PYROLYSIS AND GASIFICATION OF CASHEW NUT *(Anacardium Occidentale L.)* SHELL: LIQUID, SOLID AND GAS PRODUCTS

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Abstract: *Brazil is a great world producer of biomass. Pyrolysis and gasification are alternative processes for biomass energy recovery. In the pyrolysis process, the biomass can be transformed in combustible. Depending on biomass type, liquid (tar), char or gases, can be obtained in different proportions. In the gasification process, it is mainly obtained the gas combustible whose composition and calorific value will depend mainly on the gasifying agent used in the process. The biomass used in this study was the cashew nut shell, originally from the Northeast of Brazil. There are cashew nut improvement industries that can use its main reject (shell) as fuel, avoiding sanitary deposit embankment. By thermal conversion of biomass, in pyrolysis and gasification processes, it was quantified the production of solids (char), liquids (tar) and gases. It was evaluated the influence of the temperature (800 and 1000 ºC) and the use of* N_2*, in the case of pyrolysis, and mixtures of* N_2 *and steam in the case of gasification, in the amounts of char, tar and gas. It was observed that, in the pyrolysis process, with the decrease of the temperature, it happened an increase of char and tar, and a reduced in the amount of gas. When the percentages of steam increase, it is noticed that the amount of char decreases, and that the amount of tar and gas increases.*

Keywords*: pyrolysis, gasification, tar, char, cashew nut shell*

1. INTRODUCTION

Brazil is the great world producer of biomass. From the rationing of energy in the year of 2001, the biomass use theme in the generation of energy has been enough discussed. Some works have pointed the advantages of the energy use originated from the biomass in order to reduce CO_2 emission, generation of employments, among others, but they also noticed the need of the technology improvement of the biomass usage (Goldemberg (2002); Macedo (2002); Macedo and Nogueira, 2005).

A type of biomass used now for the production of energy is the cashew nut shell originally from the Northeast area of Brazil. This area has beneficiating industries of the cashew nut that use its principal reject (shell) as fuel, avoiding with that your deposit in sanitary embankment, that due to the great volume of shells can saturate the embankment in a short space of time.

The principal world producers of the cashew nut are: India, Nigeria, Brazil, Tanzania and Indonesia (Table 1). In Brazil, the agro-industrial plants of the cashew nut are concentrated in the Northeast States Ceará, Piauí, Rio Grande do Norte and Bahia, that participate with 95% of the production, with a planted area up to 650 thousand hectares. The cashew nut processing obtains the almond (it shells), LCC (liquid of the cashew nut), film of the almond, almond cream and the shell of the cashew nut. In Brazil, the production of cashew nut almond is, traditionally directed to the external market, generating, an average, of 150 million dollars annual exchange value. The United States and Canada are the principal consuming markets of the Brazilian almond, being responsible for about 85% of the Brazilian exports (EMBRAPA, 2003).

Table 1. Main producing of cashew nut in the world

COUNTRY	PRODUCTION (%)
India	36,6
Nigeria	14,64
Brazil	12,81
Tanzania	8,86
Indonesia	5,74

Source: Pereira et al., 2005

The pyrolysis and gasification are processes that can serve as alternative for the use of the cashew nut shell aiming the energy use. Through the pyrolysis process, depending on the biomass type, the same can be transformed in liquid, char and gases, in different proportions. By the gasification it is mainly obtained a gas combustible whose composition and calorific value basically will depend on the gasification agent used in the process.

The resulting gas of the pyrolysis and gasification of biomass, unlike that generated from coal or sewer mud, has insignificant sulfur content (Kinoshita, 1997). In relation to the CO_2 emission, if the biomass was produced and consumed in a maintainable way, it closes the cycle of consumption and production of the CO_2, not increasing the current rate in the atmosphere (Kinoshita, 1997).

Ayllón at al. (2006), study meat and bone meal pyrolysis in a fixed bed reactor, analyzing the influence of the final pyrolysis temperature and heating rate on the product (char, liquid fraction and gas) distribution and composition and the char characterization. Two sets of experiments have been performed at different final pyrolysis temperatures between 300 and 900 ºC and heating rates from 2 to 14 ºC/min. The results showed that the effect of the final pyrolysis temperature is more important than the effect of the heating rate.

The objective of this work is to evaluate the pyrolysis and gasification process of cashew nut shell in a fixed bed reactor by analyzing the influence of the final pyrolysis and gasification temperature on the product distribution and composition (char, tar and gas).

2. EXPERIMENTAL

The material used in the experiments was ground cashew nut shell with a particle size smaller than 0,8 mm. The initial sample mass was 15 g in all the experiments performed.

The pyrolysis and gasification runs were performed in a bench scale plant, shown in Fig. 1, consisting of a fixed bed reactor of 90 mm in diameter and 320 mm in length, discontinuous for the solid feed. The reactor is inside a tubular electric furnace of 325 mm in length, 355 mm in external diameter and 120 mm in internal diameter, connected to a temperature and heating control system. Computer software provides a continuous record of carrier gas flow rate, time, temperature of the furnace and temperature of up to six thermocouples placed in the sample.

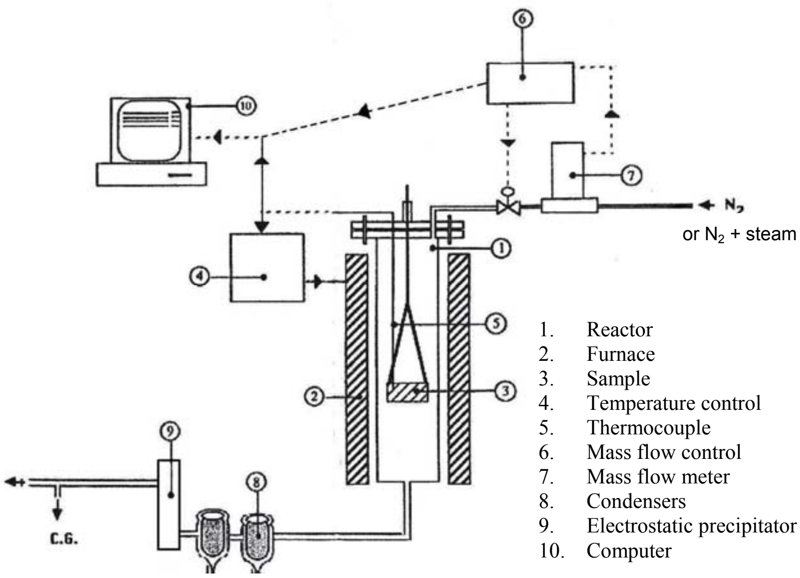

Figure 1. Experimental system used.

A steel basket with a radius of 28.3 mm and height of 41 mm containing a sample weight of 15 g was placed in the reactor prior to the experiment and hung at a depth of between 201 and 245 mm from the top. This basket has two mesh screens, the external one having a diameter of 1000 μm and the internal one of 40 μm.

Once the reactor is closed, a nitrogen flow of 13 cm^3 NTP/s (NTP: normal temperature and pressure, 0 ºC and 1 atm) is set by means of a mass flow controller. After 30 min under nitrogen flow, when the air is purged from the reactor. The furnace is heated up to the temperature required and picked up to start the reactor heating. The temperature of the reactor is then kept constant for approximately 130 min to make sure that the pyrolysis process is complete.

The exit gas passes through a tar condensation system, which consists of two glass condenser vessels cooled with a mixture of ice and water and an electrostatic precipitator. The method for collect the gas, consisting of taking gas samples every 3.5 min and analyzing them. The clean gas is analyzed by GC-TCD, in a system equipped with a Porapak N column and a Molecular Sieve. The compounds analyzed are H_2, CO, and CO_2. Heavier compounds were not detected in the experimental conditions used in this study. Once the experiment is finished and the system is cooled down to room temperature, the char is removed from the basket and weighed.

By thermal conversion of biomass, in pyrolysis and gasification processes, it was quantified the production of solids (char), liquids (tar) and gases. It was evaluated the influence of the temperature (800, and 1000 ºC) and the use of N_2, in the case of pyrolysis, and mixtures of N_2 and steam in the case of gasification, in the amounts of char, tar and gas.

3. RESULTS AND DISCUSSION

Table 2 and 3 shows the ultimate (dry basis) and proximate analyses of the sample used in the pyrolysis and gasification. The higher and lower heating value are shown in table 4.

Table 2. Ultimate analysis of cashew nut shell

Element	% (w/w) Dry basis
C	48.37
H	5.90
N	0.76
O[a]	44.94
S	0.03

[a] Calculated by difference.

Table 3. Proximate analysis of cashew nut shell

Component	Analytical Standard	(%)
Moisture	ISO-589-1981 – wet basis	9.31
Ash	ISO-1171-1976 – dry basis	1.16
Volatile matter	ISO-5623-1974 – dry basis	78.12
Fixed carbon	By difference – dry basis	20.71

Table 4. Heating value of cashew nut shell

	Analytical Standard	(kcal/kg)
Higher heating value (HHV)	ISO-1928-95	5370
Lower heating value (LHV)	ISO-1928-95	5331

The experiments results are shown in table 5, with the mix fed gas, the process and your products, in other words, char, tar, gas products and gas flow rate.

Table 5. Result of the experiments

Fed				Product		
Run	Temp	Q N_2	Q Steam	Char	Tar	Gas
	ºC	g/min	g/min	(g)	(g)	(g)
1	1000	6,25	-	3,070	4,650	5,38
2	800	6,25	-	4,040	6,584	2,51
3	1000	1,25	3,21	1,540	2,724	22,54
4	800	1,25	3,21	2,420	12,832	8,53
5	1000	4,375	1,21	2,010	1,572	14,83
6	800	4,375	1,21	2,870	11,156	6,35

3.1. Pyrolysis process products.

It was observed that, in all experiments, the increase of temperature increase gas production, decrease yield tar and not have significant change in amount of char, like showed in figure 1.

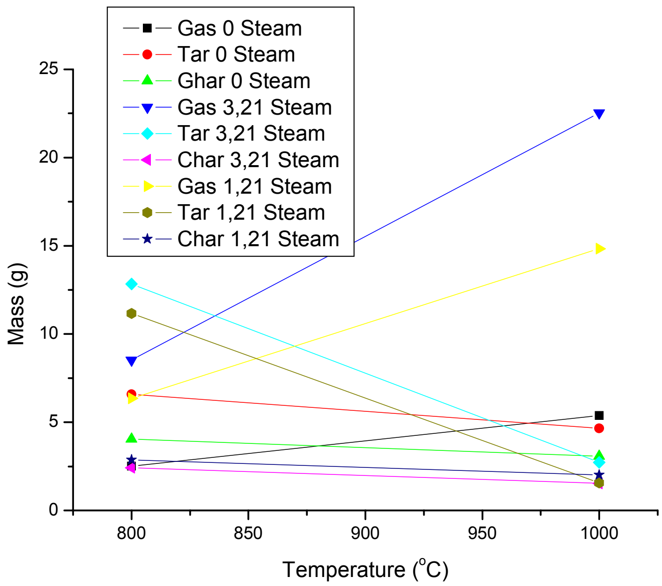

Figure 1. Influence of temperature in product gas, tar and char. Steam flow rate of 0 g/min, 1,21g/min and 3,21g/min.

The little change of char mass happens because the increase of temperature increase the degradation of biomass, in other words, the heterogeneous reaction occur (1 and 2).

$$C_{(S)} + 1/2O_{2\,(g)} \Leftrightarrow CO_{(g)} \qquad \text{reaction 1}$$

$$C_{(S)} + O_{2\,(g)} \Leftrightarrow CO_{2(g)} \qquad \text{reaction 2}$$

With the increase of temperature and steam flow ratio it was observed the increase in gas product. With temperatures higher than 700°C, occur the degradation of the coke and tar with increase on gas formation. In the experiments with steam up to 800 °C occur the increase of the formation ratio of gases through the Boudouard reaction (3) and carbon reaction with steam (4).

$$C_{(s)} + CO_{2\,(g)} \Leftrightarrow 2\,CO_{(g)} \qquad \text{reaction 3}$$

$$C_{(s)} + H_2O_{(g)} \Leftrightarrow CO_{(g)} + H_{2(g)} \quad \text{e} \quad C\,(s) + 2\,H_2O_{(g)} \Leftrightarrow CO_{2(g)} + 2\,H_{2(g)} \qquad \text{reaction 4}$$

The tar formation occurred between the temperatures 350°C to 450°C. Up this temperature it has the conversion of tar in gases. The figure 1 shows that increases of temperature, since 800 °C to 1000 °C decrease the tar formation.

3.2. Pyrolysis process with 100% of N_2 and without steam.

The obtained gas concentration can be justified by the analysis of reactions displacement.

In the experiments with 100% of N_2, it is verified that the reaction (5) has its displacement in accordance with the partial pressure intensity.

$$CO_{(g)} + ½\,O_{2(g)} \Leftrightarrow CO_{2(g)} \qquad \text{reaction 5}$$

The figure 2 shows experiments at 800°C. The displacement reaction (5) leads to CO_2 formation, because the partial pressure displacement of the equilibrium leads to CO_2 formation.

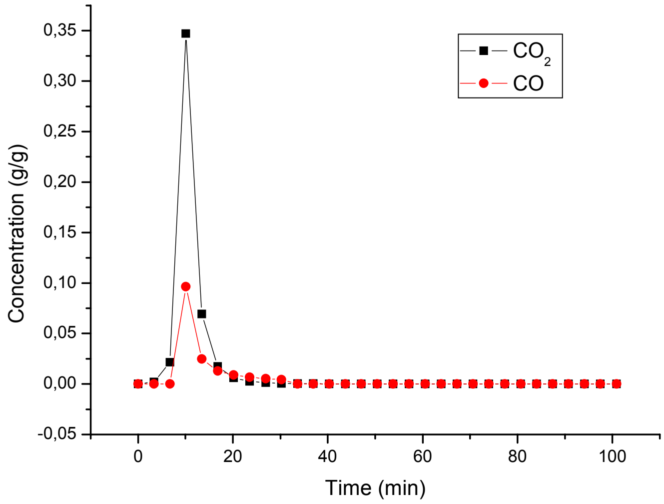

Figure 2. Concentration of the CO_2 and CO.

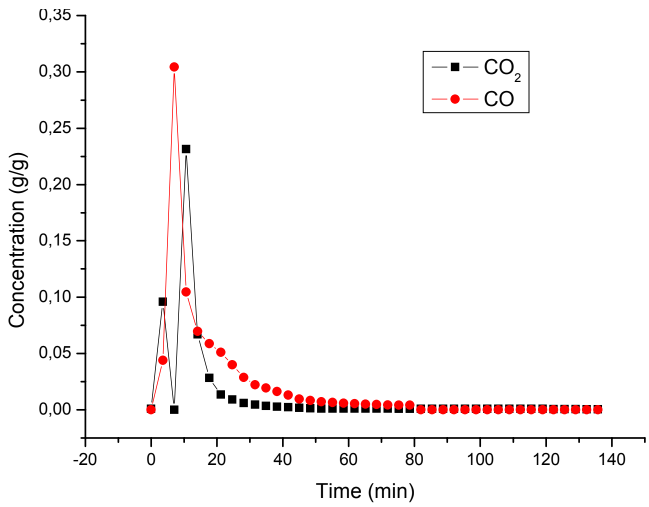

Figure 3. CO_2 and CO concentration, at temperature of 1000^0C and 100% of N2.

The figure 3 shows the experiment at 1000°C, where the equilibrium displacement lead to increase the CO formation, probably because occurred reaction (3).

3.3. Influence of steam in pyrolysis.

The experiments at 800 °C so much 2,12g/min of N_2 plus 3,21 g/min of steam as 4,37g/min of N_2 plus 1,21 g/min of steam not change the tendency with regard to experiment without steam, in other words, the displacement of the reaction (5) continue to be leading CO_2 formation.

The figure 4 shows the experiments at 900 °C and 1000 °C, with steam, where shift reaction (6) occurred.

$$CO_{(g)} + H_2O_{(g)} \Leftrightarrow CO_{2(g)} + H_{2(g)} \qquad \text{reaction (6)}$$

Experiment at 900 °C and 1000 °C shows the displacement of the reaction (5) leading to formation of CO_2. The inverse occurs with experiments without steam, where the reaction (5) equilibrium leads to CO formation. This inversion is justified by shift reaction (6), where the CO reacts with dissociated steam making CO_2 and H_2. The CO can also be made from reaction (5). Then, the shift reaction (6) increases the CO_2 formation.

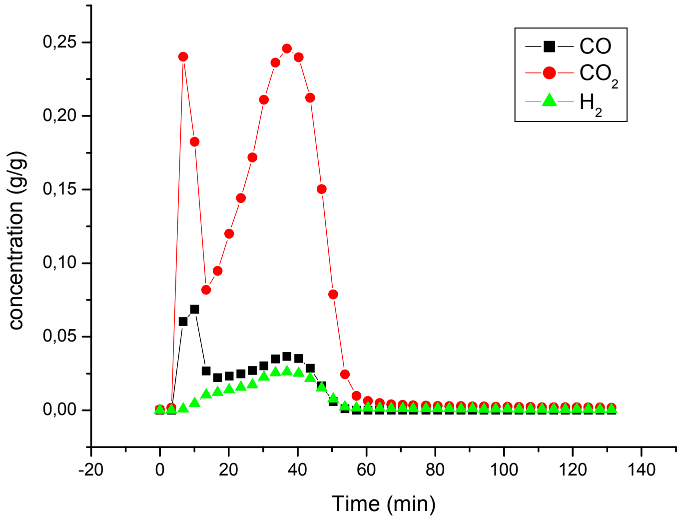

Figure 4. Gas concentration at 1000^0C with 2,12g/min of N_2 and 3,21g/min of steam.

4. CONCLUSIONS

In order to check the influence of temperature on the product distributions, char, tar and gas were obtained as products from the pyrolysis of cashew nut shells in a laboratory experimental plant.

The effect of the temperature on the product field distributions was observed. The effect of temperature increasing of temperature leads to a decrease in char production, a decrease in tar production and an increase on gas production. In other hands, the increase on steam ratio leads to a decrease char fields, an increase on tar fields and an increase on gas fields.

Instead of results dispersion, they make produced the pyrolysis use of cashew nut shells for recovery energy.

This little trend that has been observed in the tar and char productions, make not possible to assert whether the gas-solid reactions (*i. e.* char reforming by steam or carbon superficial reaction, that both improve with temperature, and that both would lead to a smaller char production) or the gas phase reactions (hydrocarbons reforming that could imply a decrease in tar production), can play a major role when the bed temperature is increased.

The gas production follows a clear tendency, as the higher temperature should promote the gasification reactions and enhance the production of gas.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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