from CAC.

2.4.3. Determination of surface functions

The surface functions were determined by Boehm's method, which uses acid-base neutralization of the functional groups and back dosing of the solutions after filtration [28]. From an experimental point of view, four solutions were prepared at 0.1 mol.L^{-1} (NaOH, Na_2CO_3 , NaHCO_3 and HCl). Then, 0.1 g of each sample was placed in contact with 50 ml of each of the solutions in plastic vials with hermetically sealed magnetic bars followed by stirring for 24 h at room temperature. Afterwards, the suspensions were filtered on Büchner. To determine the acid-type surface functions, back titrations of different filtrates (NaOH , Na_2CO_3 , NaHCO_3) at a rate of 10 ml were carried out with HCl (0.1 mol.L^{-1}) in the presence of 3 drops of the colored indicators phenolphthalein, helianthine and bromocresol green respectively. For the determination of the basic functions, they were determined overall by back titration of the filtrate (HCl) at a rate of 10 ml with NaOH (0.1 mol.L^{-1}) with phenolphthalein as a colored indicator. The values were determined according to the following formula:

$$N_i V_i - N_f V_f = n_{eq} R \dots \dots (6)$$

With:

$N_i V_i$: Number of gram equivalent before the reaction;

$N_f V_f$: Number of gram equivalent after the reaction;

$n_{eq} R$: Number of gram equivalent having reacted.

All the experiments were carried out at the ore processing laboratory of the School of Mines, Industry and Geology of Niger and at the Water and Environment Materials Analysis Laboratory of the Faculty of Science and Technology of the Abdou Moumouni University from Niamey.

3. Results

3.1. Immediate analyzes

The results of the proximate analyzes are listed in Table 1.

Table 1 Results of immediate analyzes of *Balanites aegyptiaca* and *Zizyphus mauritiana*

Biomass	Ash rate (%)	Humidity rate (%)	Volatile matter (%)	Actual density (g.cm^{-3})
CNBA	6.66	2.83	93.13	0.6763
CNZM	7.33	1.996	92.69	0.7737

3.2. Impregnation and pyrolysis

The different impregnations that were carried out on the biomasses (*Balanites aegyptiaca* and *Zizyphus mauritiana*) at different concentrations and different activating agents, as well as the pyrolysis temperature, the residence time, the heating rate and the yield after pyrolysis are recorded in Table 2 and Table 3.

Table 2 Impregnation and Pyrolysis of *Balanites aegyptiaca* shell powder

Biomass	Activating agents	Concentration of the activating agent	Pyrolysis temperature (°C)	Heating rate (°C.min ⁻¹)	Residence time	Yield
CNBA	H ₃ PO ₄	25%	400	2.66	2h	32.50%
	H ₃ PO ₄	15%	400	2.66	2h	20.70%
	H ₃ PO ₄	5%	400	2.66	2h	22.20%
	KOH	20%	400	2.66	2h	16.80%
	KOH	15%	400	2.66	2h	21.80%
	KOH	10%	400	2.66	2h	23.50%
	H ₃ PO ₄	25%	600	1.75	2h	25.40%
	H ₃ PO ₄	15%	600	1.75	2h	25.20%
	H ₃ PO ₄	5%	600	1.75	2h	22.20%
	KOH	20%	600	1.75	2h	11.90%
	KOH	15%	600	1.75	2h	14.90%
	KOH	10%	600	1.75	2h	16.30%

Table 3 Impregnation and Pyrolysis of *Zizyphus mauritiana* shell powder

Biomass	Activating agents	Concentration of the activating agent	Pyrolysis temperature (°C)	Heating rate (°C.min ⁻¹)	Residence time	Yield
CNZM	H ₃ PO ₄	25%	400	2.66	2h	34.70%
	H ₃ PO ₄	15%	400	2.66	2h	32.70%
	H ₃ PO ₄	5%	400	2.66	2h	34.20%
	KOH	20%	400	2.66	2h	19.70%
	KOH	15%	400	2.66	2h	22.70%
	KOH	10%	400	2.66	2h	26.20%
	H ₃ PO ₄	25%	600	1.75	2h	31.80%
	H ₃ PO ₄	15%	600	1.75	2h	26.20%
	H ₃ PO ₄	5%	600	1.75	2h	24.70%
	KOH	20%	600	1.75	2h	17.10%
	KOH	15%	600	1.75	2h	19.70%
	KOH	10%	600	1.75	2h	21.50%

3.3. pH at the point of zero charges (pH_{PCN})

The representation of the different curves of final pH as a function of initial pH enabled us to determine the pH at the point of zero charges (pH_{PCN}). We determined from Figures 6 to 14 the pH_{PCN} of different samples.

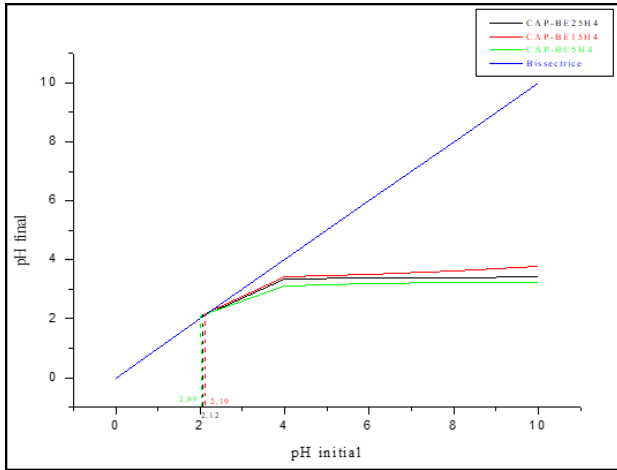


Figure 6 CAP-CNBA pH_{PCN} (H₃PO₄ at 400 °C)

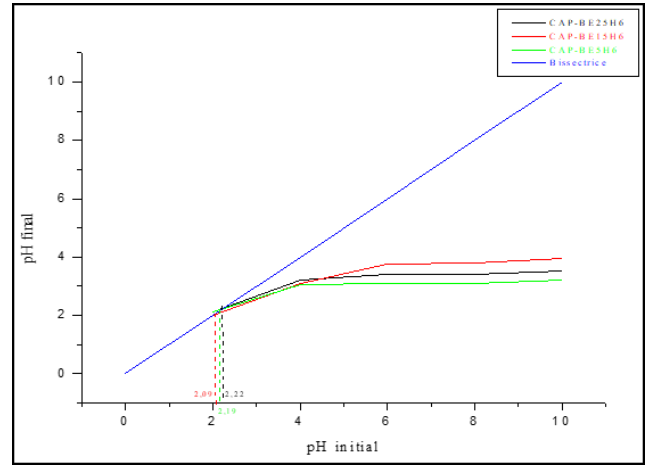


Figure 7 CAP-CNBA pH_{PCN} (H₃PO₄ at 600 °C)

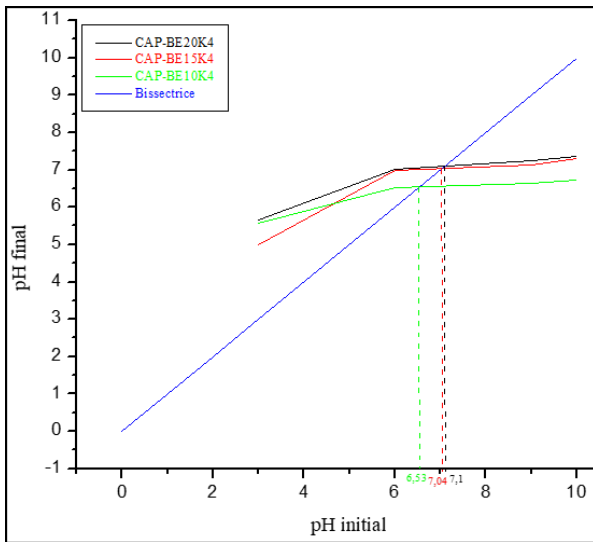


Figure 8 CAP-CNBA pH_{PCN} (KOH at 400 °C)

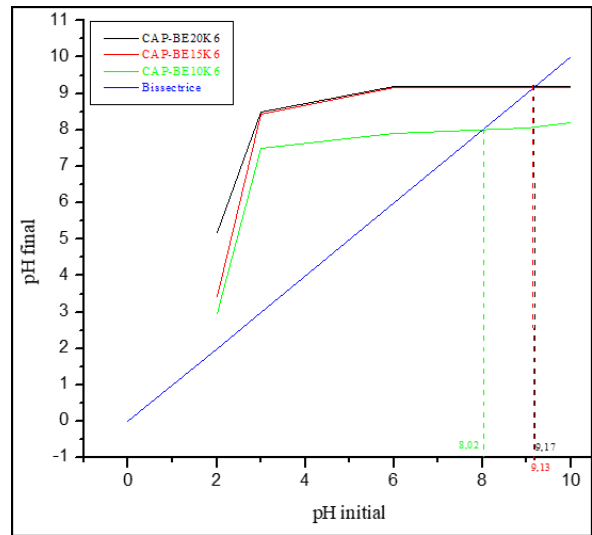


Figure 9 CAP-CNBA pH_{PCN} (KOH at 600 °C)

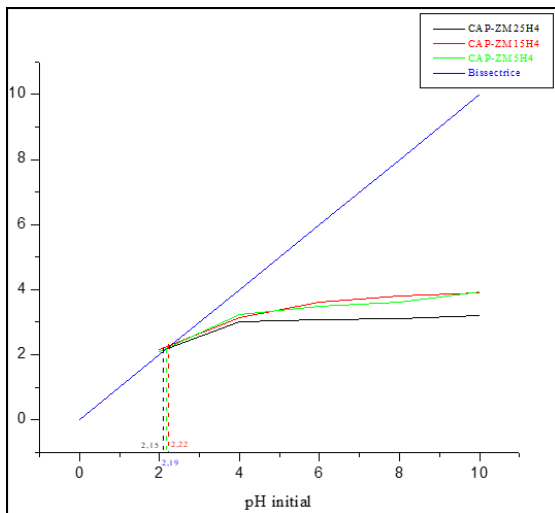


Figure 10 CAP-CNZM pH_{PCN} (H₃PO₄ at 400 °C)

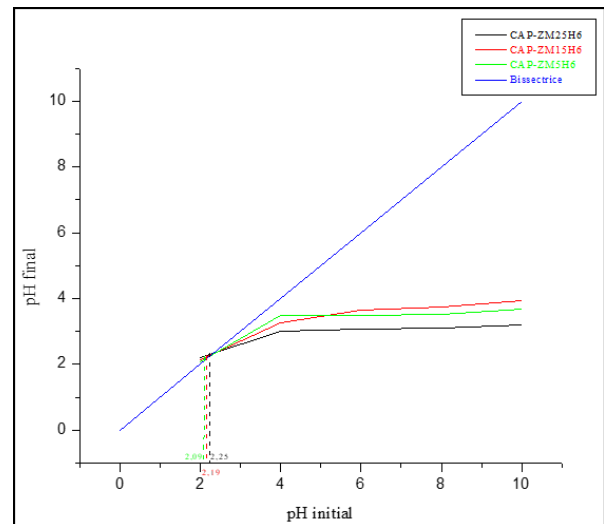


Figure 11 CAP-CNZM pH_{PCN} (H₃PO₄ at 600 °C)

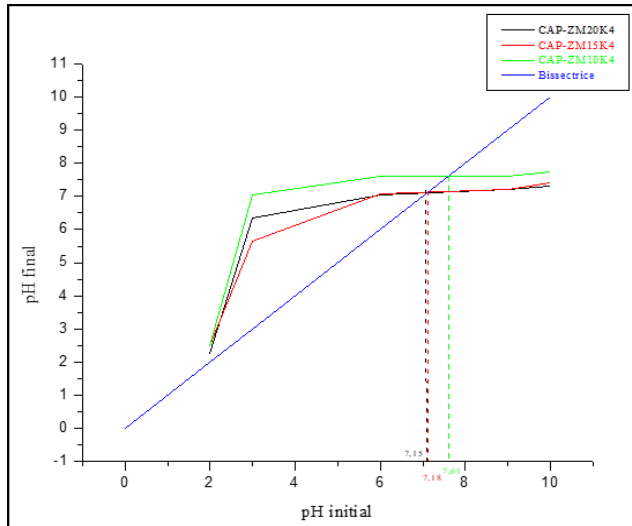


Figure 12 CAP-CNZM pH_{PCN} (KOH at 400 °C)

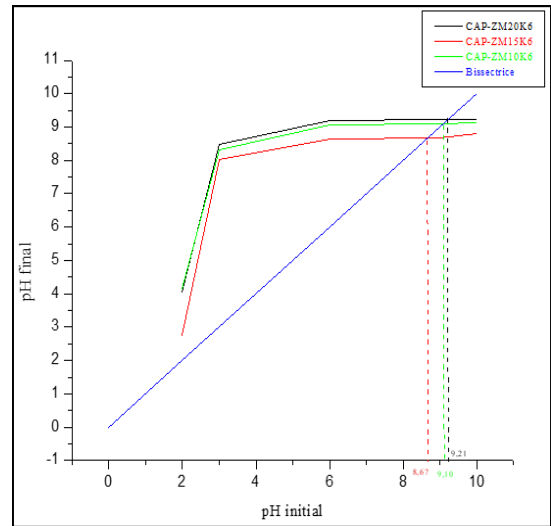


Figure 13 CAP-CNZM pH_{PCN} (KOH at 600 °C)

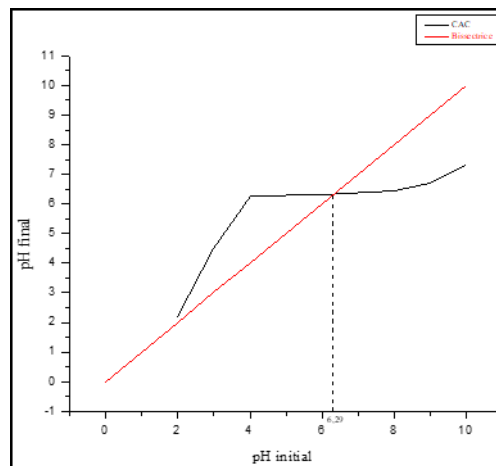


Figure 14 CAC pH_{PCN}

3.4. Surface functions

The dosage of the surface functions allowed us to determine the nature and the quantity of the functional groups of various elaborated powdered activated carbons and commercial activated carbon. The results are recorded in the table 4

Table 4 Values of PAC surface functions from CNBA

Carbons	Carboxylic groups (meq.g ⁻¹)	Lactone groups (meq.g ⁻¹)	Phenolic groups (meq.g ⁻¹)	Total acidity (meq.g ⁻¹)	Total basic groups (meq.g ⁻¹)
CAP-BE25H4	0.250	1.250	1.000	2.500	–
CAP-BE15H4	0.250	1.000	0.600	1.850	–
CAP-BE5H4	0.500	0.750	0.550	1.800	–
CAP-BE25H6	0.250	0.680	1.070	2.000	–
CAP-BE15H6	0.400	0.350	0.600	1.350	–
CAP-BE5H6	0.000	0.650	1.050	1.700	–

CAP-BE20K4	0.000	0.800	0.750	1.550	–
CAP-BE15K4	0.000	0.900	0.600	1.500	–
CAP-BE10K4	0.250	0.500	0.900	1.650	–
CAP-BE20K6	0.050	0.650	0.600	1.300	–
CPA-BE15K6	0.000	0.850	0.300	1.150	–
CAP-BE10K6	0.250	0.500	0.300	1.050	–

Table 5 Values of PAC surface functions from CNZM

Carbons	Carboxylic groups (meq.g-1)	Lactone groups (meq.g-1)	Phenolic groups (meq.g-1)	Total acidity (meq.g-1)	Total basic groups (meq.g-1)
CAP-ZM25H4	0.350	1.050	0.600	2.000	–
CAP-ZM15H4	0.150	0.850	0.800	1.800	–
CAP-ZM5H4	–	0.650	1.150	1.800	–
CAP-ZM25H6	0.250	0.950	0.900	2.100	–
CAP-ZM15H6	0.300	0.300	1.200	1.800	–
CAP-ZM5H6	0.100	0.500	1.250	1.850	–
CAP-ZM20K4	–	0.550	1.250	1.800	–
CAP-ZM15K4	–	0.550	1.300	1.850	–
CAP-ZM10K4	0.100	0.900	0.250	1.250	–
CAP-ZM20K6	0.450	0.100	0.750	1.300	–
CAP-ZM15K6	0.150	0.600	0.500	1.250	–
CAP-ZM10K6	–	0.550	0.750	1.300	–
CAC	0.200	0.600	0.300	1.100	–

4. Discussion

4.1. Immediate analyzes

It emerges from the immediate analysis of low ash rate and low humidity rate for the different biomasses chosen, so these biomasses are suitable to be used for obtaining good activated carbons. *Balanites aegyptiaca* kernel shells have more humidity and volatile matter but less ash than *Zizyphus mauritiana* kernel shells. And in terms of real density that of *Zizyphus mauritiana* and greater than that of *Balanites aegyptiaca*. Our results are comparable with those in the literature.

4.2. Impregnation and pyrolysis

The results shown in Tables 2 and 3 show variations in pyrolysis yield ranging from 20.70% to 34.70% for biomass impregnated with H_3PO_4 and from 11.90% to 26.20% for those impregnated with KOH depending on the nature of the biomass, the activation and pyrolysis conditions. It appears from this study that the pyrolysis temperature, the concentration of the activating agents and the nature of the biomasses have significant effects on the yield of the elaborated powdered activated carbons. These results show that increasing the concentration of H_3PO_4 from 5% to 25% promotes an increase in yield of 6.5% for CNBA and 3.9% for CNZM. This could be explained by the fact that H_3PO_4 in

addition to its role as an activating agent, it is a dehydrating agent which delays thermal decomposition, which limits the loss of volatile matter and which leads to the formation of a carbon matrix rigid [29]. However, increasing the pyrolysis temperature decreases the yield of the powdered activated carbons produced regardless of the biomass used. That is to say, an increase from 400 °C to 600 °C leads to a decrease in yield of 2% for CNBA and 6% for CNZM. This phenomenon is classic in thermochemistry. The higher the temperatures, the more the macromolecules that make up the biomass are degradable to form volatile molecules and a solid carbon residue. This has been demonstrated by *Diao et al.* [13]. Our results are similar to those obtained by *Reffas* [30] on coffee grounds activated with H_3PO_4 . While with KOH the effect of temperature is similar to that of H_3PO_4 , but for the effect of concentration it is the opposite. That is to say, a low concentration leads to an increase in the yield of the PAC produced.

The best yields come from CNZM impregnated with H_3PO_4 at a concentration of 25% and with KOH at a concentration of 10% all at a pyrolysis temperature of 400 °C which are respectively 34.70% and 26.20%. So CNZM produce good PAC than CNBA

4.3. pH at the point of zero charges pH_{PCN}

The nature of activated carbon can be acidic, neutral or basic depending on the pH_{PCN} . The pH_{PCN} values of powdered activated carbons from CNBA and CNZM impregnated with H_3PO_4 at different concentrations and pyrolyzed at 400 °C and 600 °C are very similar around 2.25 (Figures 6 to 9). This allows us to say that the increase in the concentration of H_3PO_4 and the pyrolysis temperature does not have a significant effect on the pH_{PCN} value of the PAC produced. Our results are similar to those obtained by *Benamraoui* [31] on olive, medlar and apricot stones activated with H_3PO_4 . Those of powdered activated carbons from CNBA and CNZM impregnated with KOH at different concentrations and pyrolyzed at 400 °C and 600 °C vary from 6.53 to 9.21 (Figures 10 and 13). This allows us to say that the increase in the pyrolysis temperature leads to an increase in the pH_{PCN} for the two biomasses.

Then, the increase in the concentration of KOH leads to an increase in pH_{PCN} for CNBA samples at 400 °C and 600 °C while for CNZM samples, it leads to a decrease in pH_{PCN} at 400 °C and a fluctuation of pH_{PCN} at 600 °C. Our results are similar to those obtained by *Lopez-Ramon et al.* [27]. The pH_{PCN} value of the CAC is 6.23. This value is closer to the values found with KOH, therefore close to neutrality.

4.4. Surface functions

The Boehm titrations carried out on all of the elaborated PAC and on the CAC show that there is a total absence of basic functions on the surface of all the carbons (elaborated and commercial), but present acidic functions (Tables 4 and 5). This could be explained by the fact that the PAC produced were not put in contact with oxygen below 200 °C or above 700 °C, they did not follow a treatment with hydrogen and they have not been degassed at room temperature because it is at this stage that the basic functions are introduced. This confirms to us that even commercial activated carbon may not follow this treatment. All the elaborate powdered activated carbons and commercial activated carbon have lactone and phenolic functions and for the carboxylic acid functions, only 7 samples are the exception, including 3 from CNBA and 4 from CNZM. The total acidity of PAC varies from 1,050 to 2,500 meq.g⁻¹ and that of commercial coal is 1,100 meq.g⁻¹. So in terms of total acidity, the PAC produced exceed the CAC, except for a single sample of CNBA. Because the higher the functional group content, the greater the degree of activated carbon adsorption. Our results are similar to those obtained by *Mounir, Oumessaad* [23] on jujube kernels and by *Reffas* [30] on coffee grounds. The average total acidity of coals produced with H_3PO_4 is 1.866 meq.g⁻¹ for CNBA and 1.891 meq.g⁻¹ for CNZM and that with KOH is 1.366 meq.g⁻¹ for CNBA and 1.458 meq.g⁻¹ for CNZM. So PAC from CNZM have more surface functions than PAC from CNBA and phosphoric acid gives more surface functions than potassium hydroxide.

5. Conclusion

The precursors (CNBA and CNZM) are rich in carbon, low ash rate, low humidity. It should be noted that the PAC produced have good mass yields. 34.70% and 32.50% for CNZM and CNBA impregnated with 25% H_3PO_4 and pyrolyzed at 400 °C respectively. 26.20% and 23.50% for CNZM and CNBA impregnated with 10% KOH and pyrolyzed at 400 °C respectively. All carbons impregnated with H_3PO_4 have acidic pH_{PCNs} between 2.09 and 2.25 and those impregnated with KOH have basic, neutral and acidic pH_{PCNs} between 6 and 9.5, as well as the pH_{PCN} value of commercial activated carbon. lies in this interval. Carbons impregnated with KOH are closer to commercial activated carbon. All the PAC produced have a total acidity mainly due to the carboxylic, lactone and phenolic functions. These functions give carbon an acid character and hydrophilic properties. Carboxylic and lactone groups tend to polarize the surface, decreasing the adsorption of non-polar organic compound in aqueous solution. The average total acidity is 1.891 meq.g⁻¹ and 1.866 meq.g⁻¹ respectively for CNZM and CNBA impregnated with H_3PO_4 and 1.458 meq.g⁻¹ and 1.366 meq.g⁻¹ respectively for

CNZM and CNBA impregnated with KOH against 1.100 meq.g⁻¹ for CAC. The two chosen biomasses can be upgraded to powdered activated carbon.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that they have no competing interests.

References

- [1] Elena F. Study of the characterization and activation of hard and soft plant precursors [PhD thesis]. University of Granada; 2002.
- [2] Increasing local Proxy By the mining Industry in West Africa. World Bank Report No.66585-AFR; 2012. <https://openknowledge.worldbank.org/server/api/core/bitstreams/5123eecf-d7cb-5458-85a0c5503fb6b97c/content> Consulted on 21/12/2022 at 11:39 a.m.
- [3] Alicia Peláez-Cid A, and Margarita Teutli-León MM. Lignocellulosic Precursors Used in the Elaboration of Activated Carbon, Lignocellulosic Precursors Used in the Synthesis of Activated Carbon - Characterization Techniques and Applications in the Wastewater Treatment, Dr. Virginia Hernández Montoya (Ed.); 2012.
- [4] Sanonka T, Koffi AK. Contribution to the recovery of agro-food waste into compost: physico-chemical characterization of composts and study of their mineralization in two agricultural soils in Togo. *Omn.Univ.Europ*; 2011.
- [5] Rodriguez RF, Molina SM. Textural and chemical characterization of microporous carbons. *Advances in Colloid and Interface Science*; 1998. 76-77: 271-294.
- [6] Basta AH, Fierro V, El-Saied H, Celzard A. 2-steps KOH activation of rice straw: an efficient method for preparing high performance activated carbons. *Bioresource Technology*; 2009. 100: 3941-3947.
- [7] Basta AH, Fierro V, EL-Saied H, Celzard A. Effect of deashing rice straws on their derived activated carbons produced by phosphoric acid activation. *Biomass and bioenergy*; 2011. 35: 1954-1959.
- [8] Oh GH, Park CR. Preparation and characterization of rice straw based porous carbons with high adsorption capacity. *Fuel*; 2002. 81: 327-336
- [9] Zhonghua H, Srinivasan MP. Mesoporous high-surface-area activated carbon. *Micropor, Mesopor Mater*; 2001. 43, 267
- [10] Dinesh M, Kunwar PS, Vinod K. Wastewater treatment using lowcost activated carbons derived from agricultural by products a case study. *J. Hazard. Mater* ; 2008. 152: 1045-1053.
- [11] Drissa B, Bini D, Albert T, Guessan EZ, Grah PA, Didier R, Jean VW. Comparative study of activated carbon preparation methods, followed by a depollution test of water contaminated with diuron. *J. Soc. West-Afr. Chem*; 2009. 028: 41-52.
- [12] Sudaryanto Y, Hartano SB, Irawaty W, Hundarso H, Ismadji S. High surface area activated carbon prepared from cassava peel by chemical activation. *Bioresour. Technology*; 2006. 97: 734-739.
- [13] Yulu D, Walawender WP, Fan LT. Activated carbons prepared from phosphoric acid of grain sorghum. *Bioresour. Technology* 2000; 2002. 81: 206-213.
- [14] Demirbas E, Kobya M, Konukman AES. Error analysis of equilibrium studies for the almond shell activated carbon adsorption of Cr(VI) from aqueous solutions. *J. Hazard. Mater*; 2008. 154: 787-794.
- [15] El Nemr A, Khaled A, Abdelwahab O, El-Sikaily A. Treatment of wastewater containing toxic chromium using new activated carbon developed from date palm seed. *Journal of Hazardous Materials*; 2008. 152(1): 263–275.

- [16] Cabal B, Budinova T, Ania CO, Tsyntsarski B, Parra JB, Petrova B. Adsorption of naphthalene from aqueous solution on activated carbons obtained from bean pods. *Journal of Hazardous Materials*; 2009. 161(2-3): 1150–1156.
- [17] Demiral H, Demiral İ, Karabacakoğlu B, Tümsük F. Production of activated carbon from olive bagasse by physical activation. *Chemical Engineering Research and Design*; 2011. 89(2): 206–213.
- [18] Zhong ZY, Yang Q, Li XM, Luo K, Liu Y, Zeng GM. Preparation of peanut hull-based activated carbon by microwave-induced phosphoric acid activation and its application in Remazol Brilliant Blue R adsorption. *Industrial Crops and Products*; 2012. 37(1): 178–185.
- [19] Girgis BS, Yunis SS, Soliman AM. carbon from peanut hulls in relation to conditions of preparation. *Materials Letters*; 2002. 57(1): 164-172.
- [20] Mbaye G. Development of activated carbon from lignocellulosic biomass for applications in water treatment [PhD thesis]. *International Institute of Water and Environmental Engineering (2iE)*; 2015.
- [21] Belkebir Z. Valorization of agro-food waste case of olive pomace [Memory of Magister]. M'HMED Bougara-Boumerdes University; 2007.
- [22] Anwar E. Thermal and kinetic reactivity of argan wood degradation application to the production of activated carbon by chemical activation with phosphoric acid. [Doctoral thesis]. Mohammed V University – Agdal. Speciality: chemistry-physics; 2007.
- [23] Mounir D, Oumessad B. Activation of a charcoal based on jujube kernels and application to the environment. Adsorption of a textile dye. The 3rd International Seminar on New and Renewable Energies; 2014.
- [24] Moustapha AS. Elaboration of activated carbons from coconut shell and *Balanites egyptiaca* kernel [Master's thesis]. Abdou Moumouni University of Niamey (Niger); 2014.
- [25] Ousmaila SM, Adamou Z, Ibrahim D, Ibrahim N. Preparation and characterization of activated carbons based on *Balanites Egyptiaca* and *Zizyphus mauritiana* kernel shells. *J. Soc. West-Afr. Chem*; 2016.041:59-67 [26] Drissa B. L'élimination du diuron dans l'eau à partir des ressources naturelles de la Côte d'Ivoire: photocatalyse solaire et adsorbants carbonés à base de coques de noix de coco. [Thèse de doctorat]. Université Paul Verlaine – Metz ; 2007.
- [26] Lopez-Ramona MV, Stoecklib F, Moreno-Castillaa C, Carrasco-Marina F. On the characterization of acidic and basic surface sites on carbons by various techniques. *Carbon* 37; 1999:1215–1221
- [27] Boehm HP. Chemical Identification of Surface Groups, *Advances in Catalysis*. Eley, DD, Pines, H, Weisz, PB, eds. Academic Press; 1966. 16: 179-274.
- [28] Zhao J, Lai C, Dai Y, Xie J. Pore structure control of mesoporous carbon as supercapacitor material. *Materials Letters*; 2007. 61: (23-24), 4639–4642.
- [29] Reffas A. Study of the adsorption of organic dyes (Nylosan Red and Methylene Blue) on activated carbons prepared from coffee grounds [PhD thesis]. Mentouri-Constatine University ; 2010.
- [30] Benamraoui F. Elimination of cationic dyes by activated carbons synthesized from agricultural residues [Memory of Magister]. Ferhat Abbas Setif-1 University. Option: Chemical Engineering ; 2014.