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Energy Recovery from Cocoa Shell, Oil Palm Seed Fibers and Sugar Cane Bagasse as Fuel in a Combustion Chamber

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Abstract

This work, concerns determination of energy potentials of three types of food waste in the Ivory Coast. The method used consists in carrying out a physical and chemical analysis of three types of waste, namely cocoa shell, sugar cane bagasse and oil palm seed fibers. The study of five (5) parameters show the energy potential of the three wastes. This is made possible by the knowledge of dry volatile matter (%MVS greater than 97%), total organic carbon (% COT about 57%) and dry matter (%MS between 17% and 79%), ash content (%K between 2.65% and 11.4%) and humidity (%TH between 20% and 83%).

It appears from this study that these wastes have energy potentials with the lower calorific value (PCI greater than 18 MJ / kg). These data are very interesting and indicate that these wastes are recoverable by combustion or methanation. However, the humidity level is very high for two of them, notably cocoa shell and sugar cane bagasse (83% and 70% respectively). The difference between PCS and PCI shows that it will be necessary to pre-dry these wastes before combustion.

Key words : solid agricultural wastes, biomass, lower calorific value, combustion, energy...

Introduction

Renewable energies are at the forefront of sustainable solutions against global warming. Among

these solutions, exist biomass, which contribute to energy self-sufficiency and to protect the climate².

Energy conversion solutions for waste are increasingly being considered and encouraged to meet the

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requirements of COP 21. Côte d'Ivoire, the world's leading producer of cocoa (2 million tons / year) has capital agricultural waste very impressive and not valued. This observation can be extended to several other agricultural products in the country such as sugar cane bagasse, oil palm seed fibers etc. The objective of this study is the establishment of reliable data on the characterization of organic waste to allow essentially: - To assess the recovery potential (energy); - Optimizing the treatment method by knowing precisely the composition of the waste; - Predict the emissions of these wastes into the environment and possibly work on mitigating their impact⁵.

To achieve this objective, our study was based on the determination of five (5) physicochemical parameters of three (3) types of food waste available. The parameters measured were used to determine the higher calorific value (PCS), the lower calorific value (PCI), the combustive and smoke-producing powers.

1. Materials and Methods

1.1. Presentation of study area and context :

1.1.1. Study Area :

The study focused on solid fuels made up of food waste (cocoa shell, sugar cane bagasse and oil palm seed fibers) from households, restaurants and plantations in the city of DANANE (7 ° 16 2 00 3 North, 8 ° 10 2 00 3 West), a city in western Côte d'Ivoire with a population of over **288 845** inhabitants.

DANANE has a tropical climate. When compared with winter, the summers have much more rainfall. According to Köppen and Geiger, the climate in this region is classified Aw. The average temperature in DANANE is 25.1° C. The rainfall here averages 1967mm.



18 mountains region, Ivory Coast.
(Google Map data, 2020)

1.1.2. Study context :

- The sugar cane bagasse:

Bagasse is a residue obtained after pressing and crushing the cane to collect its juice. It is used as solid fuel in most cane factories. With climate change and the depletion of oil reserves on the horizon, we work about the large-scale energy recovery of cane as a whole to produce electricity. This cane could be an important source of electricity tomorrow in many countries and particularly in Ivory Coast. It belongs

to the category of varieties with high energy potential; (CIRAD, 2019).

- The cocoa shell:

The issue of using bagasse can be extended to other waste produced in industrial quantities in Côte d'Ivoire, particularly to cocoa shell, the country of which is the world's largest producer of beans. Côte d'Ivoire, which aims to raise the current rate of primary cocoa processing estimated at 33% to 50% by 2020,

will become the leading producer of cocoa shells in the world with its two million tonnes of beans per year.

- *Oil palm seed fibers:*

To the sugar cane bagasse and the cocoa shell, it is necessary to add the oil palm seed fibers. According to Maxime CUMUNEL's study in February 2020, the production of palm oil in Côte d'Ivoire should increase by 94% compared to 2017/18 and reach 933,000 t by 2030/31. Internal consumption would also increase by 116%, to 701,000 tons in 2030/31; imports would increase by 384%, to 179,000 tons in 2030/31, which would correspond to 26% of internal consumption against 11% in 2017/18. Lastly, exports would be tripled compared to 2017/18, at 658,000 tons. For each ton of oil extracted, the oil palm industry must process one ton of solid organic waste, the stalks, and about 2.5 tons of liquid waste, the effluent. While this waste was a serious environmental problem since 1980, producers now recycle it as organic fertilizer in their plots, (CIRAD, 2019). Solid waste from the oil extraction process is mainly made up of fibers that are generally used as fertilizer on agricultural farms. On a small scale, women use it as a pre-ignition fuel for charcoal at home.

1.2. *Materials of study :*

1.2.1. *Waste studied*

- Cocoa shell are the residues from the crushing of the cocoa bean. This operation consists in separating the shell from the grain. The pre-dried cocoa beans are directed to a crusher, a kind of mechanical mill, and are crushed into coarse particles. At the end of the process, two essentially by-products are obtained, which are the beans and the cocoa shell (cf. Figure 1a). The latter is generally considered as waste.
- Sugar cane bagasse is the fibrous residue obtained after crushing sugar cane for the extraction of cane juice in the mills of sugar refineries and distilleries, (cf. figure 1b). It is mainly composed of cellulose from the plant. The result is 70% of the juice and

30% of the bagasse (DOTOU, 2014).

- Palm oil or *Elaeis guineensis* is a monocotyledon plant from the *Arecaceae* family, widely cultivated for its oil-rich fruits and seeds for food and industrial use. Palm oil, extracted from the pulp of the fruit, has become in recent years the first source of vegetable fats on the world market. Solid waste from the oil extraction process is mainly made up of fibers.



Figure 1a : Cocoa shell



Figure 1b : Sugar can Bagasse



Figure 1c : oil palm seed fibers

1.2.2. *Laboratory equipment :*

The laboratory material used are listed in table 1.

Table 1 : Material used for the study

Materials	Mark	Role	Standards
Analytical balance	SARTORIUS sensitivity 10 mg	Weighing of samples	
Oven (0°C à 200°C)	MEMMERT	Dry matter rate (% DM) then deduce the humidity rate (% TH).	NF ISO 11465 ou AFNOR X 90-029
Desiccator filled with silica gel	KARTELL	Protection of samples against humidity	
Oven (30°C à 3000°C)	NABERTHER	Volatile dry matter rates (% MSV) and ash or mineral matter rate (% MM) Volatile dry matter rates (% MSV) and ash or mineral matter rate (% MM)	AFNOR NF U 44-160
pH-meter	HANNA HI 8424	Measure the pH of the solutions studied	AFNOR
Magnetic agitator	HEIDOLPH	Homogenization of solutions	
Laboratory glassware (10 ml porcelain crucible, Crucible tongs, 100 ml flask, 250 ml flask, distillation apparatus, 250 ml beaker)	-	Various samples and analyzes	
Mechanical grinder	-	Waste crushing	

1.2.3. Equations used :

$$PCS = 418 C - 1672 \quad (kJ/kg); \quad (1)$$

$$PCI = PCS - (226 H + 25E) \quad (kJ/kg) \quad (2)$$

$$Va = 101. 10^{-5}. PCI + 0,5 \quad (Nm^3/kg) \quad (3)$$

$$V_f = 89. 10^{-5}. PCI + 1,65 \quad (Nm^3/kg) \quad (4)$$

PCS: higher calorific power

PCI: lower calorific power

Va: Combustive power

Vf: smoke power

(Caillat and al, 2010)

2. Results et Discussion

2.1. Results

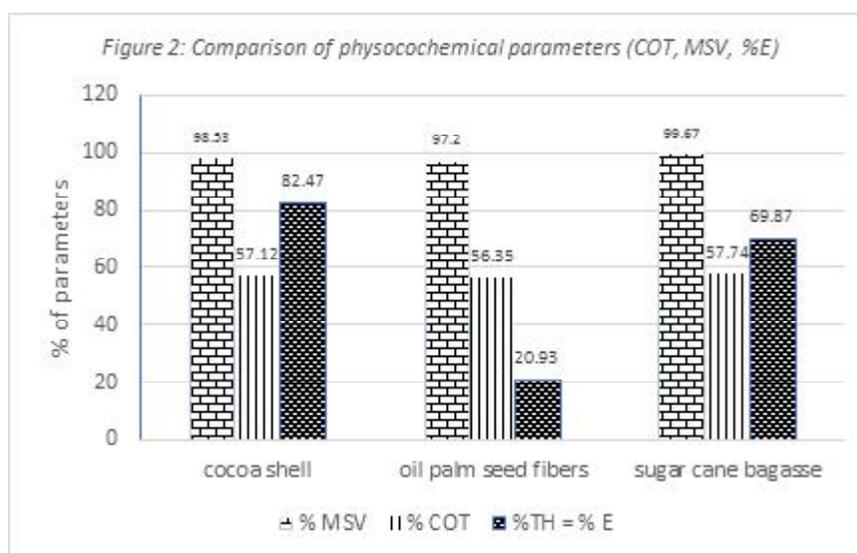
parameters determined in the laboratory (%MSV, % COT, %E, %MS and %K) and the energy parameters (PCS, PCI, Va, Vf) deduced by calculation from equations (1) to (4).

Table 2 presents the physicochemical

Table 2. Physicochemical and energy parameter

Parameters studied	Cocoa shell	oil palm seed fibers	Sugar cane Bagasse
% MSV	98,53±0,06	97,2 ±0,1	99,67 ±0,1
% COT	57,12±0,04	56,35±0,06	57,74±0,06
%TH = % E	82,47±0,83	20,93±0,29	69,87±0,29
% MS	17,53±0,83	79,4±0,42	30,4±0,38
% MM = % K	11,4±0,3	3,54±0,3	2,65±0,02
PCS (kJ/ kg)	22204,16	21882,3	22463,32
PCI (kJ/ kg)	18072,25	20834,73	18962,81
Combustive power (V_a)	18,75	21,54	19,65
Smoke power (V_f)	17,73	20,19	18,53

2.2. Discussions



MVS concentration is the rate relative to the total dry matter (mineral and organic matter which are called dry volatile matter). Figure 2 shows that these vegetable wastes studied, have a high rate of volatile dry matter (% MSV greater than 97%). They are also rich in organic carbon (% COT greater than 56%). The humidity is relatively low in oil palm seed fibers and high for the two others. These high levels of volatile dry matter (% MSV greater than 97%) and total organic carbon (% COT greater than 56%) show that these wastes are essentially made up of organic matter, this organic matter is biodegradable by anaerobic digestion, therefore a potential source

biogas and heat energy production¹¹. However, with PCI greater than 18 MJ / kg, these wastes have the characteristics of good fuels. If the humidity level of oil palm seed fibers is low (% TH = 21%), which requires short drying time before combustion⁶, this is not the case for cocoa shell (82%) and bagasse sugar cane (70%). Technical literature indicates the average bagasse humidity is between 42 and 48% (B. Robert, 1995). It is therefore clear that the sample studied here has not been pre-dried. The two latter will require pre-drying before combustion.

The energies required for drying are relative

to the difference between the PCS and the PCI (cf. Figure 3). The difference (ΔPC) therefore corresponds to the calorific energy to bring to 1 kg of waste to eliminate its humidity. This pre-drying exercise

improves waste combustion. This heat is high in the cocoa shell and sugar cane bagasse and less in the oil palm seed fibers.

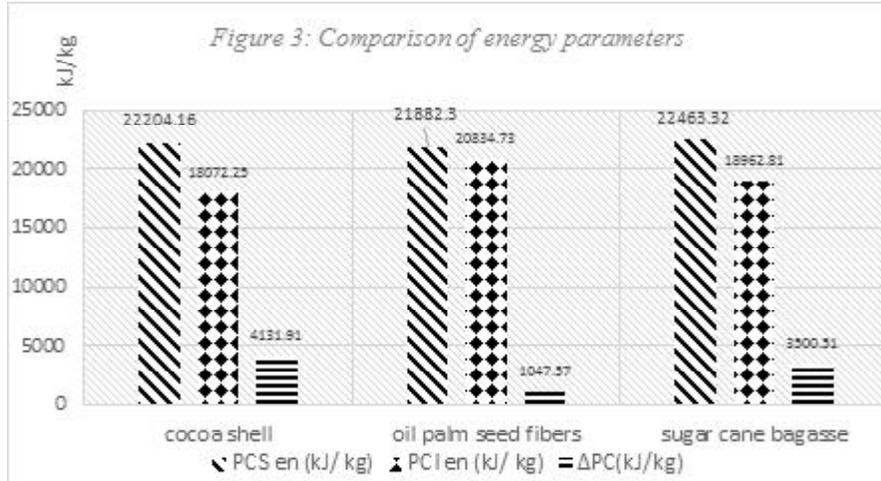
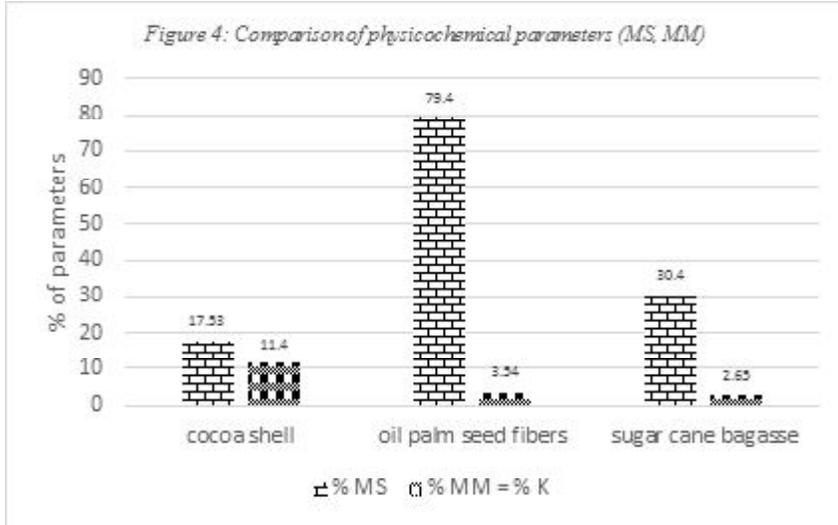


Figure 4 relates the contents of dry and mineral matter. The parameter (% K) provides information on the centesimal ash potential of the waste after

combustion¹; it is noted that cocoa shell has the highest ash content (11.4%). The two others have relatively low rates.



2.3. Combustion study :

In comparison to the fossil fuels burned in power plants, bagasse, cocoa shell and oil palm seed fibers have several advantages. They are deprived of

sulfur dioxide, and their combustion releases only the CO₂ fixed by these plants during their growth. These quantities are very small because the CO₂ consumed by the autotrophic metabolism of these plants is for

the most part stored in sugar for sugar cane, in bean for cocoa and in oil for oil palm¹⁴.

The combustive power is the quantity of air necessary to burn a unit quantity of fuel, in kg (or Nm³) of air per kg of fuel. With regard therefore to

figure 5, the wastes studied have relatively similar oxidizing powers (18 to 21 Nm³/kg). This observation is made on the smoke power which is the quantity of smoke produced by the combustion of one kilogram of fuel in air, whose values vary between 17 and 20 Nm³/kg.

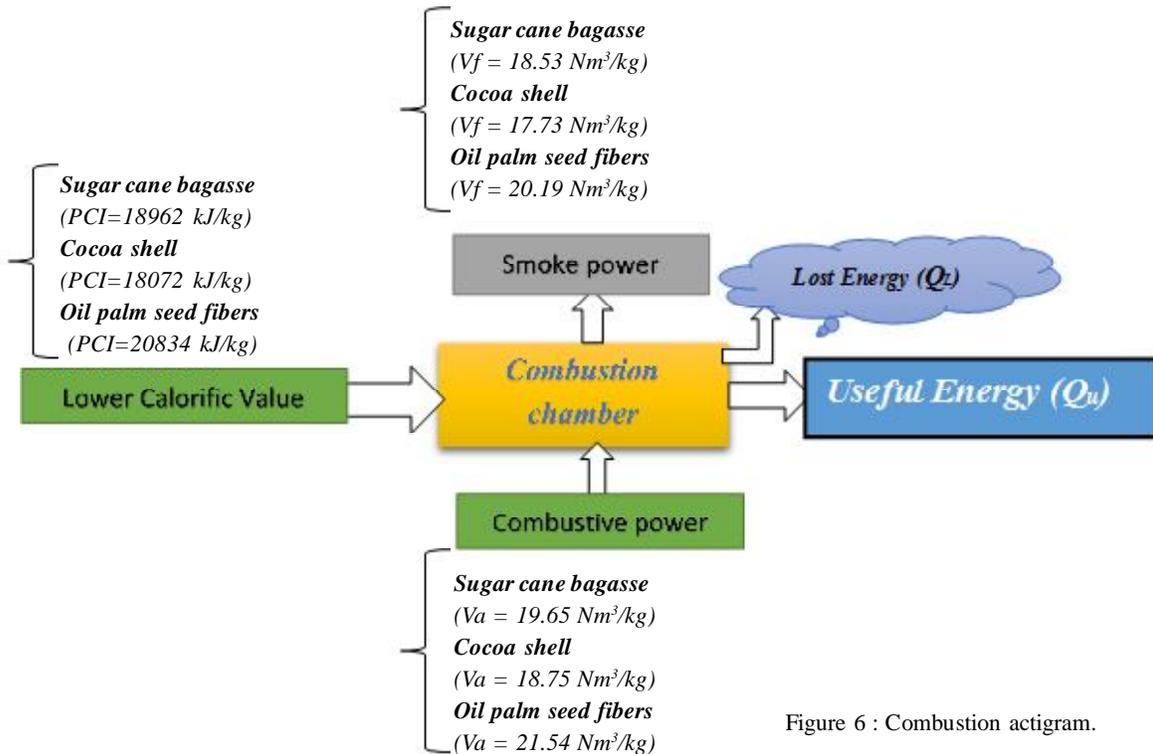
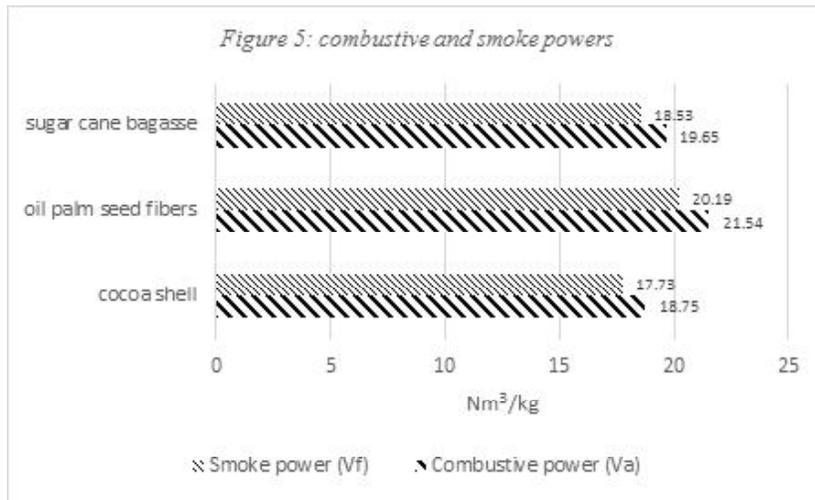


Figure 6 : Combustion actigram.

Conclusion

This work concerns the determination of the energy potentials of three types of vegetable waste (cocoa shell, oil palm seed fibers and sugar cane bagasse) in Côte d'Ivoire. It appears from this study that these wastes have energy potentials because of their lower calorific value (PCI greater than 18 MJ / kg). These PCI are in the range of common solid fuels such as wood (15 MJ / kg) and coal (15-27 MJ / kg). These data are very interesting and indicate that this waste is recoverable by combustion. However, the humidity is very high for two of them, in particular the cocoa shell and the sugar cane bagasse (83% and 70% respectively). This humidity, favourable to anaerobic digestion, can negatively influence the quality of combustion. Before combustion, it will be necessary to pre-dry the cocoa shell waste and the cane bagasse. The combustion of this waste only releases the CO₂ fixed by these plants during their growth. These quantities are considered to be very low due to the consumption of CO₂ by the autotrophic metabolism of these plants mainly stored in sugar juice for sugar cane, in bean for cocoa and in olein for oil palm¹⁴.

Further research will focus on the mathematical modeling of a thermal power plant with the use of these solid fuels in the home boiler. We will also look at the design and sizing of a burner suitable for these types of waste. This study was financed by laboratory own funds without external contribution.

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