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Recovery of cooking energy from waste paper through the production of white coal

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ABSTRACT: *This work deals with the energy recovery of paper waste for the production of a domestic fuel (white coal). In the city of Maroua, paper waste produced in large quantities is not recycled and most often burned in an opened area. However, this has a high calorific value. The aim is to produce a fuel made of paper and clay used as a binder. For this purpose, 04 proportions of paper waste (50%, 65%, 80% and 100%) were used. The best results of combustion were obtained with 80% of paper and 20% of clay. Cooking tests show that it takes an average of 0.633 Kg of white coal to cook 1 kg of rice in 32.6 minutes. The annual potential of white coal production in Maroua indicates that 839.54 tons can be obtained at the National Advanced School of Engineering and the Waste Treatment Centre of HYSACAM. This potential could cover the annual cooking energy needs of 3872 people in the city of Maroua and preserve 196 hectares of firewood collection area. A study of the economic profitability of its industrial production shows in ten years a net present value of 89,192,660 F CFA.*

KEYWORDS: *combustion, energy recovery, Maroua, paper waste, white coal*

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I. INTRODUCTION

In sub-Saharan Africa, it is estimated that more than 80 percent of the population relies heavily on firewood for their cooking energy needs [1, 2]. In some regions, such as in the Far North of Cameroon, addiction is more pronounced. It is estimated that over 98% of the population produces cooking energy from woody biomass [3]. This great dependence on biomass has many negative effects on both the local environment (deforestation, reduction of soil fertility, etc.) and global climate change. According to Cameroon's Energy Information System, (SIE-Cameroon) [4], the firewood collection is the essential cause of deforestation in Sahelian zone in the country. Consequently, negative impacts are noticed on living conditions of mainly women and children who are usually responsible for firewood collection [5]. The resource is becoming increasingly rare due to the pressure of the population who no longer respects the age of the plant before being cut down. For example, Abou and Folefack [6] report that trucks travel more than 200 km in search of this resource, while women walk more than 20 km on foot to purchase a bundle of wood. It is obvious that the available wood resource will not be able to meet the demand of the ever-growing population. A study done by Madi reported that the demand of firewood is 2.5 more than the supply in the region of Maroua [7]. In the interest of promoting sustainable development, particular interest is given to the search of any other means of cooking energy that is accessible by the vulnerable part of the population. It is in this context that this study has targeted the energy recovery from the paper waste. In fact, paper waste is most often not recycled. It is produced in very large quantities in printing houses, institutions and trading areas. They are assimilated to waste which high production causes enormous management difficulties. For instance, in the town of Douala, it was found that 3.7% of urban waste is paper [8]. In urban areas of developing countries, waste figures among the factors that distort and make cities unattractive. Waste is a source of many diseases [9]. However, waste paper made from wood can potentially provide energy during combustion. This work was initiated to test the recycling of paper waste for the production of biofuel called "white coal. Our preoccupation is firstly to look for the technical feasibility of production with the appropriate proportion of clay-paper which is appreciated at the end of the test of combustion. Then the rice cooking test was performed using the best white coal. Finally, a brief financial analysis of a project for a semi-industrial production of white coal was made.

II. MATERIAL AND METHODS

2.1 Technical feasibility of white coal production

2.1.1 Production method

The white coal was produced from a mass of paper mixed with the clay and kneaded by adding water. For this purpose, 50%, 65%, 80% and 100% of waste paper were respectively mixed with 50%, 35%, 20% and 0% mass of clay. The kneading is done until a homogeneous mixture more or less pasty is obtained. The last phase consists of agglomerating the product obtained and forming pellets. This process is summarized on Fig 1.

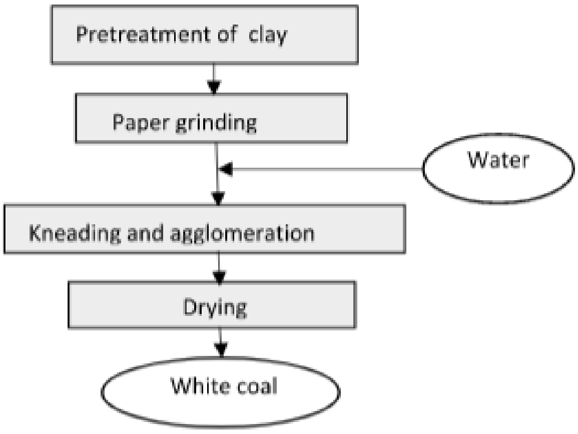

Figure 1: White coal's manufacturing process

2.1.2 - Combustion tests and selection of suitable white coal

The combustion tests carried out consisted of burning white coal in an improved cooking stove. The characteristics of each type of white coal namely ease of ignition, smoke released, time required a litre of water to boil were appreciated. For each test, a sample of 0.7Kg of fuel produced was taken. The tests were repeated three times.

2.2 Determination of some characteristics and firing test using 80% waste paper charcoal (CB80)

After the selection of the best white coal (CB80), it was produced in large quantity according to the protocol described above. This allowed us to determine some physicochemical characteristics and to test the rice cooking using CB80.

2.2.1-Characteristics of CB 80

The particle size (diameter) of CB80 produced was evaluated using vernier calipers. For this purpose, we took 30 samples of CB80 at random and measured their diameter. In addition to the particle size, the average moisture content (H) of the CB80 sample was determined by the standardized method CEN / TS 14 774. The test was conducted at the Biosciences laboratory of the University of Maroua from 10 samples taken and H is determined (1):

$$H = \frac{1}{10}\sum_{1}^{10} \quad 100 \times \frac{m1-m2}{m1-m0} \qquad (1)$$

m0: mass of the empty crucible;
m1: mass of the crucible with the sample before going to the oven;
m2: mass of the crucible with the sample after the passage to the steamer

The final moisture content of CB80 is the average of the moisture levels obtained above

Among the informative parameters, the lower heating value (LHV) of the CB80 was estimated. A study conducted by PERACOD [10] shows that clay which is a mineral binder has zero LHV. Starting from the fact that the paper comes from softwoods or hardwoods, the average LHV of the white coal is given (2):

$$LHV = \frac{1}{2 \times 1.25}\left(\frac{100-H}{100} - 0.02443 \times H\right)(Qo + Q'o) \qquad (2)$$

Q_0 is equal to: 20 MJ / kg of dry matter for conifers and 19 MJ / kg for hardwoods [12]

2.2.2 Cooking tests

The cooking tests of rice using CB80 were carried out in a household. The aim was to determine the cooking time and the amount of CB80 used. Three quantities of rice namely 0.5 kg, 1 kg and 1.5 kg were cooked. For each quantity of rice, a mass of fuel was taken to feed the stove. The cooking time was measured. The test was repeated three times for each quantity of rice. In order to compare CB80 with domestic fuels, the same quantities rice were cooked using charcoal.

2.3 Evaluation of the economic profitability of an industrial project of white coal production

This evaluation concerns an industrial production company of CB80. It is equipped with 10 agglomerators each producing 50kg of CB80 / hour and two tricycles for waste collection. It employs 20 people. The calculation of the payback time (IRR) was done (3):

$$IRR = \frac{Co}{BN_t} \qquad (3)$$

As for the net present value (NPV) it was considered that the production unit is operational for 245 days a year. Let Q be the mass of white coal produced annually and P the selling price of one kilogram of this fuel, the annual revenue of the unit of production is then given (4):

$$Rt = 245 \times P \times Q \qquad (4)$$

The net present value (NPV) was calculated (5) as done by Tizé and *al.* for a period of 10 years [12]

$$NPV = -Co + \sum_1^t \quad BN_t \qquad (5)$$

$$BN_t = \frac{(R_t - C_{vt})}{(1+i)^t}$$

Co: Fixed cost, Cvt: variable cost, BNt: Annual net profit, i: discount rate

III. RESULTS AND DISCUSSION

3.1 Technical Feasibility of White Coal Production

3.1.1 White Coal Combustion Test

Some white coal produced are presented on the below Fig.

Figure 2: White coal during drying

The difference in color observed is related to the proportion of clay. When the quantity of clay is higher, white coal is blacker. At the end of the test on the boiling of a liter of water using 0.7 kg of each type, the results are summarized in TABLE 1.

Table 1: Burning time of different types of white coal produced

White coal	Time to reach boiling point(min)	Time of complete consumption(min)	Observations
CB50	15 ± 5	27 ± 4	Difficult ignition, a lot of smoke during combustion
CB65	6.0 ± 1.7	40 ± 0.1	Ignition a little easy, enough smoke during combustion
CB80	5.2 ± 0.6	39.04 ± 0.8	Very easy ignition, few smokes only at the beginning of combustion
CB100	5.0 ± 0.2	36.4 ± 0.3	Easy and fast ignition, few smokes only at the start of combustion

In general, the firing for the CB65, CB80 and CB100 fuels was easy. However, only CB80 and CB100 burn up without releasing a lot of smoke. It therefore appears that the clay content influences the combustion quality of the white coal. It can be seen that it is the fuels with a high percentage of paper that take less time for the water to reach boiling point (about 5 minutes for CB100 and 6.20 minutes). On the other hand, the time for these fuels to be totally consumed (burning time) is reduced when the paper percentage increases (about 40 minutes for CB65 and 36 minutes for CB100). CB80 and CB100 fuels take about the same time to bring a litre of water to the boiling point. However, the CB80 has a significantly higher time of combustion. From this analysis, the CB80 fuel is more appropriate. These results are similar to those found by Tchoudi who indicated the influence of clay used as the binder on the burning time when producing biochar [13].

3.2 Characteristics and cooking test of CB80

3.2.1 Characteristic of white coal CB80

The characteristics of the CB80 white coal determined are presented in TABLE 2.

Table 2: Some characteristics of the CB80

"Normative" parameter	Diameter(cm)	4.22 ± 0.07
	Moisture content(%)	7.05 ± 0.38
"Informative" parameter	Lower heating value ($MJ.Kg^{-1}$)	13.15 ± 1.48
	Apparent volumetric mass($Kg.\ m^{-3}$)	600.00 ± 6.80

It appears from this table that the particle size of the pellets produced after drying is about 4.22 cm in diameter. This result is not far from the optimal diameter range [2.5cm, 4cm] obtained by Onyong [14]. CB80 white coal has a low moisture content of 7%. This moisture content is similar to that of charcoal (7.28%) reported by Fick [15]. The heating value of CB80 white coal is 13.15 MJ / Kg. However, it is much lower than that of charcoal varying between 29 to 35 MJ / Kg [15, 16].

3.2.2 - Rice cooking test with CB80

The results of rice cooking tests which have been carried out are presented in TABLE 3.

White coal mass CB80 (kg)	0.5	0.63	0.8
Mass of rice (kg)	0.5	1	1,5
Cooking time (minutes)	36 ± 4	32.6 ± 2.5	33.6 ± 2
Total consumption time of white coal (minutes)	46 ± 1	37.3 ± 4.7	41.6 ± 3.5

Table 3. Time for cooking rice with white CB80 coal.

Using the above amounts of white coal, it is found that 1.5 Kg of rice is cooked in 34 minutes. It has been observed that when doubling the quantity of rice (from 0.5 to 1Kg) just an increase of 26% of white coal was sufficient and the cooking time varies very little. Therefore, the fuel economy is achieved when one chooses to cook a higher quantity of rice. Fig 2 presents some aspects of these tests and Fig 3 makes it possible to obtain the quantity of fuel necessary to cook a given mass of rice between 0 and 1.5 Kg. We note a small variation of the mass of the charcoal compared to the white coal. This is very important when fixing the price of white coal. The difference is partly due to the low LHV of white coal (13.15 MJ / kg) compared to that of charcoal (29 to 35 MJ / kg).

(a) :CB80 in an improved stove	*(b) :* burning of *CB80*	*(c) : Checking the cooking*	*(d) : Rice cooked using CB80*

Figure 2: Cooking rice test using CB80

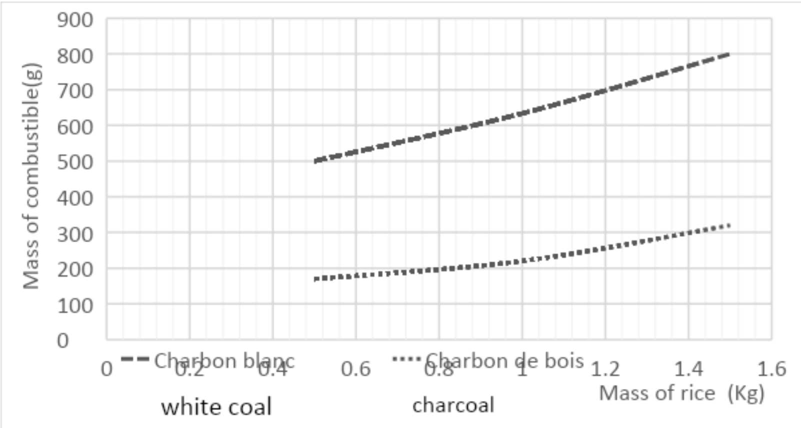

Figure 3: Variation of the mass of rice according to the mass of the fuel

3.3. Financial evaluation of industrial production company of white coal CB80

3.3.1- Estimation of the paper and white coal waste potential at NASEM and at WTC of Yonkolé

The results of the white potential estimated are summarized in the table below. With regard to the study and the calculations made, the total potential of white coal produced from the valuation of the examination books intended for destruction at the NASEM would be 3.2 tons per year. At the WTC, this potential would be 839.54 tons.

Table 4: White Coal Potential at NASEM and Yonkolé WTC

Site	NASEM	WTC	Total
Mass of Paper wastes (tons)	2.5632	669.077	671.64
Mass of white coal that can be produced (tons)	3.2	836.34	839.54

Our study reveals that with respect to PCI, 1 kg of charcoal corresponds to 2.2 kg of white coal. In addition, PREDAS [16] has indicated that an average of 7 tons of wood is required to produce 2.1 tons of charcoal. Starting from what precedes the potential of white coal in both sites is equivalent to about 1272.03 tons of firewood. And according to the fact that a person consumes an average of 0.9 kg of wood per day in the town of Maroua [7], the use of white coal could fully satisfy the annual cooking energy needs of about 3872 people. If all the important areas of paper waste production in the town of Maroua are targeted, this offer in white coal would be at least five times more important. According to Tizé et *al.*, [17], the consumption of a ton of wood leads to the destruction of 0.154 hectares of forest in the Sahelian zone. It shows that the use of paper waste in the above mentioned sites would allow the annual preservation of a vegetation cover of about 196 ha. This can reduce that deforestation caused mainly by the collection of firewood in the Sahelian zone such as in Maroua. For instance, SIE-Cameroon has estimated to 199 490 ha the surface destroyed from the use of firewood in 2008 [4].

3.3.2 Evaluation of economic profitability

With the objective of a semi industrial production unit of white coal evaluated, an investment of 24,553,000F CFA is needed. The company will produce approximately 490 tons of white coal annually. It has been calculated that the cost of production of 1 Kg of white coal is 55F CFA and its selling price is 65F CFA. The payback period of this investment is 5 years and 5 months. The result obtained from the Net Present Value (NPV) presents the positive amount of 89,192,660 F CFA. These analysis show that this type of project is financially profitable. There is a great opportunity to recycle paper waste for the production of white coal. It therefore creates new wealth, new jobs and can significantly contribute to the environment protection.

IV. CONCLUSION

This study, which deals with the recovery of cooking energy from paper waste indicates the possibility to produce the best white coal when using 20% of clay in the mixture. The characteristics of white coal produced are 4.22cm of diameter and a LHV of 13.15 MJ / Kg. Cooking tests have revealed that an average of 0.633Kg of CB80 is sufficient to cook 1Kg of rice for about 32 minutes. These properties show that white coal is a good fuel which can substitute charcoal. If the paper waste available annually were recovered as white coal, it would produce 3.43 tons at the NASEM and 836.34 tons at WTC Yonkolé. Used as source of energy for cooking, these quantities of white coal could supply annually 3872 people in the city of Maroua. The initiative to create a business for industrial production could be financially and environmentally sound. The amount of 24,553,000F CFA would be sufficient for the investment. The company will generate a net present value of about 89,192,660 F CFA over a period of 10 years with à payback period of 5 years 5 months.

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