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Study of Mass and Energy Yields of an Agroforestry Residues Carbonizer

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Abstract *- Energy recovery from processing wastes of agricultural products is a solution to their management issues and a means of energy production. In addition, it contributes to the reduction of deforestation. The objective of this study is to develop a method of agroforestry residues carbonization. The residues used to consist of the shell of the doum palm (hyphaenethebaica) and the rice husk. Carbonization is in partial combustion, and the device used is a metal furnace made up of three (3) stages. The peaks of temperatures, mass and energy yields, and the quality of the coal (fixed carbon rate) were determined at each stage of the carbonized. The mass yields obtained for stages 3, 2, and 1 are 66.41%, 42.60%, and 21.57% for the shell of the doum palm and 46.94%, 67.19% 24.83% for the rice husk. The energy yields are 82.41%, 57.05%, and 30.97% for the shell of the doum palm and 56.1%, 74.58%, and 26.66% for the rice husk. The coal quality (fixed carbon rate) for the same stages 3, 2, and 1 is 35.32%, 44.42%, and 52.32% for the shell of the doum palm and 32.55%, 30, 43%, and 30.75% for the rice husk. The cycle time is 9.03h for the shell of the doum palm against 11.22h for the rice husk. This study shows that the shell of the doum palm produces better quality charcoal compared to the rice husk and that the charcoal obtained at stage 1 (E_1) can be used not only for gasification but also for direct home use.*

Keywords *- Rice husk, Coal/Charcoal, Carbonization/charring, Hull/Shell of doum palm.*

I. INTRODUCTION

At present, the world is experiencing rapid population growth. This growth causes huge energy demand because all human activity consumes energy (transport, construction, etc.). According to ADAMON [1], the fossil fuels we use are becoming increasingly scarce. On the other hand, fossil fuels have an increasingly high cost and negatively impact our environment [2]. They are very polluting and release a lot of carbon dioxide into the atmosphere, which is partly the cause of global warming, leading to natural disasters. According to studies by Pana-BENIN, the impact of climate change is the source of flooding and the decline in rainfed agriculture yields with serious consequences in terms of food security and malnutrition [3]. To fight against global warming and protect the environment, replacing fossil fuels with new energies is more than necessary. Indeed, many forms of so-called renewable energy have been developed, such as photovoltaic, wind power, hydraulics, energy conversion from biomass, or geothermal energy. Biomass remains the first renewable energy used in the world [4]. It is abundant and can be used for home heating, power generation, or biofuels [5]. The wood reserves we use are being depleted, and this is causing deforestation. However, the biomass energy recovery sector must be used without aggravating the phenomenon of desertification. Indeed, plants play an important role in reducing carbon dioxide in our ecosystem through photosynthesis [1], hence the need to enhance agroforestry residues. The use of energy recovery from agricultural biomass presents a major problem linked to the lack of control of the process, thus causing a loss in mass and energy, hence the need to reduce these losses. This article aims to develop a carbonization method adapted to agroforestry residues and optimize the mass and energy yields of carbonization.

II. MATERIALS AND METHODS

A. Materials used

a) Metallic carbonizer

The carbonizer used for this article is a carbonizer from the University of Maradi and is shown in Figure 1. It is a circular carbonizer with an internal diameter of 57 cm and a height of 1.20 m. It consists of two parts: the drum and the furnace (Figure 2).

- The 94 cm high drum has three floors separated by grids: the first grate is placed at the bottom of the drum, the second 30 cm from the first, and the third 30 cm from the second. Each floor has four (4) 2 cm diameter air inlets and a thermocouple to measure its temperature. Inside the drum, we have a chimney with a height of 80 cm and an internal diameter of 8.5 cm, and on the outside (on the lid), a chimney with a height of 1.70 m and an internal diameter of 8 cm. A sealing groove connects the end of the drum and the cover.

- The furnace is 32 cm high. It has two parallel air inlets with 10 cm * 40 cm arranged 4 cm from the bottom. A grid is placed 4 cm above the air inlets. A sealing groove connects the two parts of the carbonator (drum and furnace).

Figure 1: Study carbonizer

b) Balance

This is a "Ws-150 computer charging scale" model. It can measure loads less than 150 kg with an accuracy of 1% and weighs the masses of raw biomass, coal, and ash obtained.

c) Temperature acquisition

The temperatures are acquired using three thermocouples of the K type placed in the carbonizer. The first thermocouple is placed 20 cm above the first grid, and the other two are evenly spaced 30 cm apart. The thermocouples are then connected to a Testo 176T4 data logger (DATA LOGGER) giving a measurement range of -195 ° C to 1000 ° C. The data logger (Testo 176T4) records the temperature every minute. Immediate analysis

The immediate analysis involves determining humidity, ash, volatiles, and fixed carbon in the fuels. To carry out this analysis, a RESISTANCE FURNACA brand oven was used. The oven used in this work made it possible to analyze the humidity level in a temperature range of 105 ± 2 °C. A balance of 220g capacity and precision ± 0.1mg allowed us to measure the samples for immediate analysis.

A bomb calorimeter is used to determine the higher calorific value of fuels.

B. Methods

a) Preparation of raw materials

The raw materials used in our work are the shell of doum palm (hyphaenethebaica) and rice husk.

The first phase consists in collecting, drying, and crushing these materials. The rice husk was supplied to us by the Kirkissoye husking plant in Niamey. As for the shells of the doum palm, we bought them from the street vendors in Maradi. The hyphaenethebaica shells have been pre-dried in the sun for three (3) days before use. Figure 2 gives us the raw materials used.

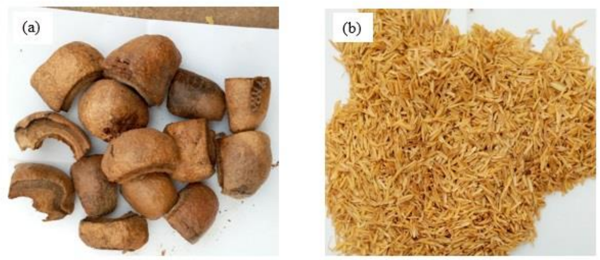


Figure 2: (a) Raw doum palm shells, (b) Raw rice husk.

b) Carbonization Protocol

Carbonization corresponds to partial combustion of the material. The amount of charcoal obtained for one operation is approximately 2 kg.

Filling begins from stage 1 (bottom stage), where approximately 0.5 kg of charcoal is used to initiate charring.

- A 0.5 kg quantity of charcoal is ignited and then poured onto grid 1 located at the bottom of the carbonator.
- A small quantity of biomass (100g to 300g) is then poured into the carbonizer to initiate the reaction.
- The biomass is then gradually poured until the first level (located at the bottom of the device) of the carbonizer is filled.
- The grid of floor 2 is placed above the fuel bed of the first floor.
- We proceed in the same way to fill floor n ° 2 (middle stage) and floor n ° 3 (upper stage).
- The carbonizer is closed at the end of filling, and water is introduced directly into the sealing groove.
- The carbonizer is first closed with its cover. Then will come the turns of the air inlets.
- The secondary air inlets located at the level of the floors are gradually closed (from the first to the second floor) depending on the change in the temperature of the fuel bed of each floor. The reference temperature for closing each stage is set at 300 ° C. to allow the fuel load's carbonization while avoiding considerable biomass burning.

- The cooling time is evaluated from the end of the closing of the air inlets until the temperature drops to a level below 50 ° C.
- Once all the temperatures drop below 50 ° C, the stages are unloaded, starting with stage # 3, then stages # 2 and # 1, respectively.
- The quantities of coal and ash obtained for each stage are separated and then weighed after unloading.
- Coal samples are taken and analyzed.

c) *Estimation of the duration of the different stages of carbonization*

The measurements carried out as part of our work are the filling time, the closing time of the primary and secondary air inlets, the cooling and cycle time.

The method used to calculate filling time, closing time, cooling down, and cycle time is as follows:

- ***The duration of the filling (T_{remp}) :***

The duration of the filling **(**$\mathrm{T_{remp}}$**):** of the device is counted from the start of carbonization initiation until the lid is closed.

- ***The duration of the closure of the primary and secondary air inlets:***

The duration of the closing of the primary air inlets ($\mathrm{T_{FEAP}}$) is counted from the closing of the carbonizer until the closing of the primary air inlets (E_{AP}). The time between the closing of the primary air inlets and the secondary air inlets of the first stage is noted (T_{FAES1}). The time between the closing of the secondary air inlets of the first stage and the secondary air inlets of the second stage is noted ($\mathrm{T_{FAES2}}$). The carbonization reaction time is given by the time between the end of filling and the closing of the secondary air inlets of the second stage ($\mathrm{T_{rc}}$).

- ***The cooling time (T_R) :***

The process cooling time is counted from the end of the closing of the secondary air inlets until the temperatures of all levels drop below 50 ° C, which corresponds to the opening of the carbonizer.

- ***Cycle time (CT):***

The cycle time is given by the sum of the filling, reaction, and cooling time (equation 1).

$$DC = T_{remp} + T_{rc} + T_R \qquad (1)$$

d) *The maximum cycle temperature*

The carbonization cycle maximum temperature was also identified for each stage of the carbonizer during the tests carried out. The recorded temperature curves were used for this purpose.

e) *Immediate analysis*

The immediate analysis was carried out at the level of the food science and technology laboratory of the Dan DickoDankoulodo University in Maradi, and the calorific value at the level of the Research Institute of Applied Sciences and Technologies (RIAST) of Burkina Faso. The immediate analysis allows us to learn about the quality of the product, including its moisture content, ash, volatiles, fixed carbon, and coal energy content. More details on immediate analysis are available in the literature [6]. For each sample, five (5) tests were carried out to guarantee the results' repeatability.

- ***The humidity content***

The humidity content is the amount of water (water content) in the fuel. According to the French standard, the humidity level is determined from the experiments carried out in an oven (AFNOR/X 34 B N° 110). The raw biomass is first weighed, and then it is brought to a temperature of 105 ± 2 ° C until a constant mass is obtained. The dehydrated biomass is finally weighed. The humidity rate (in percentage) on a wet basis is given by equation 2.

$$H = \frac{(m_2 - m_3)}{(m_2 - m_1)} 100 \qquad (2)$$

Or :

- m_1 is the mass in grams of the empty crucible;
- m_2 is the mass in grams of the crucible plus the sample before drying;
- $m_3$is the mass in grams of the crucible plus the sample after drying.

- **The ash rate**

This is the amount of mineral matter contained in the fuel. The ash content is analyzed using a muffle furnace according to the AFNOR standard (AFNOR/X 34 B N° 113). The ash content on a dry basis is given by equation 3:

$$C = \frac{(m_3 - m_1)}{(m_2 - m_1)} \times 100 \times \frac{100}{(100 - \mathrm{H})} \qquad (3)$$

Or

$m_1$is the mass in grams of the empty crucible;

$m_2$is the mass in grams of the crucible and the test sample;

$m_3$is the mass in grams of the crucible plus the ash;

H is the humidity on a wet basis expressed as a percentage of the mass.

- ***The rate of volatile matter***

Volatiles are components that can quickly escape when subject to high temperature. The biomass is introduced into an oven at a temperature of 900 ° C ± 10 ° C for a time of 7min. The volatile matter of the sample, expressed as a percentage by mass on the dry basis, is given according to the AFNOR standard by equation 4 (AFNOR/X 34 B N°

289):

$$MV = \frac{(m_2 - m_3)}{(m_2 - m_1)} \times 100 \times \frac{100}{(100 - \mathrm{H})} \qquad (4)$$

With:

- m_1 is the mass in grams of the empty crucible and lid;
- $m_2$is the mass in grams of the crucible and the lid and the test portion before heating;
- m_3 is the mass in grams of the crucible and the lid and the contents after heating;
- H is the humidity on a wet basis expressed as a percentage of the mass.

– ***The fixed carbon rate***

This is the amount of carbon remaining after the removal of moisture, volatiles, and ash; we followed the AFNOR standard for its determination with equation 5 (AFNOR/X 34 B N° 289)

$$CF = 100 - (MV + C) \qquad (5)$$

f) Higher calorific value (PCS)

The higher calorific value (PCS) was determined using a calorimetric bomb according to the AFNOR standard (AFNOR/X 34 B N° 254) given by equation 6.

$$PCS = PCI + latent\ heat\ of\ evaporation \qquad (6)$$

g) Mass yield (η_m)

The mass yield (η_m) was calculated on a wet basis. The mass yield of each stage is obtained by making the ratio of the mass of the coal (without ash) obtained on the mass of the biomass introduced (equation 7) [7]. The yield of the whole test is given by the same relationship taking into account the total mass of coal and biomass.

$$\eta_m = \frac{m}{M} * 100 \qquad (7)$$

- m: mass of the coal obtained;
- M: mass of the biomass introduced.

h) Energy efficiency (η_e)

The energy efficiency calculation was performed using the PCS of biomass and coal, dry mass introduced, and coal obtained. The energy efficiency is given by equation 8:

$$\eta_e = 100 * \frac{PCScharbon * \left(1 - \frac{H}{100}\right) m}{PCScharbon * \left(1 - \frac{H}{100}\right) M} \qquad (8)$$

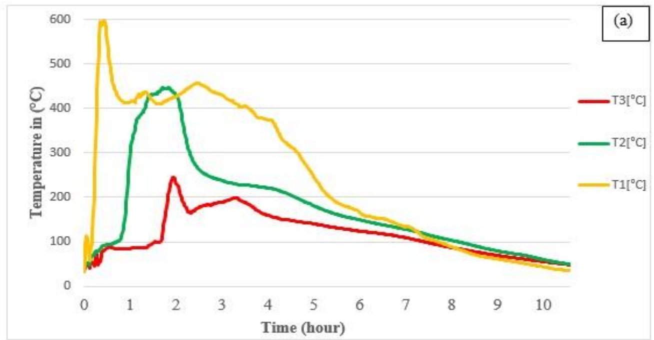
With :

- PCS coal: the higher calorific value of the coal obtained;
- Biomass PCS: the higher calorific value of the biomass introduced.

III. RESULTS AND DISCUSSIONS

A. Temperature fields

The temperature fields obtained during the carbonization for each studied biomass (the shell of the doum palm tree and the rice husk) are shown in Figure 3. Three (3) tests were considered for each biomass studied, but in view not to overload the document, we present a curve by biomass. The curves are taken from the acquisition of temperatures on the three (3) thermocouples placed inside the carbonizer



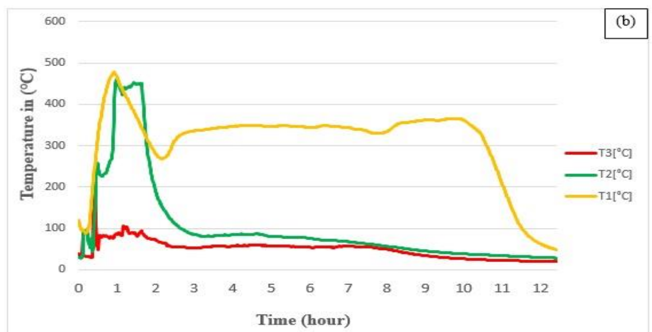


Figure 3: Temperature curve for carbonization: (a) Shell of the doum palm; (b) Rice husk

In general, the temperature fields present a similar shape for the three (3) temperatures T_1, T_2 andT_3, this evolution can be divided into two phases. The first phase corresponds to an increase in the three (3) temperatures until their temperature peak. A second corresponds to a decrease in temperatures from their temperature peak to a temperature level below 50 ° C. The first phase is called the combustion phase and the second is the cooling phase.

For the doum palm shell, the temperature T_1gradually increases to its average peak of 620 ° C, then begins to drop just after the primary air inlets are closed; meanwhile, the temperatures T_2 and T_3continue to rise until they reach their peaks respectively 499.7 ° C and 249.13 ° C. All three (3) peaks are reached in less than 2 hours. For carbonization of the rice husk, the average temperature peaks of 429.03 ° C;

381.86 ° C and 125.7 ° C for T_1, T_2 andT_3 respectively are recorded. The combustion phase is the phase during which the fuel undergoes thermal degradation under the effect of heat. The combustion phase is the carbonization phase at the origin of the quality of the coal obtained. A temperature peak between 250 ° C and 300 ° C results in a roasted product. On the other hand, a temperature peak between 300 ° C and 500 ° C leads to a carbonized product. An excessive rise in temperature leads to excessive combustion, which results from obtaining ashes, reducing mass and energy yields.

The evolution of temperatures shows a clear difference between the floors, the rice husk, and the doum palm shells. The temperature of stage 1 (lower stage) is higher than that of the other stages (2 and 3) due to its proximity to the primary air inlets below the carbonizer and the furnace. The temperature peak of stage 2 (middle stage) is also higher than stage 3, located above the carbonizer. The temperature T_3 The upper stage is very low (less than 250 ° C) because the thermocouple placed on this stage is located above the fuel bed. In the case of the rice husk, the temperature drop once the peak is reached is faster during charring than the temperature drop observed when charring the hulls of the doum palm (Figure 3). In less than 3 hours, T_2 and T_3reach a temperature below 100 ° C. Indeed, the rice husk suffocates the charcoal used for the initiation of stage 2 (middle stage) just after closing the primary air inlets which supply stage 1, thus causing the temperature T2 to drop sharply even before closing its air inlets (E_{ASE1}). The evolution of temperatures clearly shows the crucial role of primary and secondary air inlets on the temperature level and the carbonization phases for the rice husk and the hulls of the doum palm. Table 1 summarizes the average temperature peaks obtained during the three (3) carbonization tests for each stage and by fuel type.

Table 1: Averages of the temperature peaks obtained during the carbonization tests of the rice husk and doum palm hulls for each stage

Fuel type	Floor 1 (lower floor)	Floor 2 (middle floor)	Floor 3 (upper floor)
Rice Ball (°C)	429.03	381.86	125.7
Doum palm shells (°C)	620	499.7	249.13

In general, we note that the peaks reached by the shell of the doum palm during charring are greater than those obtained for the rice husk at each level, but also that the lower (lower) level for each fuel reaches a higher peak than the two (2) others, respectively that of the middle and the top (lower).

B. Duration of the different phases of carbonization

The averages of the durations of the filling and closing phases of the various air inlets, combustion, cooling, and the cycle are summarized in Table 2.

Table 2: Average duration of the filling phases, the closing time of the various air inlets, combustion, cooling, and the carbonization cycle of the rice husk and doum palm hulls

Duration of the carbonization stages	Rice ball	Doum palm shell
Filling time (min)	40	15
The closing time of primary air inlets (min)	60	1
The closing time of the secondary air inlets of stage 1 (min)	70	43
The closing time of the secondary air inlets on stage 2 (min)	40	53
Combustion time (hour)	3.5	1,86
Cooling time (hour)	7.72	7.17
Cycle time (hour)	11.22	9.03

The different times recorded for filling and closing the rice husk's primary and secondary air inlets are longer than those of the doum palm hulls. The duration of 1.86 and 3.5 hours represent the combustion time (filling and closing the air inlets) for charring the husks of doum palm hulls and rice husk. The second phase corresponds to that of cooling, during which the air inlets are closed, the fuel is deprived of air, hence the temperature in the carbonizer decreases. This cooling phase lasts 7.17 h and 7.72 h for the carbonization of the hulls of the doum palm and the rice husk, respectively.

The combustion phase lasts longer during the carbonization of the rice husk compared to the carbonization of the hulls of the doum palm, with a duration of 3.5 hours for the rice husk against 1.86 hours for the hulls of the doum palm. On the other hand, the cooling time is little influenced by the nature of the fuel. The total duration of the cycle is 11.22 hours or almost half a day and 9.03 hours for the shells of the doum palm. Rice husk has a longer cycle time than doum palm shells. In general, we notice the doum palm degrades more quickly than the rice husk, with a total carbonization time of 9.03 hours compared to 11.22 hours for the rice husk. The two-cycle times obtained are significantly less than the times obtained for traditional carbonizes, which can last for days or even weeks. The studies of the FOA [8] underline that these traditional processes have a cycle duration varying between 12 and 14 days with a temperature peak close to 500 ° C.

C. Immediate analysis and yields

The results of the immediate analysis of the PCS (higher calorific value) and the different yields (mass and energy) presented in this part, just like the temperature fields, represent the average of three (3) tests of each stage. Table 3 gives the characterization of the rice husk and hulls of the raw doum palm. PCS is given on a dry (anhydrous) basis.

Table 3: Results of immediate analysis and anhydrous PCS of raw rice husk and hulls of doum palm compared to wood.

Fuel type	Humidity level (%)	Ash rate (%)	Volatile matter rate (%)	Fixed carbon (%)	Higher calorific value (MJ/kg)
Rice ball	5.07	19.47	71.28	9.25	16
Doum palm shell	6.25	5.56	80.75	13.69	19
Drink [9]	30-60	-	70-80	15-25	-

The immediate analysis of the raw materials of the doum palm hulls and the rice husk summarized in table 3 gives us a fixed carbon rate of 13.69% and a higher calorific value of 19 MJ / kg for the doum palm against 9, 25%, and 16 MJ / kg for the rice husk. This first analysis gives us an idea of the energetic qualities of each of the biomasses. It emerges from this comparison that the doum palm has a higher energy power than the rice husk because of its high fixed carbon content. By comparing the fixed carbon rate of the two fuels with wood, we notice that wood has a higher energy content than the latter because of its higher fixed carbon rate [9].

Table 4 shows the result of the immediate analysis and the anhydrous PCS per stage of the charcoal-based on the rice husk and the hulls of the doum palm obtained as a result of the charring.

Table 4: Results of immediate analysis and PCS of charcoal in rice husks and doum palm hulls by stage and average values

Fuel type	Floor	Humidity level (%)	Ash rate (%)	Volatile matter rate (%)	Fixed carbon (%)	Higher calorific value(MJ/Kg)
Rice husk charcoal	Floor 3	2.41	38.41	29.03	32.55	19.12
	Floor 2	2.32	34.54	35.01	30.43	17.76
	Floor 1	3.31	37.75	31.48	30.75	17.18
	Mean	2.68	36.9	31.84	31.24	18.02
Doum palm shell smut	Floor 3	3.47	10.77	53,91	35.32	23.57
	Floor 2	2.47	11.371	44.21	44.42	25.44
	Floor 1	2.35	18.30	29.38	52.32	27.27
	Mean	2.76	13.48	42.5	44.02	25.42

The results show that after the two biomasses' carbonization, the humidity and volatile matter rates have decreased compared to their natural state. On the other hand, the rate of ash, fixed carbon, and PCS increased due to carbonization.

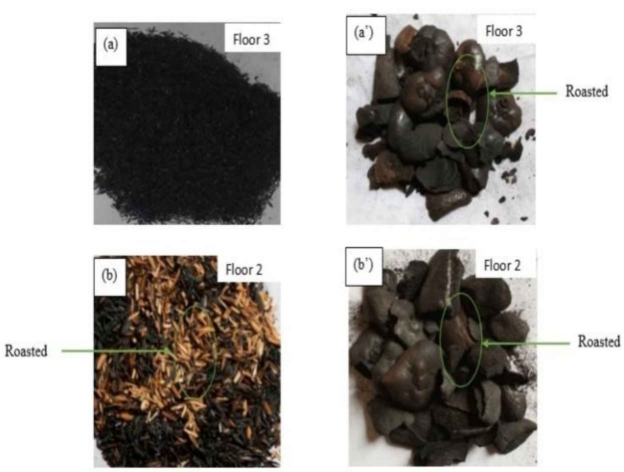
Table 5 summarizes the results of the mass and energy yields obtained on an anhydrous basis during the carbonization of the rice husk and the hulls of the doum palm tree by floor.

Table 5: Results of mass and energy yields of rice husk and doum palm shell carbonization by floor.

Fuel type	Floor	Mass yield (%)	Energy efficiency (%)
Rice husk charcoal	Floor 3	46.94	56.1
	Floor 2	67.19	74.58
	Floor 1	24.83	26.66

	Mean	46.32	52.44
Doum palm shell smut	Floor 3	66.41	82.41
	Floor 2	42.60	57.05
	Floor 1	21.57	30.97
	Mean	43.52	56.81

Fig. 4 shows the different coals obtained by type of fuel and by floor. We notice a decrease in the volatile matter and humidity level when passing from the upper level to the lower level of the carbonized during the doum palm hulls carbonization. This increases the quality of the coal, within particular an increase in its PCS and its fixed carbon rate. On the other hand, a decrease in the mass and energy yields from the top to the bottom of the carbonizer is observed due to the combustion of a greater quantity of biomass from the bottom to the top of the carbonizer (Table 5). This is because of the increased peak temperature resulting from better air supply from the bottom to the top of the carbonizer. Indeed, the more the temperature increases, the more the volatile matter and the yield decrease. The decrease in mass yield and the increase in the fixed carbon rate are similar to the behavior of wood during its carbonization. Antal [10] 's work for wood shows that the increase in temperature causes a decrease in mass yield and an increase in the fixed carbon rate. The results obtained by stage confirm this because stage 1, having been exposed to a high temperature compared to the other two stages (2 and 3), has a low efficiency compared to them and a higher carbon rate, respectively stage 2 with respect to stage 3. This characterization of the carbon obtained also enables us to express an opinion with respect to its quality at the level of the various stages.



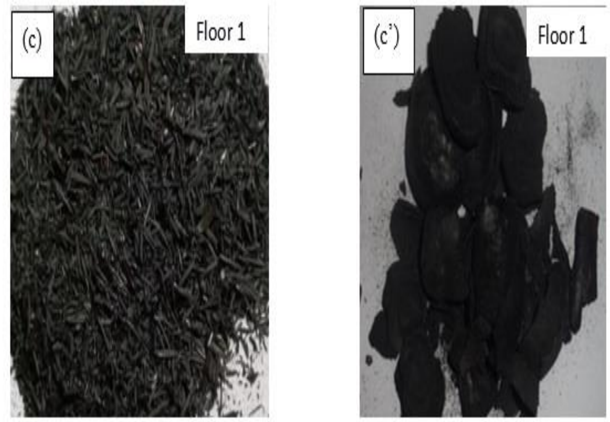


Figure 4: Charcoals obtained from the rice husk and doum palm hulls, (a, a ') floor 3; (b, b ') floor 2; (c, c ') floor 1.

The coal obtained in stage 1 can be used for domestic use and gasification, with a volatile matter content of 20 to 30% [2]. As for the coals of the other two stages, 2 and 3 can be used for gasification. By comparing the results of stage 3 having undergone less mass loss in Table 2 presenting some data on the different torrefactions, we note that the results of stage 3 for the mass yield, energy, volatile matter, fixed carbon, ash rate, and PCS are in the different intervals of severe torrefaction, which allows us to conclude that stage 3 has undergone a severe roasting. Referring to the work of Blin [11], who states that we can classify coal according to the rate of volatile matter and its fixed carbon content, we can compare the result of the coal of stage 1 to those obtained in the work of Zeïda for the carbonization of cashew nut cake [12]. It obtained a volatile matter content of 40.75% and 51.64% fixed carbon, respectively, against 29.38% and 52.32% for stage 1 of our carbonizer. Analysis of these results shows that the charcoal obtained in stage 1 is better than that obtained by ZEÏDA for cashew cake.

The results of the charcoal characterization of the rice husk show, like those of the doum palm (Table 4), a decrease in the humidity and volatile matter levels compared to the raw rice husk and an increase in the ash percentages and fixed carbon, as well as PCS. For the rice husk, stage 1 undergoes more mass loss than the other two, and then stage 3 comes compared to stage 2. This is explained by the fact that stage 1 has been exposed at a higher temperature than the other two stages. The rice husk charcoal from the carbonizes first and third stages can serve for domestic use due to the rate of volatiles belonging to the range of 20 to 30% and gasification. The coals from the rice husk obtained in stage 2 can be used for gasification.

The coals obtained at the different stages for the two (2) fuel types show that the coal obtained from the hulls of the doum palm is better than that of the rice husk because its average fixed carbon rate of 44.02% is greater than that of the rice husk (31.24%).

IV. CONCLUSIONS

This article has focused on the charring of agroforestry residues and, more specifically, the shell of the doum palm and the rice husk. The study was carried out with a metallic device consisting of three (3) stages and consisted of determining the different yields, the quality of the coal per stage, and the cycle times for each biomass studied. This study concluded that the shell of the doum palm takes less time to carbonize than the rice husk, with a time of 9.03 hours against 11.22 hours. These times are better than those obtained by traditional carbonizes, which can last days or even weeks. The cycle times for the two fuel types can allow for planning two (2) carbonization turns per day. The obtained yields are acceptable, with an average mass yield of 43.52% against 46.32%, an energy yield of 56.81% against 52.44%, and the coal's quality 44.02% against 31.24%, respectively for the hulls of the doum palm and the rice husk. We note a better yield for the palm shell than the rice husk, and the quality of its charcoal is also better than that of the rice husk.

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