CHAPTER

56

Different experiments for the production of charcoal with green coconut shells

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ABSTRACT
OBJECTIVE: To produce charcoal from green coconut shells. METHODS: The green coconut shells were collected from vendors in the city, sanitized, opened and placed outdoors to reduce humidity. 8 different experiments were carried out at varying temperatures (300 and 450ºC), time (1 and 2 h), and mass (35 and 100 g) to obtain the best product yield. The data were submitted to Tukey's new test, $p<0.05$. RESULTS: The best yield was obtained at a temperature of 300ºC, for 2 h in 100 g of coconut shell samples producing 54.81 ± 2.29 g of charcoal, that is, a yield of 53.80 ± 0.89%, with volatile moisture content equal to 6.97 ± 1.71 % and 6.50 ± 2.50 % of ash. CONCLUSIONS: The smaller amounts of ash, as well as moisture and volatiles, are more interesting because they reduce soot and the inefficiency of the burning process. Coals produced from the shell of green coconut can be one of the sustainable solutions to the Brazilian energy crisis.

Keywords: Green coconut shell, Charcoal, Environment, Sustainability.

1 INTRODUCTION

The global scenario is witnessing numerous problems regarding the scarcity of sustainable energy (DUPONT et al., 2015). To solve this problem, most countries seek renewable energy sources, such as biomass, which Brazil can stand out with the reuse of coconut shells (ANDRADE et al., 2004; SILVA et al., 2022).

Coconut waste usually has two destinations or is thrown in landfills and dumps where it will remain until they decompose (8 to 12 years), releasing toxic gases to the environment, or is burned without heat recovery and use, which also releases harmful gases to the atmosphere (ANDRADE et al., 2004).

Because it has a large amount of biomass (organic matter existing in a medium) and also a lot of moisture, a way to take advantage of the full energy potential of coconut shells is through the use of a thermal process, pyrolysis, which consists of burning biomass under controlled amounts of oxygen (CARDOSO, 2012). The main products to be obtained are coal (solid waste), pyroligneous liquid or bio-oil (condensable gases), and non-condensable gases (NICOLINI et al., 2013).

According to Nicolini et al. (2013), there are different types of pyrolysis in the presence of little oxygen, they are carbonization, slow pyrolysis, fast pyrolysis, and ultra-fast pyrolysis, being determined according to the heating rate, temperature, and residence time of the sample.

Although they are different procedures, the main products obtained in each type of pyrolysis are the same, varying only in the proportions in which they appear (ROCHA et al., 2004). Carbonization, for example, aims to maximize the production of charcoal, while in rapid pyrolysis, the major product is bio-oil. Thus, it is possible to choose the type of pyrolysis according to the desired product (NICOLINI et al., 2013).

An important characteristic of biomass that must be analyzed and that can greatly influence the pyrolysis process (especially in the production of coal) is the moisture content. According to Fernandes (2014), the higher the moisture content of the matter the lower the efficiency of the process, because when there is an excessive amount of water in the biomass, a greater portion of the matter is necessary (during pyrolysis) to perform the drying, thus reducing the yield of coal.

This property affects not only the quantity of product obtained but also its quality, a high moisture content implies to coal a reduction of the calorific value. This in turn can be defined as the amount of energy released in the form of heat in a combustion, per unit mass, that is, the higher the humidity, the lower the heat released by coal, consequently, the lower its efficiency (ZANUNCIO, 2013; MELANI et al., 2021).

Another important property to determine the quality of the coal produced is the ash content, which corresponds to the residue obtained by the complete combustion of the coal (SANTOS, 2010).

According to Assis et al. (2012) the higher the ash content, the lower the calorific value of the product, that is, the lower the heat transfer in the fuel. For Brand et al. (2013), coal for domestic use contain low ash content, in addition to high calorific value and low humidity.

2 METHODS

The green coconut shells were donated by local merchants. These were divided into several parts and arranged on the surface in the open air and carried to pyrolysis in muffle as shown in Tables 1 and 2.

Table 1 - Coded and decoded levels for assay determination

Coded Levels	**Decoded Levels**		
	Pyrolysis temperature (ºC)	Pyrolysis Time (h)	Mass of sample (g)
-1	300	1	35
1	450	2	100

Source: Own authorship (2017).

Table 2 - Operating conditions for each test

Essay	Temperature (ºC)	Time (h)	Mass of sample (g)
1	-1	-1	-1
2	1	-1	1
3	-1	-1	1
4	1	-1	-1
5	-1	1	1
6	1	1	-1
7	-1	1	-1
8	1	1	1

Source: Own authorship (2017).

3 RESULTS AND DISCUSSIONS

The results obtained with the temperature variation, pyrolysis time, and initial mass of the coconut shell are shown in Table 3.

Table 3 - Sample mass, coal, and process yield

Essay	Sample mass (g)	Coal mass (g)	Yield (%)
1	35,19 ± 0,10	17,76 ± 1,95	50,49 ± 5,65
2	100,48 ± 0,41	35,34 ± 1,59	35,17 ± 1,65
3	100,34 ± 0,61	51,39 ± 2,84	51,20 ± 2,54
4	35,10 ± 0,28	12,60 ± 0,17	35,90 ± 0,63
5	101,85 ± 2,60	54,81 ± 2,29	53,80 ± 0,89
6	35,37 ± 0,40	14,41 ± 1,03	40,74 ± 2,65
7	34,96 ± 0,27	10,78 ± 0,46	30,85 ± 1,50
8	100,31 ± 0,24	31,42 ± 0,98	31,33 ± 1,00

Source: Own authorship (2017). * All results were obtained in triplicates.

The percentage yield data allow us to better observe that experiment 5 obtained the highest results, which is equal to 53.80 ± 0.89 %. The worst result was 30.85 ± 1.50 in trial 7. The difference between these two procedures was the amount of sample, that is, the largest amount of it presented better results.

Pyrolysis performed at a lower temperature favors the production of coal, while at higher temperatures they favor the generation of gases contributing to lower performance (NICOLINI et al., 2013). The data of this work showed higher coal generation at lower temperatures in all experiments, except assay 7 in which another factor evaluated influenced more significantly.

Table 4 shows the values of ash percentage, moisture content, and volatiles obtained in both the raw material and the final product.

Table 4 – Ash and moisture content and volatiles in the coals obtained and in the raw material.

Exp. No.	Ash content (%)	Moisture content (%)
1	6,90 ± 0,10bc	7,24 ± 1,13b
2	9,50± 0,50abc	8,67 ± 0,58b
3	7,97 ± 0,92bc	8,28 ± 0,55b
4	5,31 ± 0,54c	10,33 ± 2,31b
5	6,50 ± 2,50bc	6,97 ± 1,71b
6	8,64 ± 2,11bc	9,63 ± 2,02 [b]
7	14.09 ± 0.94th	8,39 ± 1,55b
8	11,23 ± 4,06from	7,59 ± 2,07a
Green coconut shell	3,94 ± 0,02	13,55 ± 2,62

Source: Own authorship (2017). *Results expressed as mean ¯ standard deviation of analyses in triplicates. Equal letters do not present significant differences in the 5% confidence level by Tukey's test.

As shown in Table 4, the best results were obtained at 300ºC for moisture content (6.97 ±1.71%), with assay 5 having the lowest value. However, this only showed a significant difference when submitted to the application of ANOVA (Tukey's test, $p< 0.05$) with assay 8 (11.23 ± 4.06 %).

The percentage of ash was lower in assay 1 with a value equal to 6.90 ± 0.10 % and a higher value in assay 7 (14.09 ± 0.94 %). It is worth mentioning that a high amount of moisture and ash impairs the quality of coal to its calorific value (FERNADES, 2014).

Mangueira (2014) worked with three different proposals to obtain charcoal from the coconut endocarp, and these found results for moisture content ranging from 4.49 – 6.34% and ash content between 1.9 – 2.38%, presenting great divergence from those obtained in this experiment, mainly concerning ash content.

Comparing the values found in commercial charcoal produced from the coconut endocarp, the moisture content was equal to 9.67% and the ash content was 3.96%, values above those found by Mangueira (2004) and below those of this study.

4 FINAL CONSIDERATIONS

A pyrolysis is an excellent option for the reuse of green coconut shells and sustainable energy generation, as well as proportional, an innovative form of income for small coconut water traders.

The lower levels of ash, as well as moisture and volatiles, are more interesting results both commercially and for the quality of life and preservation of the environment, as they reduce soot and the inefficiency of the burning process.

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