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Research Article

Comparative study of two activated carbons from *Borassus aethiopum* produced in electric and artisanal furnaces

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Abstract: The comparison of activated carbons of *Borassus aethiopum* produced in an electric and artisanal furnaces showed similarities and differences in their characteristics. The activated carbon produced in an electric furnace (BA-AC FE) with a specific surface area of 888 m^2/g is less microporous than the activated carbon produced in an artisanal furnace (BA-AC FA) which has a specific surface area of 1431 m^2/g. Also, with its BM index (IBM) of 329.5 mg/g the BA-AC FE is more macroporous than the AC-BA-Fa which has an IBM of 28.8 mg/g. This, importance of macroporosity on the AC-BA-FE allowed to obtain an abatement rate of 95.11 % of BM against 72.24 % for the AC-BA Fa. Both carbons have type IV adsorption isotherms. In view of the good characteristics of the BA-AC FA activated carbon, the water issue can be improved in rural areas by building artisanal furnaces. These will allow to produce quality activated carbon and to design carbon filters.

Keywords: *Borassus aethiopum,* adsorption, specific surface, activated carbon, furnace

1. INTRODUCTION

The carbon industry is booming in the last decades. Its use is now beyond industries. It is used in all fields, especially in water treatment. Formerly used (1500 years before Jesus Christ) by Egyptian physicians [1], activated carbon was recognized as an adsorbent from the 18th century[2]. They used it to adsorb gas. Since then, it has been used in large drinking water treatment units. Its production can require any plant material, especially fiber-rich materials. However, industries only consider activated carbons with specific surfaces greater than or equal to 100 m^2/g. Thanks to its ease of production and use, projects for the installation of mobile activated carbon units for the potabilization of water are increasingly formulated for rural areas.

These populations, powerless to cope with the lack of drinking water, are turning to non-drinking water sources. Thus, many negative consequences related to the consumption of these waters are reported. Certain microorganisms such as viruses contained in these waters are responsible for the diseases of hepatitis A and hepatitis E [3]. This two hepatitis alone cause the death of 57,000 people per year (WHO, 2013). Beyond these two diseases, cholera is in full swing in many countries, especially developing ones. Indeed, despite the non-reporting of actual cases by some countries, a number of 500,000 to 700,000 people with cholera are reported. In addition to cholera, typhoid is one of the diseases that causes the death of thousands of people. An estimated 22 million people have contracted the disease, killing 216,000 people, mostly school-age children and young adults[4]. In light of these consequences, one of the alternatives found by researchers is the use of activated carbon filters to purify these waters. Thus, faced with an absence of activated carbon industries in developing countries whose populations are most exposed, this use of carbon filters remains utopian. Indeed, its production, even if it is simple, requires enormous means for the acquisition of an electric furnace. This furnace, which allows carbonization and activation for the chemical method, would constitute a brake on the use of activated carbon in rural areas. Faced with such a dilemma, a furnace built from artisanal materials is compared to an electric furnace in order to judge the capacity to produce a quality activated carbon without great economic means. Several authors have already compared activated carbon [5,6]. But many of these studies have only varied the conditions of preparation of the coals or the method of preparation [7]. Few studies have compared carbons taking into account the type of furnace used.

Since electric furnaces are very expensive, replacing them with artisanal furnaces would be a way to encourage the use of activated carbon in rural areas. This could reduce or eradicate the risks associated with raw water consumption. Activated carbon filters are simple and easy to design. chemicals pollutants such as nitrate can be reduced through carbon filters [8]. Some have disinfected water using carbon columns[9]. Others have reported 78 % COD removal from an activated carbon column [10]. As for researchers [11,12] they used commercial granular activated carbon columns and achieved 83 % and 0.02 kg GAC m^{-3} removal of nitrate and pesticides respectively from carbon.

2. MATERIAL AND METHODS

2-1. Material: Two furnaces were used in this study. It differs from each other in their architecture. The electric furnace **(Figure 1)** contains a single chamber that allows the material to be carbonized or activated. It is equipped with knobs for precise temperature and time control. In this study the electric furnace (Nabertherm) used is from Chinese has a capacity of 2 L and a maximum temperature of 1200 °C. In contrast, the artisanal furnace contains two chambers **(Figure 2)**. The lower chamber has a volume of 15,000 cm^3 and is rectangular in shape. It is the part that receives the firewood which is the main source of energy. The upper chamber has a capacity of 10 L and is conical in shape. It receives

the material to be carbonized or activated. The artisanal oven built in banco mounted around an iron skeleton reaches a high temperature (550 °C) if its supply of firewood is well provided and kept constant. The branches or petioles of *Borassus aethiopum* tree were used as raw materials. These were cut, washed and sun-dried for 3 days. Two methods related to the types of furnace were applied for the activated carbons production.

Figure 1: Electric furnace   **Figure 2:** Artisanal furnace

2-2. Methods

2-2-1. Preparation of *Borassus aethiopum activated* carbon (BA-AC) in the electric furnace (BA-AC FE): The production of activated carbon with the muffle furnace (electric furnace) was carried out according to previous work [13]. The technique consisted to impregnated 200 g of raw material in 250 mL of orthophosphoric acid solution at 3 mol/L for 24 h. The substrate was recovered by filtration, dried at 105 °C for 24 h and then carbonized at 600 °C for 3 h using a muffle furnace. The possible carbonization residues were removed by an abundant washing with distilled water until a neutral pH of the rinsing water is obtained. Activated carbon obtained were then dried in an oven at 105 °C for 24 h. After cooling in the desiccator, the dried residues are ground to obtain particle sizes less than or equal to 0.5 mm.

2-2-2. Preparation of activated carbon in the artisanal furnace: The *Borassus aethiopum* branches was carbonized for 3.5 hours at 400 °C using an artisanal furnace. After carbonization, the char was crushed in a wooden mortar and two successive sieving operations were performed to obtain particles sizes between 0.25 and 0.5 mm. Chemical activation of the carbon was done by impregnating 200 g of the char in phosphoric acid solution at 3 mol/L for 24 hours. Then, the impregnated carbon was heated in an artisanal furnace at 550 °C for 5 h and the resulting activated carbon has undergone a hot washing before rinsing with distilled water until a neutral pH of the rinsing water is obtained. Finally, activated carbon was dried at 105 °C in an oven for 24 h.

2-2-3. Characterisations of activated carbons

2-2-3-1. Porosity structure of the–*Borassus aethiopum* activated carbons: The porous structure of the activated carbons was determined using adsorption/desorption isotherm of N_2 at 77 K. Measurements were performed using an automatic volumetric gas adsorption apparatus model Autosorb-I, Quantachrome BELMaster. BET specific surface area was obtained using Brunauer-Emmet-Teller (BET) (Eq.1) [1]. The total pore volume (Vp) was determined from the amount of N_2

adsorbed at a relative pressure near unity. It was defined as the maximum amount of nitrogen adsorbed at the relative pressure of P/P0 = 0.99. The average pore diameter (Dp) was obtained from equation 2 [14]:

$$S_{BET} = \frac{V_m \times N_A \times a_m}{m \times V_M} \qquad (1)$$

$$Dp = \frac{4 \times V_p}{S_{BET}} \qquad (2)$$

Pore size distribution was done using Barrett-Joyner-Halenda (BJH) method [15]. The microporous volume (Vmi) is obtained by deducting the mesoporous volume from the total pore volume (Vp). From the slope 'P' and the y-intercept 'O' of the BET line we can then calculate Vm by this relations (Eq.3) [3]:

$$V_m = \frac{1}{O + P} \qquad (3)$$

2-2-3-2. Iodine number: The procedure used is an adaptation of the AWWA B 600-90 standard method. Activated carbon was treated for 30 s with 100 mL of an iodine solution at 0.1 N in the presence of 10 mL of hydrochloric acid solution at 5 %. The solution was filtered and titrated with sodium thiosulfate solution at 0.1 N. The iodine number (in mg. g^{-1}) is the capacity of iodine adsorbed per gram of carbon for a residual concentration of 0.02 N. It is calculated from equation (4).

$$Iodine\ number \left(\frac{mg}{g}\right) = \frac{12693\ N_{I_2} - 279{,}246 N_{th} V_{th}}{m} \qquad (4)$$

With, N_{I2}, the iodine concentration (eqg/L); m the mass of activated carbon (g); N_{th} and V_{th} are the concentration (eqg/L) and the volume (mL) of sodium thiosulfate solution respectively.

2-2-3-3. pH of zero charge point (pHpzc): For the determination of pHpzc, 0.15 g of activated carbon was introduced into reactors containing 50 mL of NaCl solution (0.01 M). The pH of each reactor was adjusted (variation of values between 2 to 12) using solutions of 0.1 M NaOH or HCl. The mixtures were stirred during 48 h using a multi-stirring system at 25 °C. After filtration, the final pH of each mixture was measured. The pHpzc is defined as the intersection point of the curve pH$_{final}$ = f(pH$_{initial}$) and the first bisector [16,17].

2-2-3-4. Elemental analysis: The C, H and N contents (%) of activated carbons were measured using elemental analysis (PERKIN ELMER 2400 Series II). The samples were finely ground (100 µm) before being used for the C, H, N analysis. The process consists in burning a sample of known mass at a high temperature (about 1000 °C) under an oxygen atmosphere. The samples were completely burned and reduced to CO_2, elemental gases, H_2O and N_2. The produced gases (CO_2, H_2O, N_2) were separated in a chromatographic column and detected by a thermal conductivity detector.

2-2-4. MB and nitrate adsorption test: The experiments were carried out in 100 mL flasks containing 50 mL of MB or potassium nitrate solutions at different concentrations (30 to 180 mg/L) and 0.05 g of activated carbon. For the MB solutions, pH was maintained at 6.4 and 4 for the nitrate solutions. The solutions were stirred for 1 h at 200 rpm for MB and 250 rpm for nitrate and after filtration, the residual concentrations were determined at 664 nm and 415 nm for MB and Nitrate

respectively, using an UV/VIS spectrophotometer. The adsorption percentages were calculated according to equation (6)

$$\%R = \frac{C_0 - C_e}{C_0} \times 100 \qquad (6)$$

Where C_0 and C_e (mg/L) are the initial and equilibrium concentrations of MB or nitrate solutions respectively.

3. RESULTS AND DISCUSSION

3-1 Textural properties: Table 1 shows the characteristics of two activated carbons produced in an electric (BA-AC FE) and some artisanal furnaces (BA-AC FA). According to IUPAC [18] activated carbons prepared are microporous. Indeed, 0.35 and 0.28 belong to the interval [0.2; 0.6] which is the interval defined for good quality and microporous activated carbon [19].The specific surface areas 888 m^2/g and 1431 m^2/g for BA-AC FE and BA-AC respectively show that activated carbons are of good qualities [19].

Table1: Activated carbon characteristics comparison

Characteristics	BA-AC FE	BA-AC FA
BET surface (S_{BET}) (m^2/g)	888	1431
External surface area (S_{ext}) (m^2/g)	890	1432
Total pore volume (V_p) (cm^3/g)	0.67	0.58
Microporous volume (V_{mi}) (cm^3/g)	0.35	0.28
Mesoporous volume (V_{me}) (cm^3/g)	0.32	0.30
Pore diameter (DFT) (nm)	3.03	2.76
Iodine number ((mg/g)	655.5	958.09
pH$_{PZC}$	2.4	2.2

The different values obtained would be due to the preparation method. Indeed, raw material was impregnated before carbonization and crushing, whereas in the artisanal furnace the raw material was carbonized and after crushing, only the resulting particles were impregnated. This allowed the granulometry would be play an important role in the activation process. The iodine number values of 655.5 mg/g and 958.09 mg/g of the BA-AC FE and BA-AC FA respectively are in line with the specific surface areas. The pH$_{PZC}$ values show that activated carbons are acidic. indeed, activated carbons prepared by chemical activation with H_3PO_4 ranging from 2.4 to 1.9, depending on the level of impregnation [17]. The pore size distribution obtained with the DFT method **(Figure 3)** shows that activated carbons are mesoporous. Indeed, according to the IUPAC classification, when the radius is between 2 nm and 50 nm, activated carbon surface contains mesopores. This is an agreement with So [11] who reported that mesoporosity and microporosity favour the movement of the adsorbate within the adsorbent leading to a better adsorption. It can be stated that the AC-BA produced in both furnaces are good adsorbents.

With regard to the nitrogen adsorption isotherms **(Figure 4)**, the activated carbon produced in the two furnaces are of type IV [20]. This confirms that both activated carbons are micro-mesoporous.
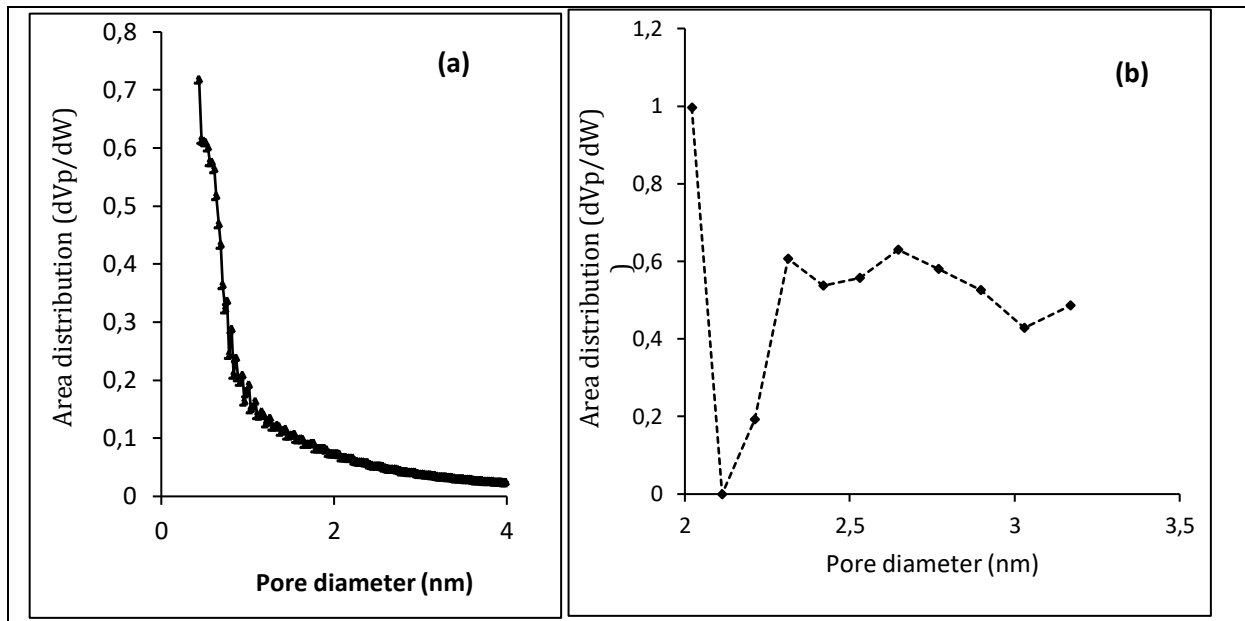
Figure 3: Pore size distribution of activated carbon from the modern furnace (a) and the artisanal furnace (b)
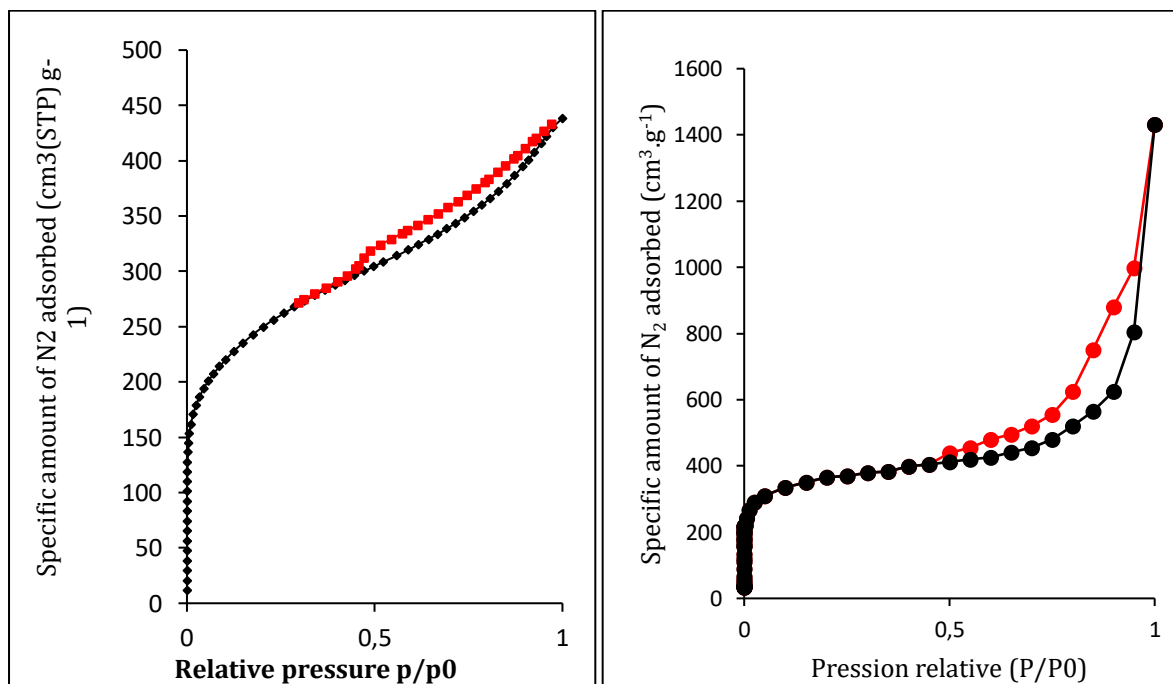

Figure 4: Nitrogen adsorption isotherm curves for activated carbons from the electric furnace (A) and the artisanal furnace (B) at 77 K

3-2. Elemental analysis: Table 2 gives the C, H, and N composition of the two activated carbons. The results show that the activated carbons prepared contain mainly carbon, whatever the furnace used, with small quantities of hydrogen and nitrogen. This importance of carbon is indicative of a good precursor for activated carbon production [8,21,22]. Indeed, according to these authors, any carbon

content between 50; to 90 % is indicative of a suitable plant for activated carbon production. The hydrogen content (1.04 - 2.77 %) of BA-AC is higher than the typical value of 0.5 % [23]. These values are in agreement with those found by some authors which vary from 42.2 to 72.4 % for carbon; 1.6 to 7.1% for hydrogen and 0.1 to 1.4 for nitrogen [22,24–27].

Table 2 : Elemental composition of activated carbon

Charbon actif	Composition (%)		
	C	H	N
BA-AC FE	65.78	1.04	0.44
BA-AC FA	74	2.77	0.69

3-6. Methylene blue and nitrate adsorption: The activated carbon BA-AC FE and BA-AC FA were used for MB and nitrate adsorption. It appears in **figures 5a and 5b** that, abatement rate decreases with increasing initial concentration of pollutant. Indeed, increasing the concentration induces the elevation of the driving force of the concentration gradient, thus increasing the diffusion of molecules of adsorbate in solution through the surface of the adsorbent [28]. In addition, the fixation kinetics are limited by the low residual concentration of adsorbate.
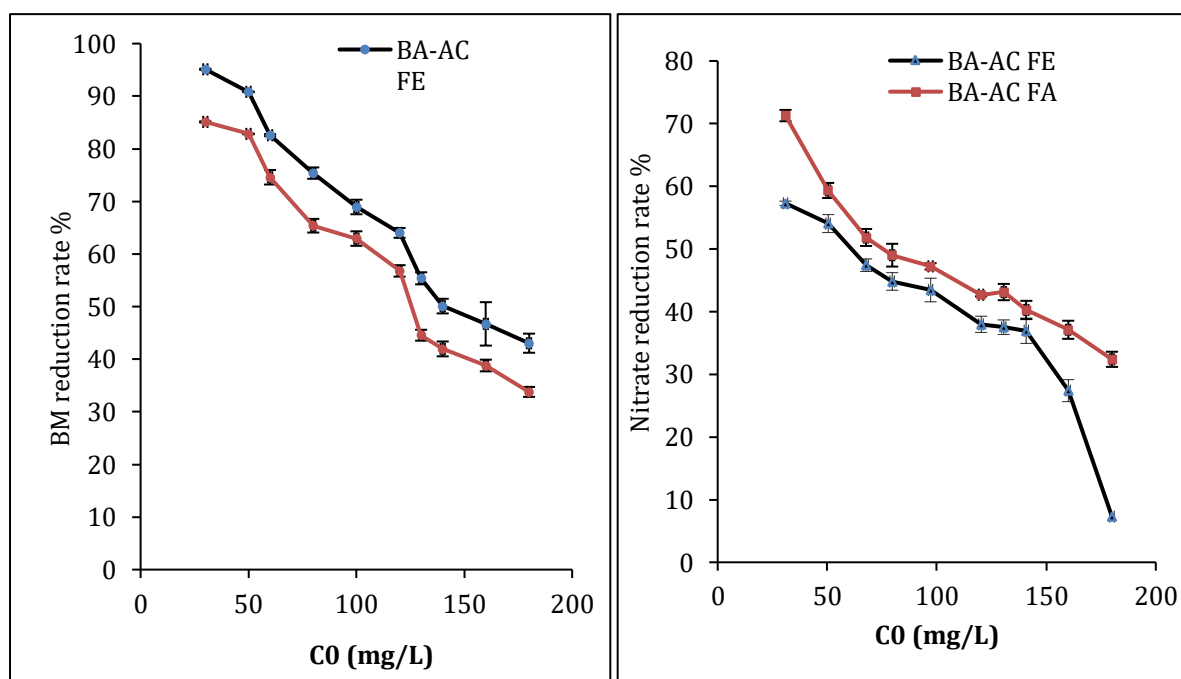

Figure 5: Adsorption test of BM (a); pH = 7; and adsorption test of nitrate (b); pH = 4

BA-AC FE have a better MB abatement rate BA-AC FA. This difference observed in the adsorption of MB would be related to the activated carbon characteristics. BA-AC FE being mesoporous, can easily adsorb medium and large-sized molecules like methylene blue. Contrary to MB adsorption, adsorption of nitrate is better with activated carbon produced with the artisanal furnace. The opposite for nitrate adsorption is due to the large specific surface area of the BA-AC FA, which is favourable to the adsorption of small molecules such as nitrate.

3-7. Economic evaluation: Table 3 gives an economic estimate of the carbon production according to the type of furnace. For the same quantities of activated carbon produced (4 kg) the overall costs are very different. Indeed, for a production in the artisanal furnace, a maximum of 280.5 $US is needed. This sum includes the construction of the furnace, the activator, the water to wash the activated carbon and the firewood used as energy during carbonization and activation. On the other hand, it takes a minimum of 859.5 $US to obtain the same amount of activated carbon with the electric furnace. With regard to the two production costs, the artisanal furnace offers a great advantage, especially in rural areas. This production cost can be reduced if the user decides to obtain the firewood himself by going to look for it, as the farmers do for cooking foodstuffs. In addition to being less expensive during the production of activated carbon, the artisanal furnace can be built with a larger volume depending on the objective. However, the modern furnace offers a time saving and accuracy. However, it took much longer total carbonization time with the artisanal furnace (8 h 30 min) against 3 h with the electric furnace.

Table 3: Economic study of the production of activated carbons according to the type of furnace

	Furnace (artisanal (A)-electric (E))		Phosphoric acid (g)		Carbonization time		Activation time		Carbon washing water (m^3)		Energy consommation	
	A	E	A	E	A	E	A	E	A	E	A	E
Quantity	1	1	100	100	3h30	3h	5 h	3h	500 L	500 L	10 boots	10 kw/h
Unit cost ($US)	200	829	20	20	-	-	-	-	0.5	0.5	5	0.5
Cost TTC ($US)	280.5	859.5	20	20	-	-	-	-	0.5	0.5	50	10

4. CONCLUSION

Activated carbons produced using electric and artisanal furnaces are similarly properties. Both furnaces are suitable for the production of quality activated carbon. Specific surface areas (888 m^2/g and 1431 m^2/g respectively for BA-AC FE and BA-AC FA), clearly indicated that artisanal furnace is an alternative for the production of activated carbons in rural areas. To obtain a *Borassus aethiopum*-based activated carbon with a large surface area, the char must be crushed before impregnation. Artisanal activated carbon production is economic than electric activated carbon production.

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